Canopy Parameters in Coffee Orchards Obtained by a Mobile Terrestrial Laser Scanner

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**A paper from the Proceedings of the
14th International Conference on Precision Agriculture
June 24 – June 27, 2018
Montreal, Quebec, Canada**

Abstract. The application of mobile terrestrial laser scanner (MTLS) has been studied for different tree crops such as citrus, apple, olive, pears and others. Such sensing system is capable of accurately estimating relevant canopy parameters such as volume and can be used for site-specific applications and for high throughput plant phenotyping. Coffee is an important tree crop for Brazil and could benefit from MTLS applications. Therefore, the purpose of this research was to define a field protocol for MTLS data collection in commercial coffee orchards and evaluate the spatial variability of canopy parameters. A LiDAR sensor and a RTK-GNSS was used for data acquisition. Two coffee orchards were scanned by a MTLS to test the proposed protocol. The data obtained were processed to generate 3D point clouds of the orchards. Canopy volume and height maps were generated for one of the fields. A minimum distance between the sensor and the canopy of 1m was determined based on the sensor scanning properties. A metal structure was constructed and attached to the three-point hitch of the tractor creating an offset between the sensor and the tractor. Such a design allowed the sensor to be at least 1 m from the canopy. The point clouds showed that for both fields the sensor was able to scan the entire coffee plants. The coefficients of variation of volume and height were 6.5% and 15.7%. The canopy volume and height maps showed that there was spatial variability in the field. Furthermore, according to the geostatiscal analysis, the spatial dependence was limited to short distances. Consequently, the use of sensors such as LiDAR should be preferred over sampling methods for a good representation of the orchard spatial variability.

Keywords. 3D modeling, LiDAR, Site-specific management

Introduction

LiDAR technology (Light Detection and Ranging) is based on the emission and reception of a laser beam, in which the time-of-flight principle is used to determine the distance to the object. Based on this technology, Rosell-Polo et al. (2009) described a methodology using a tractor-mounted 2D LiDAR (such a system has been referred to as "Mobile Terrestrial Laser Scanner", MTLS) for non-destructive measurement of vegetative volume and surface area of tree-row crops. However, in their study, no Global Navigation Satellite System (GNSS) was used, so the tractor had to follow a predefined straight parallel track from the crop row axis so that each sensor scan could be assigned to a reference position. On the other hand, in the work of del-Moral-Martínez et al. (2015), a GNSS receiver obtained the coordinates of each LiDAR scan, allowing each point in the point cloud to be assigned with an accurate geographic positioning. This methodology solved several problems related to data collection, such as the matching of the two scanned sides of the trees and the necessity of keeping the alignment between the tractor path and the crop row.

Based on these methodologies, the application of MTLS have been studied for different tree crops, such as citrus (COLAÇO et al., 2017), apple (WALKLATE et al., 2002; WALKLATE et al., 2003), olive (MOORTHY et al., 2011; MIRANDA-FLUENTES et al., 2015; ESCOLÀ et al., 2015) and pears (ROSELL-POLO et al., 2009). The information obtained by the MTLS can be used for different site-specific management of these crops. Variable-rate applications could be determined by the plants geometric parameters (height, volume, leaf density) obtained by the MTLS (ZAMAN et al., 2005; ESCOLÀ et al., 2013). Besides that, the management of irrigation and pruning could be based on monitoring the canopy growth (ESCOLÀ et al., 2017). Moreover, LiDAR sensors have been used for high throuput plant phenotyping (SUN, LI and PATERSON, 2017).

Brazil is the world's largest coffee producer (USDA, 2017). The market for coffee has been more exigent for quality and environmental care. From this perspective, there is a potential for PA practices based on MTLS, given that such applications could help increase input use efficiency and reduce environmental waste. So far, no MTLS studies were carried out in coffee. One of the singularities of this crop is the narrow width of the orchard alleys, which can make the side scanning a challenging task. Moreover, according to Camargo e Camargo (2001), coffee has a biannual production cycle, which means that in one year the coffee plant invests more energy in vegetative growth, leading to lower yield. The following year is characterized by higher yield, but lower vegetative growth. Thus, besides the yield variations, there are also variations in the geometric parameters of the tree canopy, such as volume and porosity. Finally, in Brazil most of coffee orchards are mechanically harvested, in which one of the requirements is that the plants must have a specific shape. Although homogeneous canopy is desired, plants might have different shapes (FERRAZ et al., 2011). In consequence, it is necessary to have a pruning plan for the coffee crop, in order to optimize the mechanical harvest. The characterization of canopy volume and porosity should also help to estimate damages to the tree canopies after the mechanical harvest.

The ability to map the spatial variability of the canopy parameters should allow better crop management and better operational planning. Also, according to Duga et al. (2015), volume and porosity of plants are the canopy characteristics that most influence the on-target deposition during spraying. This study is a preliminary assessment of the potential use of MTLS for coffee. It also seek to verify which are the main constrains and challenges for field data acquisition. Therefore, the objective of this study was to define a field protocol for MTLS coffee data collection and evaluate the spatial variability of geometric parameters from coffee plants in a commercial orchard.

Methodology

A LMS200 terrestrial 2D laser scanner (Sick, Waldkirch, Germany), a GR-3 GNSS (Topcon, Tokyo, Japan) with RTK (Real Time Kinematics) correction and a rugged laptop were used to obtain the data. A customized data acquisition software, using Python 2 programming language,

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was developed to collect the LiDAR and GNSS data synchronously. The LiDAR sensor was programed to collect data with an angular resolution of 1°, an angular range of 180° and a distance range of 8 m. The distance resolution was 1 mm. The distance error specified in the sensor manual is ± 5 mm. The scanning rate was 72 Hz. Regarding the GNSS, the acquisition rate was 10 Hz and ±10 mm of accuracy in the kinematic mode. Because of the different acquisition rates between the LiDAR sensor and GNSS receiver, the geographical coordinates were interpolated in the time domain to obtain different positioning for each scan of the laser sensor.

Figure 1 shows the LiDAR data acquisition method based on Llorens et al. (2011), which inspired the method used in this study. In this method, D is the distance between the sensor and the obstacle and j is the measurement angle in the vertical plane, from 0 to 180°. Distance measurements were collected in angular steps of 1° along the vertical plane. The third dimension (Y-axis) of the data (not represented on the figure) is obtained from the movement of the MTLS along the alleys of the orchard. The RTK-GNSS receiver was used to collect the sensor position at each scan. These coordinates were then shifted to each laser beam impact, based on the distance and angle of each measurement.
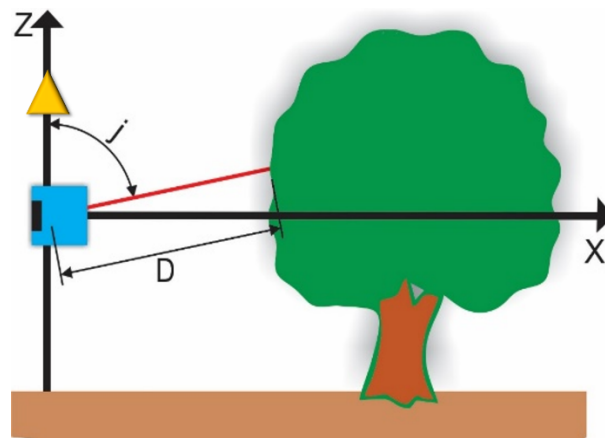

Figure 1. Measurement of the distance D at the j angle. The triangle represents the RTK-GNSS and the blue square the LiDAR

A field protocol for MTLS data collection in coffee was developed and tested in two different fields. The first field (Field 1) is located in the state of Sao Paulo (21°57'40.40"S, 46°51'32.47"W), where a coffee cultivar named "Mundo Novo" (*Coffea arabica*) was cultivated in an area of 1.27 ha with alley width of 3.5m and plant distance of 0.8 m. The second field (Field 2) is located in the state of Minas Gerais (19°22'35.40"S, 46°22'10.15"W). In this field a coffee cultivar named "Catuaí 144" (*Coffea arabica*) was cultivated in an area of 2.15 ha with alley width of 3.8m and distance between plants of 0.6m. In both fields, the data acquisition took place immediately before the crops were mechanically harvested.

After data acquisition, point clouds were generated using the methodology presented in Colaço et al. (2017). Data processing for point cloud generation was done using custom scripts in R, version 3.14 (R CORE TEAM, 2017). The open source software Cloud Compare, version 2.10.alpha (GPL Software, 2018) was used for data visualization and 3D manipulation.

The point cloud generated for Field 2 was further analyzed to extract the canopy parameters, such as height and volume. Such a processing was not carried out in Field 1 due to the curved shape of the tree rows, which was not suited for the R code used in this study. In Field 2, the transversal sections methodology presented by Colaço et al. (2017) was used. According to this method, the crop row is divided into sections, which are used to calculate the volume and height. Each row was divided into 0.2m transversal sections, which is equivalent to dividing each tree into 3 sections along the row axis. The convex hull algorithm from R software library rgeos was used to obtain the volume and height. The shapefile generated in the previous step was opened in QGIS software, version 2.14.13 (QGIS DEVELOPMENT TEAM, 2017) and the centroid of each transversal section was extracted. The data was filtered, removing all values with differences from

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the mean greater than two standard deviations. Then, a descriptive statistic and kriging interpolation were generated for the data using R software. In addition, the potential of MTLS to generate information of tree porosity was explored in this work.

Results and Discussion

- MTLS coffee data acquisition – field protocol

A structure to hold the sensor and the GNSS was developed. This structure was fixed on the three-point hitch of a narrow width tractor. The sensor height was adjustable and was set to the half of the maximum height of plants in the field (ROSELL-POLO et al., 2009). A minimum distance that the LiDAR sensor should be kept from the row side been scanned was calculated. Such a distance should allow the sensor to scan the entire plant. The sensor angle range used in this works was 180°, but an effective range of 100° and a plant height of 2.4m were used for the calculation of the minimum distance (Figure 2), which was 1.01 m. Based on this information, in the structure developed the sensor and the GNSS was shifted from the center of the tractor, ensuring the minimum distance necessary. Figure 3 show the structure developed mounted on the three-point hitch of the tractor.
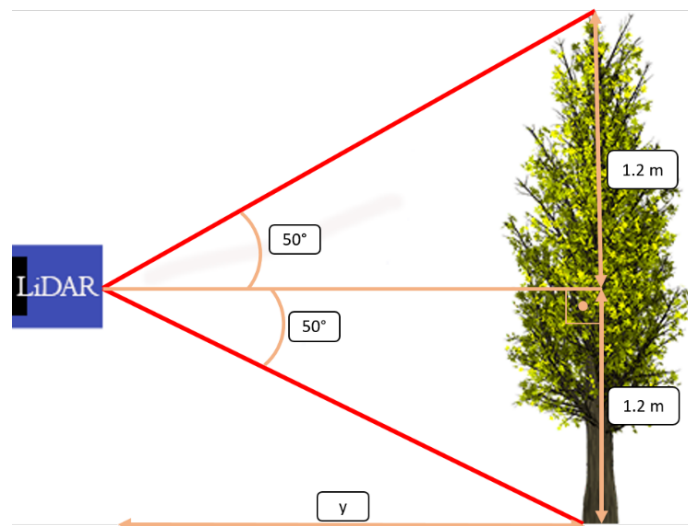

Figure 2. Sketch used for the calculation of the minimum distance (y) that the sensor should keep from the crop row (not in scale).

Figure 3. Tractor mounted structure for MTLS field data collection for coffee

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- Point Clouds

Figure 4 presents the 3D point clouds from the LiDAR data acquisition for the two fields. This is a particularly important result given that these are the first two coffee fields scanned by a MTLS. Visual inspection of the point clouds shows that for both fields the sensor scanned the entire coffee plants. Therefore, the equipment and structure used were sufficient to create a 3D point cloud similar to the geometry of the real plants for two different fields with different alley widths. However, some difficulties can be pointed. The first one relates to the small spacing between the rows, which makes difficult the scanning of the top of the plants. For Field 2, the top of the plants had lower density of points (Figure 5A). Nevertheless, the overall shape of the plant was considered fairly close to the real shape of the plants (Figure 5B). Further validation is expected to complement this initial visual assessment. Another difficulty was the roughness of the terrain on some parts of the field, which might have compromised the accuracy of the point cloud in some rows. In this respect, data acquisition could be further improved with the use of an inertial measurement unit, to account for yaw, pitch and roll rotations of the sensor
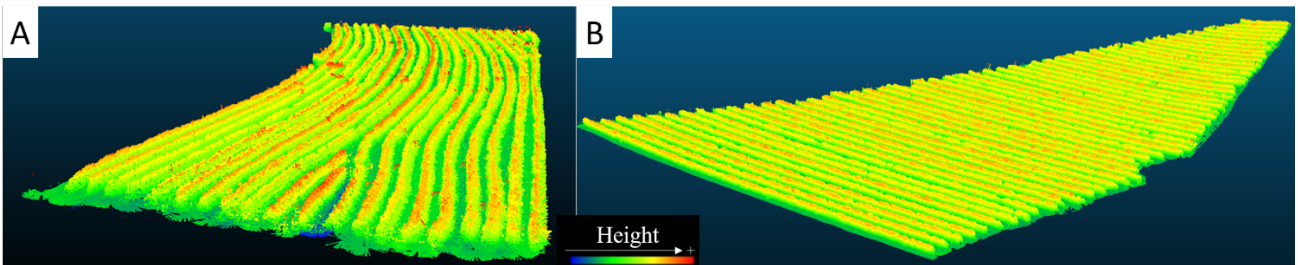

Figure 4. Point cloud obtained for Field 1 (A) and Field 2 (B).
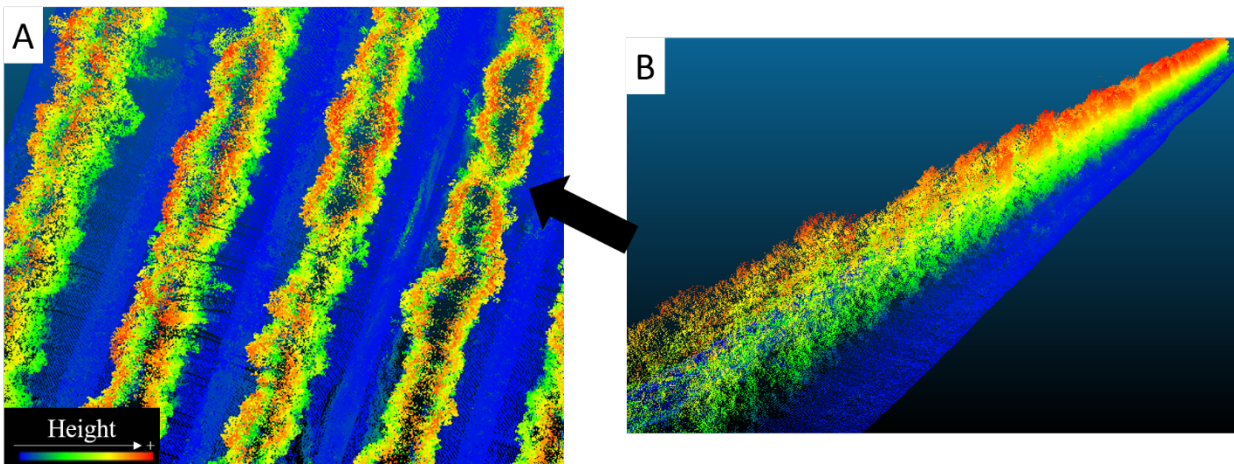
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Figure 5. Top view of the point Cloud from Field 2 showing the low density of points on the top of the plants (A). One of the tree rows from a different perspective (B).

- Canopy Geometric Parameters

According to the biannual coffee production cycle, Field 2 was in a year of vegetative growth. Moreover, according to the farm registers, this field was pruned right after the previous harvest. Therefore, because of the pruning, it was expected that the field would present a relatively uniform map of height and volume. Table 1 presents the descriptive statistic of volume and height for Field 2. It is possible to infer that there is variability in the field, given the coefficients of variation of 6.5% and 15.7% for plant height and volume. The histograms (Figure 6) for both variables present a normal distribution.

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Table 1. Descriptive statistic of volume and height for Field 2

Variables	Mean	Standard Deviation	Median	Minimum	Maximum	C.V.(%)*
		------------------ m³ (volume) or m (height) --------------------				
Height	2.91	0.19	2.92	2.41	3.37	6.55
Volume	0.78	0.12	0.79	0.48	1.06	15.77

*C.V. = coefficient of variation
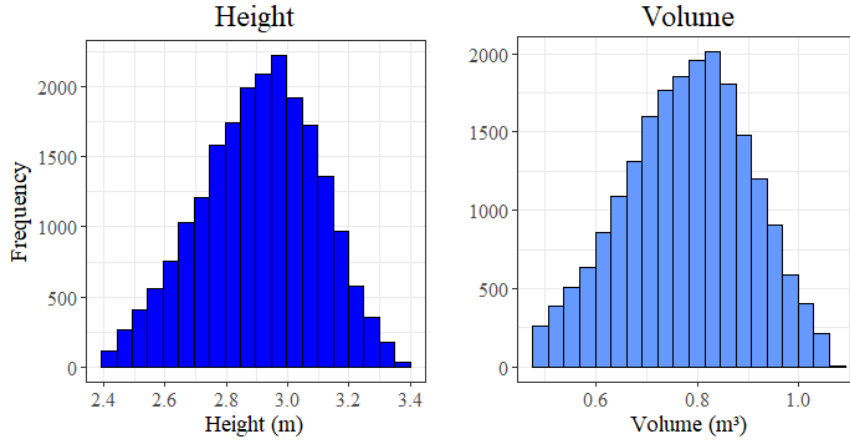
Figure 6. Histograms of canopy height and volume from Field 2

Table 2 presents the variogram parameters from the geostatistical analysis of the volume and height obtained for the 0.2m sections. According to the range of both variables, approximately five meters, it is possible to infer that the spatial dependence is limited to short distances. Therefore, for a good representation of the spatial variability of these geometric parameters, it is necessary to use a sensor, such as LiDAR, over a method based on sampling the tree rows. Within the dependence range, the spatial dependence is high, since the nugget (C0) is low in relation to the sill variance (C0+C1).

Table 2. Variogram parameters for volume and height from geostatistical analysis

Variables	C0*	C1**	Range (m)	C0.(C0+C1)$^{-1}$
Height	1.4×10^{-3}	3.2×10^{-3}	5.3	4.2×10^{-2}
Volume	0.8×10^{-3}	1.4×10^{-3}	4.5	5.4×10^{-2}

* Nugget effect (C0); **Structural variance (C1);

The kriged maps of canopy volume and height are presented in Figure 7 (B and C). According to the maps, there is spatial variability in the field, even after pruning. This justifies the use of the sensor to monitor the crop variability in the field and reinforces the importance of this information for crop management. It is possible to identify some coincident regions in the maps, where the plants are smaller and with low volume. The correlation between the two maps were 0.66, which may be a consequence of the management, depending on how severe was the pruning on the sides of the plants.

According to the descriptive statistic for these two maps, the volume and height vary between 0.46m³ to 0.95m³ and 2.5m to 3.3m. Therefore, a variable-rate could be driven by the volume of the sections and the opening of the nozzles of a sprayer could be controlled by the height of the plants, turning on just the ones to cover the plant surface. Moreover, if the height and volume would be measured along the crop development, a growth pattern could be determined. This information could be used for the management of pruning of the coffee plants.
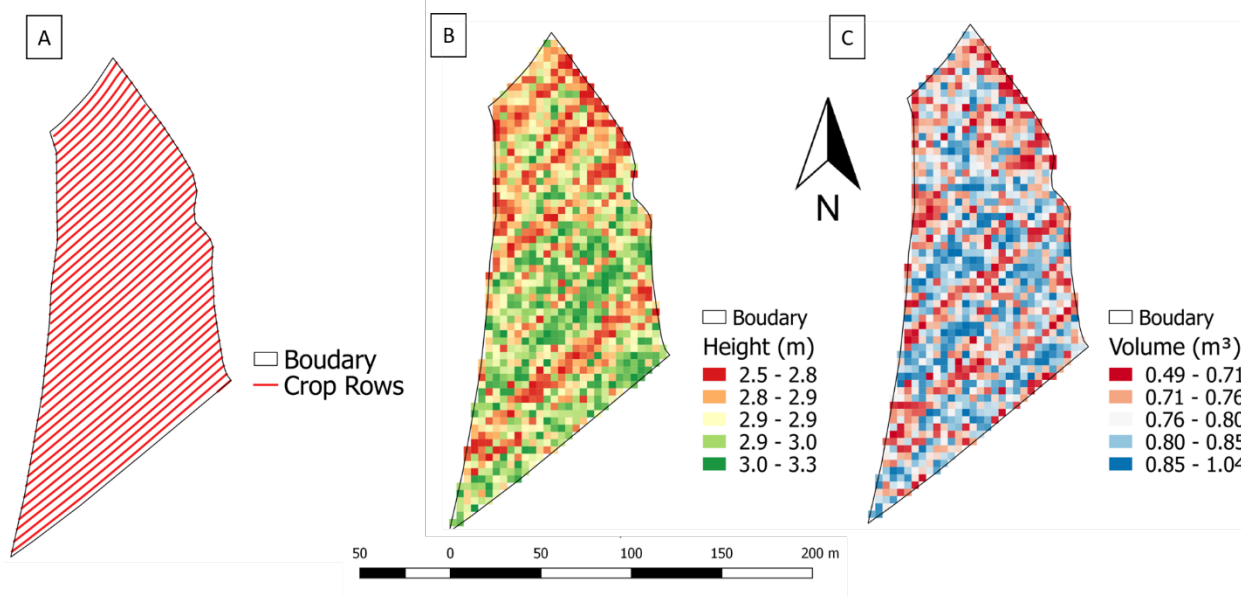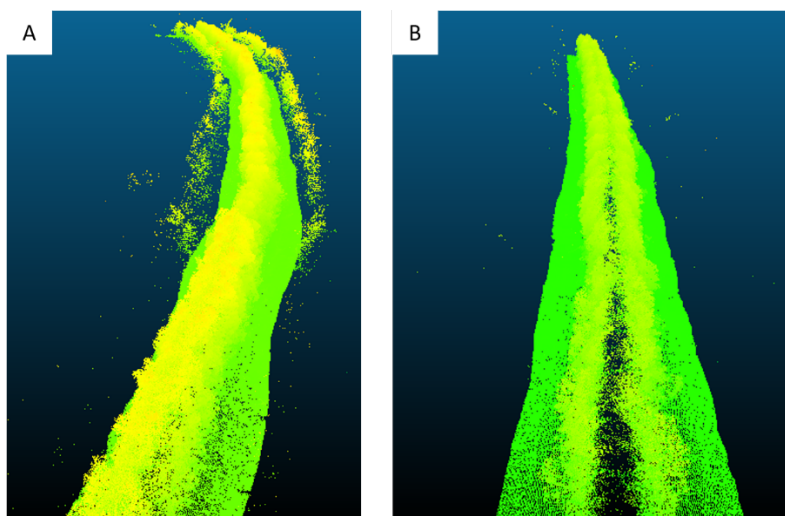
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Figure 7. Crop rows (A) and maps of height (B) and volume (C) and crop rows from Field 2

- Tree Porosity

In the data processing methodology presented by Colaço et al. (2017) used in this work, there is a step in which for each crop row scanning, the points that passed through the canopy reaching the adjacent crop row are excluded from the row point cloud file. In this filter, a maximum distance for a particular reading is set. Figure 8 shows point clouds from Field 1 and 2 without a maximum distance filter. By comparing the two point clouds, it is possible to identify that in Field 1 more points pass through the plants reaching the other crop row than in the Field 2. According to Dunga et al. (2011), plant porosity can be defined as the ratio between the canopy free spaces and the spaces occupied by the leaves and branches. Based on this definition, the points that passed through the crop row being scanned can be considered related to the porosity of these plants. Therefore, we could infer that Field 1 is more porous than Field 2. In summary, according to the porosity definition presented and the results obtained on Figure 8, a MTLS has a potential to estimate the plant porosity. The plant porosity could be calculated simply by the ratio between the points that passed through the row being scanned and the ones that reached the leaves and branches.

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Figure 8. Point cloud from Field 1 (A) and Field 2 (B) without filtering with a maximum distance

Conclusion

A field protocol for MTLS data acquisition in coffee orchards was proposed and tested. The 3D models derived from the MTLS were satisfactory given the detailed representation of the plants. Canopy volume and height maps where generated showing opportunity for site-specific practices based on MTLS. Even in areas where there is a pruning management plan, there was a significant spatial variability of canopy parameters. Finally, there is potential to use the MTLS to estimate the porosity of plants, which is an important characteristic for spraying deposition.

Acknowledgements

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