Universidade de São Paulo
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Spatial variability of canopy geometric parameters in a commercial coffee field

Felippe Hoffmann Silva Karp

Final paper presented to obtain the bachelor degree in Agriculture

Piracicaba
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Advisor:
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DEDICATION

To my parents, Willian and Paula Emilia (in memoriam),
for their endless love, support, encouragement and effort
on giving me the best education they could

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To God, for blessing, protecting and giving me power to reach this objective.

To all my family, for all the love, support and incentive.

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To all my friends, who always supported and encouraged me.

EPIGRAPH

"If I have seen further it is by standing on the shoulders of Giants."
Isaac Newton

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RESUMO

Variabilidade espacial de parâmetros geométricos de copa em um campo comercial de café

O café é uma cultura de grande importância para o Brasil, o maior produtor mundial deste produto. Contudo, apesar da importância dessa cultura para o país, o desenvolvimento de tecnologias e da agricultura de precisão (AP) para o café iniciou apenas nos anos 1990. Entretanto, com o desenvolvimento da primeira colhedora de café e de monitores de produtividade, novas técnicas de gestão das lavouras de café começaram a ser desenvolvidas e adotadas, como é o caso da AP. O uso de um sistema terrestre para coletas de dados com sensor a laser (MTLS) em culturas arbóreas tem sido estudado no intuito de utilizar as informações obtidas para as práticas de AP. Porém, poucos estudos utilizando esta tecnologia vêm sendo desenvolvidos para a cultura do café. Sendo assim, o objetivo deste trabalho foi avaliar a variabilidade espacial de parâmetros geométricos das plantas em uma área produtora de café, assim como, o potencial de utilizar o MTLS para guiar uma aplicação em taxa variável baseada no volume do dossel. A coleta de dados foi realizada utilizando um sensor a laser e um receptor de Sistemas de Navegação Global por Satélites com correção diferencial RTK (*Real Time Kinematic*). A coleta dos dados ocorreu em três diferentes datas (colheita e floração de 2017 e colheita de 2018) em um campo comercial de café no estado de Minas Gerais, Brasil. O volume e altura de plantas foram estimados em seções transversais de 0,2m de comprimento ao longo das linhas. Os coeficientes de variação obtidos para o volume e altura de copa foram maiores que 14% e 5%, respectivamente. Os histogramas gerados possuem distribuição próxima a normal e são aproximadamente simétricos. Uma economia de 35,2% de calda aplicada foi calculada para esta área quando as informações de volume de copa foram utilizadas e comparadas com o volume aplicado pelo método convencional. Além disso, um mapa de porosidade de plantas foi obtido, esta informação pode ser utilizada no intuito de aumentar a eficiência da pulverização. Os mapas de altura e volume de plantas apresentaram uma variabilidade espacial significativa, sugerindo que benefícios poderiam ser obtidos ao adotar as práticas de gestão localizada baseando-se nas informações geradas pelo sensor. Portanto, de acordo com os resultados deste trabalho, existe um grande potencial para a adoção de práticas de AP baseadas no uso de tecnologias como o LiDAR na cultura do café.

Palavras-chave: LiDAR; modelagem 3D; aplicação em taxa variável; gestão localizada

ABSTRACT

Spatial variability of canopy geometric parameters in a commercial coffee field

Coffee is a very important crop for Brazil, which is the world biggest producer. Besides this importance, technology development and precision agriculture (PA) became issues for coffee just in late 1990's. However, the development and availability on the market of a harvester and yield monitors allowed the development and adoption of new management strategies, such as PA. Mobile Terrestrial Laser Scanner (MTLS) have been studied on different tree crops and for different purposes focused on PA. So far, not many studies have been developed in order to apply MTLS in coffee. Therefore, the aim of this study was to evaluate the spatial variability of canopy geometric parameters together with the potential of guiding a variable-rate application based on the volume of the plants, in order to analyze the possibility of using a MTLS in coffee. For data collection, a laser scanner sensor and a Global Navigation Satellite System with RTK (Real Time Kinematic) differential correction were used. The data acquisition occurred in three different dates (harvest and flowering of 2017 and harvest 2018) at a field located in Minas Gerais, Brazil. Volume and height were estimated in 0.2m length transversal sections along the rows. The coefficient of variation for canopy volume and height was greater than 14% and 5%, respectively. Histograms for both variables were close to a normal distribution and fairly symmetric for all collection dates. An input saving of 35.2% of the total volume sprayed was observed for this field when the spray volume was calculated based on the sensor information. Moreover, a plant porosity map was generated, information that could be used in order to raise the spray efficiency. Maps of canopy height and volume reveled a significant spatial variability suggesting that benefits could be obtained by site-specific management practices on this field. Therefore, according to the results obtained on this research, there is a great potential on PA practices based on data obtained from laser scanners in coffee.

Keywords: LiDAR; 3D surface reconstruction; variable rate application; site-specific management

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1. INTRODUCTION

Brazil is the biggest coffee producer in the world, responsible for approximately 35% of global coffee production. Moreover, according to the 2018 USDA Coffee Report, Brazil will reach a record output on 2018/2019 season (USDA, 2018). Therefore, coffee, the fifth most exported product in Brazilian agribusiness (BRASIL, 2018), is a very expressive and important crop for Brazil.

Besides the importance of coffee to Brazil, according to Molin, Faulin and Stanislavski (2009), the mechanization in coffee started late compared to other major crops in the world. According to Molin et al. (2002), the release of the first coffee harvester just happened in 1979 and just in late 1990’s precision agriculture (PA) techniques related to coffee became as an issue. Moreover, only in 2000 a yield monitor was developed and incorporated to the coffee harvester (SARTORI; FAVA; DOMINGUES, 2002).

Despite the late development of these technologies in coffee when compared to other crops, such as grain crops in which in early 1990’s yield monitors were already available in the market (FULTON et al., 2009), these two facts (first harvester and the yield monitoring) allowed the development and adoption of new management strategies, such as PA. Therefore, some initial studies were developed in order to understand the spatial variability of the coffee production fields.

Molin et al. (2002) developed a research using the coffee yield monitor to evaluate spatial variability of this attribute. They observed a significant variability of production on the studied fields and concluded that differentiated management zones should be defined, mainly for fertilizer application. Moreover, despite the low correlation values obtained by these authors between soil fertility and yield, it offered important insights into crop yield variability.

According to the Brazilian Commission on Precision Agriculture (CBAP), an advisory body of the Brazilian Ministry of Agriculture, Livestock and Supply (MAPA), PA is a set of tools and technologies applied to allow the agricultural management based on the spatial and temporal variability of the fields, aiming to raise the income and reduce the environmental impacts (BRASIL, 2014). Therefore, to reach the aims of PA its necessary the development of protocols, technologies and tools.

In this scenario, LiDAR (Light Detection and Ranging), a common technology used on robotics, have been studied on agricultural fields in order to obtain three dimension models of plants. Based on this technology, Del-Moral-Martínez et al.

(2015), adding a Global Navigation Satellite System (GNSS) to get the coordinates of each LiDAR scan, improved the methodology presented by Rosell-Polo et al. (2009). This approach is based on the use of a tractor-mounted 2D LiDAR to acquire the canopy data from the crop and has been referred as “Mobile Terrestrial Laser Scanner” (MTLS).

According to Colaço et al. (2018a), MTLS has been studied in different tree crops, such as peach, apple, citrus, olive and pear. The information obtained from the MTLS has been used for different site-specific management, such as the use for variable-rate applications based on the tree canopy parameter (height, volume and leaf density) (ESCOLÀ et al., 2013; GIL et al., 2013), irrigation and pruning management that could be based on the canopy growth (ESCOLÀ et al., 2017), and high throughput plant phenotyping (SUN; LI; PATERSON, 2017).

Most of the studies related to the application of precision agriculture in coffee have been developed in order to understand the soil spatial variability (SILVA et al., 2010; SANTOS; GONTIJO; SILVA, 2014; ARAÚJO et al., 2017). Others are studying the relationship between the soil fertility attributes and coffee yield (SILVA; LIMA, 2013; FERRAZ et al., 2012; FONSECA et al., 2015). However, Silva and Alves (2013), state a simplification of precision agriculture has been made for coffee. According to these authors, most of the PA practices and studies are focusing on the characterization of soil attributes and site-specific application of inputs. However, the coffee producers do not accept well the results obtained.

So far, on coffee, not many studies have been made in order to apply MTLS. Therefore, in order to analyze the possibility of using a MTLS in coffee, the aim of this study was to evaluate the spatial variability of canopy geometric parameters together with the potential of using a MTLS on a variable-rate technology based on the plants’ volume.

2. METHODOLOGY

2.1. Coffee field

This study was developed in a field located in Rio Paranaíba municipality, state of Minas Gerais (19°22'3.40"S, 46°22'1.15"W - WGS84) with approximately 1.2 ha. This field was established in 1991 with a coffee cultivar “Catuaí 144” (*Coffea arabica* L.) with alley width of 3.8m and distance between plants of 0.6m. Plants were pruned in 2011 in order to adequate their shape to the mechanical harvesting system.

2.2. LiDAR data acquisition and processing

The coffee field was scanned with a MTLS based on a 2D laser scanner sensor (LMS-200, Sick, Waldkirch, Germany) and a RTK-GNSS receiver (Real Time Kinematic – Global Navigation Satellite System, GR3, Topcon, Tokyo, Japan). The laser sensor and the GNSS were mounted on a structure fixed on the three-point hitch of a narrow width tractor (Figure 1). During the data acquisition, the system was operated along the crop alleys in a constant speed of approximately 1.4ms^{-1}. The MTLS was configured to acquire 75 vertical scans per second in a resolution of 1°, 181 points per scan, a total of 13,575 points per second.

Figure 1. Laser scanner sensor and GNSS on the structure used for the data acquisition (KARP et al., 2018)

The data acquisition occurred in three different dates, harvest of 2017 (June 24, 2017), flowering of 2017 (October 19, 2017) and harvest 2018 (July 14, 2018).

The harvest data was acquired right after harvesting. In order to acquire the laser sensor (75Hz) and GNSS data (10Hz) synchronously, it was necessary the use of a customized data acquisition software, developed using Python 2 programming language. To deal with the different data acquisition rates a linear interpolation on time domain was carried out by the software.

The data processing method used is the same described by Colaço et al. (2017). A point cloud with the density of 1,700 points per square meter was obtained from this process. The processing flow can be resumed as the generation of the georreferenciated 3D point cloud (Figure 2A), filtering the points of interest (Figure 2B), segmentation of the row perpendicularly to its longitude (Figure 2C) and the calculation of canopy volume and height. Custom scripts in R (v. 3.14) were used on these data processing. Moreover, the open sources softwares Cloud Compare (v. 2.10 alpha) and QGIS (v. 2.14.13) were used for data visualization and 3D manipulation.

The canopy and volume height were computed for every 0.2m (transversal section length). This length was defined according to the distance between plants, theoretically computing three sections per plant.

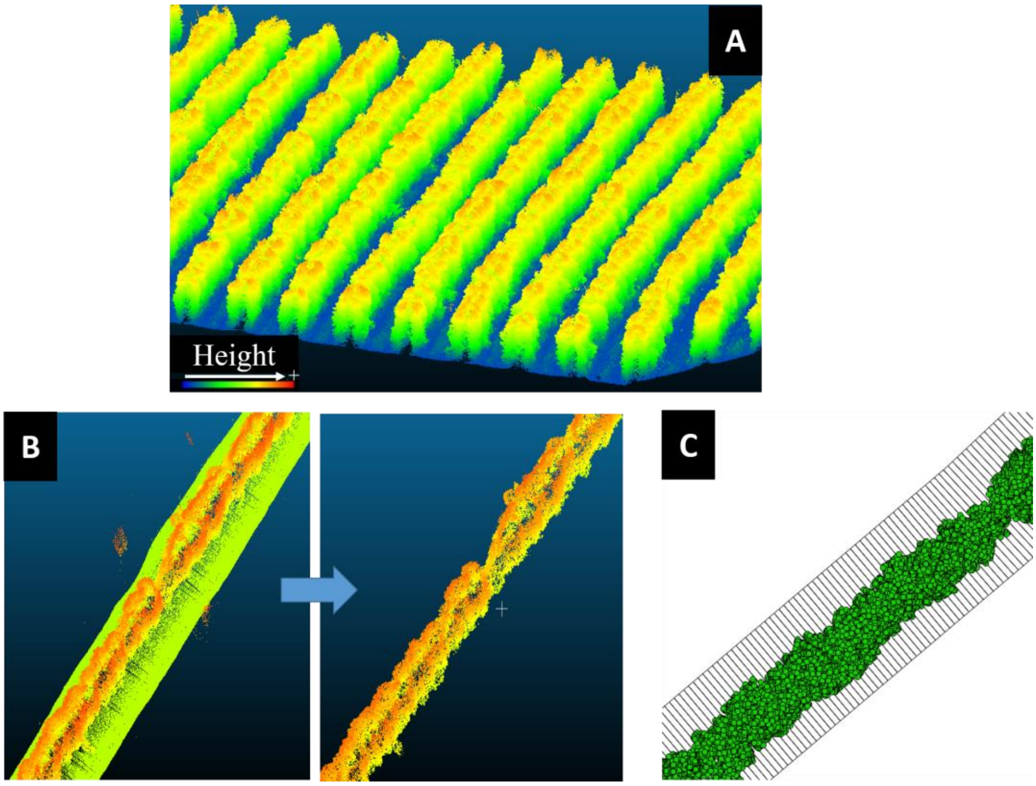

Figure 2. Data processing steps. A - Obtainment of the 3D georreferenciated point cloud; B – Selection of the points of interest; C - Segmentation of the row perpendicularly to its longitude (transversal sections)

2.3. Variability of canopy geometric parameters

The distribution and variability of the plant sections' volume and height were assessed by using histograms and descriptive statistical analysis. A spatial variability analysis was conducted in order to understand if the variations of the canopy volume were random in the space or spatially dependent. This spatial variability analysis was made by analyzing the volume and height variograms for each collection date and generation of interpolated maps for these parameters. Moreover, a correlation between all the maps generated was carried out. According to Colaço et al. (2018b), for citrus crop, prior to geostatistical analysis, a merge of transversal section, equivalent to the distance between plants (i.e. if the tree spacing was 4m, the transversal sections length of 0.25m, 16 transversal sections would be merged), was made in order to mask the within-plant variability of volume and height. However, for coffee, this step was not carried out because the tree spacing is too narrow as the crop is managed as a continuous since the beginning. Therefore, the plants can grow within the neighbor plants and it is not possible to consider that one plant is limited to its original tree spacing.

2.4. Sensor-based variable rate application

In order to estimate the potential benefit of sensor-based variable rate applications (SBVRA), two scenarios of input application were designed. In one scenario, the volume applied was calculated just based on the product label – without considering the tree volume variability (Scenario 1). The other scenario was based on the volume of the plants obtained by the MTLS (Scenario 2). For this second scenario, the applied volume was determined based on the Equation 1, adapted from Doruchowski et al. (2012).

$$Q = \frac{V}{A} * k \qquad (1)$$

where:

Q is the spray volume (Lha^{-1});

V is the transversal section volume (m^3);

A is the transversal section area (ha);

k is the spray volume index (Lm^{-3}).

According to Doruchowski et al. (2012), the spray volume index (k) should be obtained by experimental tests conducted on real conditions. Sousa Júnior et al.

(2017) developed some field tests in order to determine the spray volume index for coffee. These authors determined regression formulas for three coffee development stages (filling, maturation and post-harvest fruit) in which based on the droplet density recommended on the product label, the spray volume index is obtained.

Therefore, to analyze the potential benefit of the SBVRA a common product used by the producers was chosen to allow the comparison between the two scenarios. The product chosen, which has the active ingredient pyraclostrobin, is used in order to control two important fungi diseases in coffee, the coffee rust and cercosporiosis caused, respectively, by the fungus *Hemileia vastatrix* and *Cercospora coffeicolal.*

According to this fungicide label, the optimum droplet density range is 70 to 100 droplets cm^{-2} (BASF, [n.d].). Therefore, using the regression for the post-harvest stage obtained by Sousa Júnior et al. (2017), the k is approximately 0.036 Lm^{-3}.Based on the k value obtained and the product label recommendation the total volume that should be applied was determined for both scenarios. Moreover, a study of the over and sub application was carried out.

Only the data from the flowering of 2017 was considered on the variable rate application analysis. At this period, frequent applications are necessary. Coffee flowering is inducted by the first rains (ALVIM, 1973), marking the start of the rainy season that favors the development of diseases, such as the coffee rust. Therefore, according to Mariotto et al. (1979), at the rainy season is when coffee crop needs an intensive protection with periodic spraying.

Moreover, according to Duga et al. (2015), the on-target deposition is strongly correlated to the total leaf area, tree volume and tree porosity. According to these authors, porosity is defined by the ratio of the pore space to the space occupied by leaves and branches. Based on this definition, a porosity map was developed in order to evaluate the potential of the MTLS to estimate the tree porosity. Therefore, during the processing steps, an original point cloud was processed not eliminating the points that passed through the plants. Thus, the porosity was calculated by the ratio between the points that passed through the plant and the ones that reached the leaves and branches.

3. RESULTS AND DISCUSSION

3.1. Point cloud analysis

A 3D point cloud was obtained for each data set acquired. Figure 3 shows the point cloud obtained for harvest 2017. Visual inspection of all the point clouds shows that apparently the MTLS is capable to characterize well the plant structure. However, the narrow spacing between the rows difficult the scanning of the top of the plants. Therefore, on the top of the plant there is a lower density of point when compared to the rest of the plant (Figure 3B). Nevertheless, the overall plants' shape were considered close to their real shape. According to Karp et al. (2018), besides the low density of points on the top of the plants, another difficulty on the use of the MTLS would be the roughness of the terrain that could compromise the point cloud accuracy in some rows. They also concluded that the data acquisition could be improved using an inertial measurement unit to acquire the yaw, pitch and row rotations of the MTLS.

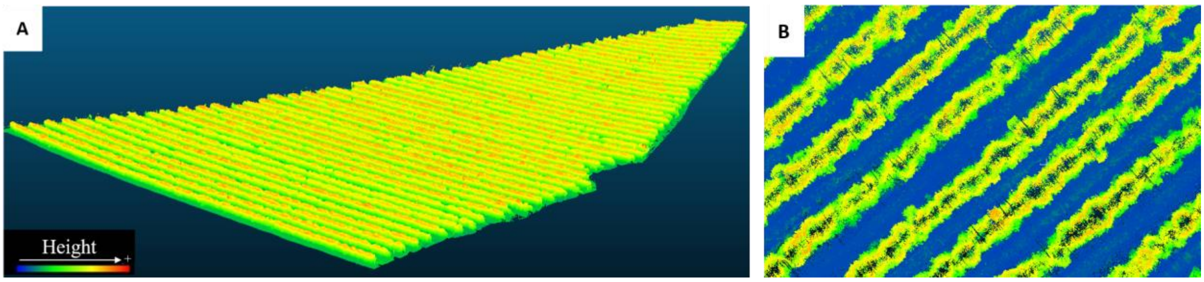

Figure 3. A - Point cloud obtained for harvest 2017**;** B – Top view of some rows from the point cloud

3.2. Variability of canopy geometric parameters and potential benefit of sensor-based variable rate application

The descriptive statistics are presented on the Table 1 for the data acquired on 2017 and 2018. It is possible to verify that the height and volume from flowering 2017 are lower than for the other dates. This result could be explained by the damages that the coffee trees suffer during mechanical harvesting (SANTINATO et al., 2014) and a very dry season (DAMATTA et al., 2007) that happened on 2017 (CEPEA, 2017). According to Gomes and Garcia (2002) the coefficient of variation (CV) can be used in order to classify the attribute variability, which is low when CV is below 10%, moderate between 10% and 20%, high between 20% and 30% and very high when above 30%. According to these authors statement, it is possible to infer that there is a low and moderate variability for height and volume, respectively. However, besides the magnitude, there still a variability of these attributes on the field, which can be observed at the histograms from Figure 4. The variability of height was always lower than for volume. This could be explained by the pruning system that shape the plants for the mechanical harvest.

Table 1. Descriptive Statistic for volume and height in the different acquisition dates

Data	Mean	Std. Dev.	Med.	Min.	Max.	CV(%)	Kurt.	Skew.
	--- m³ (volume) or m (height) ---							
Height Harvest 2017	2.92	0.18	2.93	2.47	3.34	6.32	2.42	-0.15
Volume Harvest 2017	0.79	0.12	0.8	0.51	1.05	14.79	2.44	-0.14
Height Flowering 2017	2.78	0.15	2.79	2.4	3.14	5.52	2.48	-0.18
Volume Flowering 2017	0.71	0.11	0.71	0.44	0.97	16.06	2.38	-0.10
Height Harvest 2018	3.02	0.17	3.04	2.57	3.43	5.69	2.53	-0.32
Volume Harvest 2018	0.81	0.13	0.81	0.5	1.11	16.3	2.43	-0.06

Std. Dev.: Standard Deviation; Med.: Median; Min.: Minimum; Max.: Maximum; CV: Coefficient of Variation; Kurt.: Kurtosis; Skew.: Skewness

According to the kurtosis and skewness values from Table 1 and the histograms presented on Figure 4, all the histograms are close to a normal distribution (kurtosis close to 3) , fairly symmetric (skewness between -0.5 and 0.5) (BULMER, 1979) and very similar among them. For citrus, Colaço et al. (2018b) found histograms with two peaks, caused by small trees present on the fields. According to these authors, the reason for it was related to the replacement of trees because of diseases, such as huanglongbing (greening - *Candidatus* Liberibacter spp). However, in coffee usually it is not necessary tree's replacement; therefore, coffee crop has more uniformity in volume and height when compared to citrus.

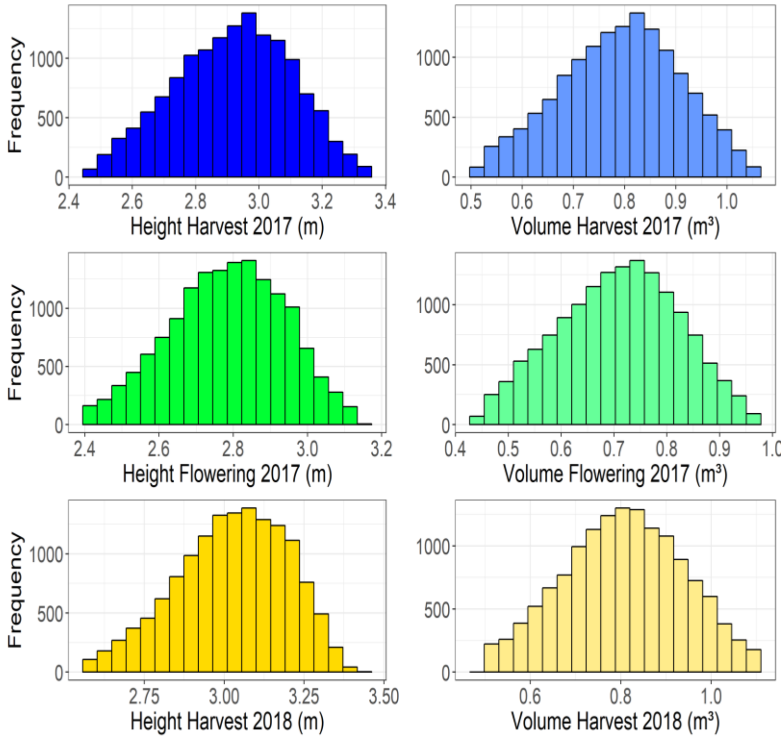

Figure 4. Histograms for volume and height from the different acquisition dates

Since a variation of volume and height was found in this field, it is expected that the SBVRA would provide a better use of the inputs. According to the product label, a spray volume of 500 Lha^{-1} should be applied. This number was considered for the Scenario 1, in which a total of approximately 587.7 L would be applied on this area. On the other hand, for the Scenario 2 a total of approximately 380.6 L would be applied in the same area. Therefore, the SBVRA would save approximately 35.2% of the total volume sprayed. Table 2 show the descriptive statistic for the spray volume determined by the SBVRA and the balance between the spray volume from Scenario 1 and Scenario 2.

Table 2. Descriptive Statistic from the spray volume for the sensor-based variable rate application (SBVRA) and the balance between the spray volume obtained by the SBVRA and the first scenario.

Data	Mean	Standard Deviation	Median	Minimum	Maximum	CV(%)*
		------------------------- l.ha^{-1} -------------------------				
SBVRA	323.8	52.0	326.1	202.5	441.6	16.1
Balance**	176.2	52.0	173.9	58.4	297.5	29.5

*CV: Coefficient of Variation **Scenario 1 spray volume minus Scenario 2 spray volume

According to the Table 2 it is possible to infer that calibrating the sprayer to apply 500 Lha^{-1} without considering the tree volume would cause an over application on 100% of the area, since the SBVRA maximum spray volume is 441.6 Lha^{-1}.

However, it is important to understand that the spray volume index defined by Sousa Júnior et al. (2017) was determined calculating the tree volume based on the tree-row-volume concept (BYERS, 1987). Therefore, the volume considered to obtain this index is not the same calculated based on LiDAR data. Thus, further studies should be developed in order to determine a spray volume index based on MTLS data, which is more detailed than the tree-row-volume.

Moreover, the potential to obtain an estimative of plant porosity was analyzed for the data acquired on flowering 2017. Figure 5A present the map for the porosity calculated according to Duga et al. (2015) porosity definition. Figure 5B present the comparison between the map and the information that could be observed on the point cloud generated.

According to Figure 5, we can conclude that the map obtained is loyal to the point could. However, further studies are necessary to check the accuracy of the porosity values obtained. According to Sousa Júnior et al.(2017) coffee plants change their leaf density according to several factors (ambient, plant age, harvest damages, diseases). Therefore, the tree porosity changes. Thus, if the plant porosity is an important factor for the on-target deposition (DUGA et al., 2015) it should be considered on the further determination of the spray volume index based on MTLS data.

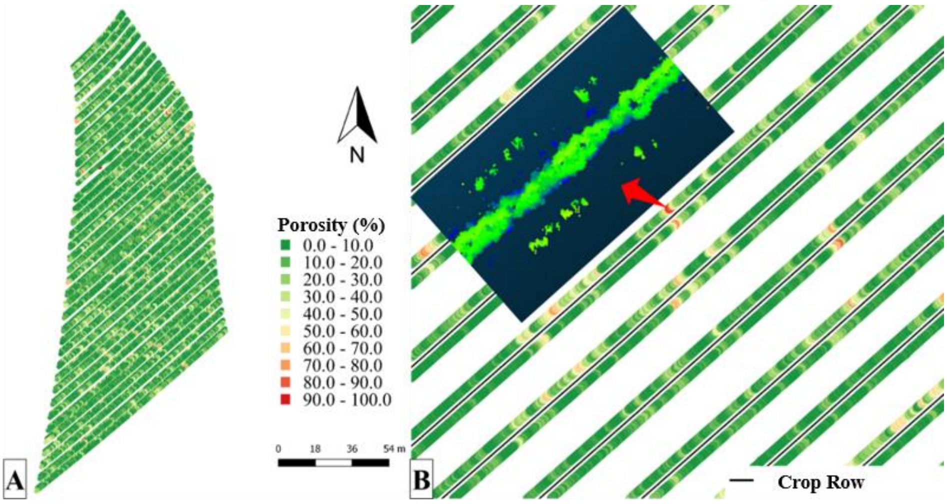

Figure 5. A - Porosity map for the data acquired on Flowering 2017; B - Comparison of the map results to the point cloud

3.3. Spatial variability of canopy geometric parameters

Geostatistical analysis showed that the canopy geometric parameters (height and volume) was spatially dependent, evidenced by the low nugget variance (C0).

Moreover, the nugget (C0) is low in relation to the sill variance (C0+C1), which characterize a strong spatial dependence (Table 3). However, the range values are very low. Therefore, there is spatial dependence, but within short distances, i.e. height and volume changes plant by plant. This observation shows the importance of the use of sensors, such as the ones based on LiDAR technology, to have a good characterization of the spatial variability of these geometric parameters.

Table 3. Geostatistical analysis for the volume and height in the different data acquisition dates

Data	C0*	C1*	A (m)*	C0 (C0+C1)$^{-1}$
Height Harvest 2017	0.001	0.031	1.89	0.031
Volume Harvest 2017	0.001	0.012	1.53	0.077
Height Flowering 2017	0	0.024	1.31	0
Volume Flowering 2017	0.001	0.012	1.30	0.048
Height Harvest 2018	0	0.030	1.25	0
Volume Harvest 2018	0	0.017	1.25	0

*C0: nugget; C1: structural; A: range; C0+C1: sill variance

Figure 6 presents the maps obtained by kriging using the variograms parameters presented on Table 3. The values were normalized by the average. These maps reinforce the plant-by-plant variation of volume and height. However, it is possible to identify some similar regions among them. Table 4 presents the correlation matrix of these maps.

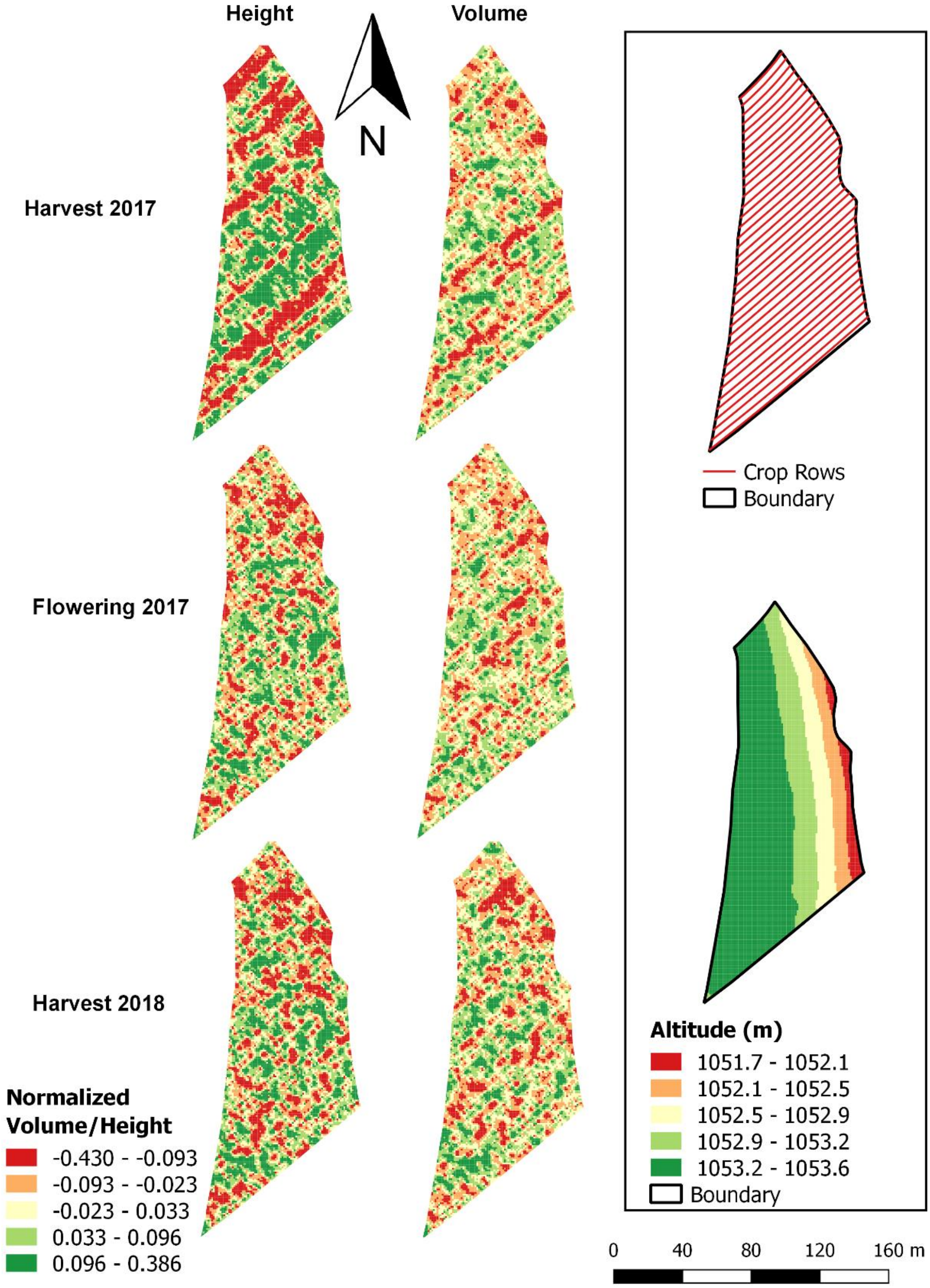

Figure 6. Interpolated maps from volume and height in the different data acquisition dates, field digital elevation model and crop rows direction.

According to the Table 4, a strong relationship between canopy and volume was observed within the same acquisition date, results also found by Colaço et al. (2018b) for citrus. The highest correlation value obtained (0.76) was between height and volume for Harvest 2018. Moreover, a not so strong relationship was found between the variables at different acquisition dates. However, there is still a correlation and similar regions can be observed on the maps (Figure 5).

Table 4. Correlation Matrix for volume and height in different acquisition dates

Data	Volume Harvest 2017	Volume Flowering 2017	Volume Harvest 2018	Height Harvest 2017	Height Flowering 2017
Volume Flowering 2017	0.47	-	-	-	-
Volume Harvest 2018	0.51	0.43	-	-	-
Height Harvest 2017	0.67	0.39	0.50	-	-
Height Flowering 2017	0.44	0.73	0.48	0.54	-
Height Harvest 2018	0.58	0.48	0.76	0.67	0.59

Since there are some correlation and similar regions among the maps, besides the SBVRA, the LiDAR data could be used for the management of the coffee fields, i.e. follow the development of the crop and determine the best moment for pruning. Moreover, it could help to understand the spatial variability presented on the fields and the reasons for the presence of regions with shorter and lower volume plants, even along the same season.

4. CONCLUSIONS

A coffee commercial field was scanned using a mobile terrestrial laser scanner during three different dates within a period of a year and a half. Canopy geometric parameters (volume and height) were variable within all acquisition dates. Therefore, a sensor-based variable rate application could minimize the over application, raise the application efficiency and compared to the label recommendation, 35% of spray volume could be reduced. Moreover, the porosity map obtained using the MTLS presented a potential to be used in order to raise the spray efficiency.

Furthermore, a strong relationship between canopy volume and canopy height information was found. Geostatistical analysis presented that canopy geometric parameters for this coffee field was spatially dependent, but in short distances, which shows the necessity of using sensors to have a good characterization of the spatial variability for these parameters. Overall, this study showed that there is a great potential on PA practices based on the data obtained from laser scanners in coffee.

5. REFERENCES

ALVIM, P. DE T. Factors affecting flowering of coffee. In: SRB, A. M. (Ed.). . **Genes, Enzymes, and Populations (Basic Life Sciences v. 2)**. Boston, MA: Springer US, 1973. p. 193–204.

ARAÚJO, G. et al. Comparativo entre os atributos químicos do solo amostrados de forma convencional e em malha. **Coffee Science**, v. 12, n. 1, p. 17–29, 2017.

BASF. **Opera ® SE**, [n.d.]. Retrieved from: <http://www.adapar.pr.gov.br/arquivos/File/defis/DFI/Bulas/Fungicidas/opera_se.pdf>

BRASIL. **Agricultura de precisão**. Ministério da Agricultura, Pecuária e Abastec imento. Secretaria de Desenvolvimento Agropecuário e Cooperativismo. Brasília: Mapa/ACS, 2014. 36p. (Agenda Estratégica 2014 – 2030). Retrieved from: < http://www.agricultura.gov.br/assuntos/sustentabilidade/tecnologia-agropecuaria/agricultura-de-precisao-1/arquivos-de-agricultura-de-precisao/agenda-estrategica-do-setor-de-agricultura-de-precisao.pdf >.

BRASIL. **Café no Brasil.** 2018. Retrieved from:< http://www.esalq.usp.br/biblioteca/pdf/normas.pdf >.

BULMER, M. G. **Principles of statistics**. Courier Corporation, 1979.

BYERS, R. E. Tree-row-volume spraying rate calculator for apples. **Horticulture Science**, v. 22, p. 506–507, 1987.

CEPEA. **Dry weather in Brazil concerns arabica growers - Center for Advanced Studies on Applied Economics**. Piracicaba: CEPEA, 2017. Retrieved from: <https://www.cepea.esalq.usp.br/en/brazilian-agribusiness-news/dry-weather-in-brazil-concerns-arabica-growers.aspx>.

COLAÇO, A. F. et al. A method to obtain orange crop geometry information using a mobile terrestrial laser scanner and 3D modeling. **Remote Sensing**, v. 9, n. 8, p. 10–13, 2017.

COLAÇO, A. F. et al. Application of light detection and ranging and ultrasonic sensors to high-throughput phenotyping and precision horticulture: Current status and challenges. **Horticulture Research**, v. 5, n. 1, 2018a.

COLAÇO, A. F. et al. Spatial variability in commercial orange groves. Part 1: canopy volume and height. **Precision Agriculture**, 22 set. 2018b.

DAMATTA, F. M. et al. Ecophysiology of coffee growth and production. **Brazilian Journal of Plant Physiology**, v. 19, n. 4, p. 485–510, 2007.

DEL-MORAL-MARTÍNEZ, I. et al. Georeferenced scanning system to estimate the leaf wall area in tree crops. **Sensors (Switzerland)**, v. 15, n. 4, p. 8382–8405, 2015.

DORUCHOWSKI, G. et al. Calibration of orchard sprayers – the parameters and methods. In: GANZELMEIER, H.; WEHMANN, H.-J. (Eds.). . **Fourth European Workshop on Standardised Procedure for the Inspection of Sprayers in Europe**

- SPISE 4 -. Lana (South Tyrol), Italy: Julius-Kühn-Archiv, 2012. p. 140–144.

DUGA, A. T. et al. Spray deposition profiles in pome fruit trees: Effects of sprayer design, training system and tree canopy characteristics. **Crop Protection**, v. 67, p. 200–213, 2015.

ESCOLÀ, A. et al. Variable rate sprayer. Part 1 - Orchard prototype: Design, implementation and validation. **Computers and Electronics in Agriculture**, v. 95, p. 122–135, 2013.

ESCOLÀ, A. et al. Mobile terrestrial laser scanner applications in precision fruticulture/horticulture and tools to extract information from canopy point clouds. **Precision Agriculture**, v. 18, n. 1, p. 111–132, 2017.

FERRAZ, G. A. S. et al. Variabilidade espacial e temporal do fósforo, potássio e da produtividade de uma lavoura cafeeira. **Engenharia Agrícola**, v. 32, n. 1, p. 140–150, 2012.

FONSECA, A. S. da et al. Spatial and temporal variability of the productivity of coffee canephora. **Coffee Science**, v. 10, n. 4, p. 400–407, 2015.

FULTON, J. P. et al. Grain yield monitor flow sensor accuracy for simulated varying field slopes. **Applied Engineering in Agriculture**, v. 25, n. 1, p. 15–21, 2009.

GIL, E. et al. Variable rate sprayer. Part 2 – Vineyard prototype: Design, implementation, and validation. **Computers and Electronics in Agriculture**, v. 95, p. 136–150, 2013.

GOMES, F.; GARCIA, C. H. **Estatística aplicada a experimentos agronômicos e florestais**. Piracicaba: FEALQ, 2002. 305p.

KARP, F. H. S. et al. **Canopy parameters in coffee orchards obtained by a mobile terrestrial laser scanner**. Proceedings of the 14th International Conference on Precision Agriculture. **Proceedings**...2018

MARIOTTO, P.R. et al. Estudos sobre o controle quimico da ferrugem do cafeeiro (*Hemileia vastatrix* Berk. et Br.) e seus efeitos na produção, nas condicões do Estado de São Paulo. **Biológico**, v. 45, p. 165-174, 1979.

MOLIN, J. P. et al. **Precision agriculture for coffee in Brazil**. Proceedings of the 6th International Conference on Precision Agriculture and Other Precision Resources Management. **Proceedings**...[St. Paul, Minn.] : University of Minnesota, 2002

MOLIN, J. P.; FAULIN, G. D. C.; STANISLAVSKI, W. M. Yield mapping and variable rate of fertilizers for coffee in Brazil. **Acta Horticulturae**, v. 824, p. 261–266, 2009.

ROSELL POLO, J. R. et al. A tractor-mounted scanning LIDAR for the non-destructive measurement of vegetative volume and surface area of tree-row plantations: A comparison with conventional destructive measurements. **Biosystems Engineering**, v. 102, p. 128–134, 2009.

SANTINATO, F. et al. Análise quali-quantitativa da operação de colheita mecanizada de café em duas safras. **Coffee Science**, v. 9, n. 4, p. 495–505, 2014.

SANTOS, E. O. DE J.; GONTIJO, I.; SILVA, M. B. DA. Spatial variability of soil acidity attributes and Liming Requirements for Conilon Coffee. **Coffee Science**, v. 9, n. 2, p. 275–283, 2014.

SARTORI, S.; FAVA, J. F. M.; DOMINGUES, E. L. Mechanical harvester. n. 701, 2002.

SILVA, F. M.; ALVES, M. C. Cafeicultura de precisão. Lavras: UFLA, 2013. 227 p.

SILVA, S. de A. et al. Variabilidade espacial de atributos químicos de um latossolo vermelho-amarelo húmico cultivado com café. **Revista Brasileira de Ciência do Solo**, v. 34, p. 15–22, 2010.

SILVA, S. D. A.; LIMA, J. S. de S. Atributos físicos do solo e sua relação espacial com a produtividade do café arábica. **Coffee Science**, v. 8, n. 4, p. 395–403, 2013.

SOUSA JÚNIOR, J. M. de et al. Determinação do índice de volume de pulverização para a cultura do café. **Coffee Science**, v. 12, n. 1, p. 82–90, 2017.

SUN, S.; LI, C.; PATERSON, A. H. In-field high-throughput phenotyping of cotton plant height using LiDAR. **Remote Sensing**, v. 9, n. 4, p. 1–21, 2017.

USDA. **Coffee** : world markets and trade. Washington: USDA, 2018. 9 p. Retrieved from: <https://apps.fas.usda.gov/psdonline/circulars/coffee.pdf>.