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METHODOLOGY FOR AVOCADO (*Persea americana* Mill.) ORCHARD EVALUATION USING DIFFERENT MEASUREMENT TECHNOLOGIES

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ABSTRACT

Avocado crop (*Persea americana* Mill.) is of great commercial importance due to its high profitability. However, it is being affected by various diseases and pests that affect yield and reduce fruit quality. The aim of this research was to develop methodologies for the evaluation of avocado plantations using different non-destructive technologies for rapid phenotyping and early detection of the incidence of diseases or damage due to stress in the stem. A plot of 0.7 ha. was evaluated, with a total of 44 individuals using Field-Map technology (dasometric and morphological characterization), RGB-multispectral images from Remotely Piloted Aircraft System (RPAS) (rapid phenotyping), while 15 individuals were evaluated using tomography (assessment of the internal state of the stem). The results with tomography indicated that there is a tree with wood rot of 14% with a lower acoustic speed with respect to the other trees evaluated. A high correlation was observed between the dasometric variables (r-Pearson from 0.63 to 0.98) estimated with Field-Map [crown base height, crown projection (m^2) and total height] and with RPAS (height, perimeter and area). The vegetation indices do not have a direct correlation with the dasometric variables; five of the indices have a high contribution to variability except for the Normalized Difference Red Edge (NDRE). It can be

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concluded that the technologies used in this study would help to perform evaluations with a greater number of reliable and precise data with respect to the information obtained in a traditional way, while they can be replicated in commercial plots or research studies of different perennial crops, generating useful information for management decisions and crop evaluation.

Keywords: Field-Map, RPAS, tomography, phenotyping, vegetation indices

INTRODUCTION

Agriculture is the basic source of food supply worldwide and plays an important role in the entire process of enrichment and social development of a country (Bula, 2020). Avocado (*Persea americana*) cultivation has aroused great interest in growers due to its high profitability and excellent prospects for the future. Avocado is a high nutritional value food, its pulp is rich in proteins, lipids, carotenoids, vitamins, fibers, polyphenols and unsaturated fatty acids (Dreher and Davenport, 2013). Its consumption has grown exponentially in recent years, being Peru the second exporting country (12.4%) after Mexico (MINAGRI, 2019). Avocados are native to Mexico and Central America. It is one of the most important commercial species in the Lauraceae family, which includes around 2,200 species (Pérez et al., 2015). The cultivation of avocado has a social and economic importance. It is, therefore, essential to solve problems related to agronomic management, pest and/or disease control, among others, which cause significant decrease in yields and reduction in the quality of the fruit. It affects the commercial interest, and as a consequence, it generates less income for the growers (Bedoya and Julca, 2021, Pérez-Jiménez, 2008; Terán, 2018).

Currently, there are technologies, instruments and models based on mathematical principles to obtain data with greater precision, accuracy, effectiveness, and efficiency (Baron et al, 2018). Field-Map technology is a useful tool for surveying and monitoring plots of vegetation, and it is adaptable to any methodology. It combines real-time GIS software with electronic equipment for more effective and precise cartographic digitization and dasometric detection, allowing data processing and analysis to be carried out quickly, efficiently and in real time (Benavides et al., 2018).

Some non-destructive techniques have been used with precision equipment, such as the tomograph, in order to identity internal defects and evaluate the quality of the wood of standing trees (INIA 2018; INIA 2019; Angulo-Ruiz, 2021). Acoustic tomography was applied in the evaluation of the trunk of the trees in order to determine the percentage of wood damage in the cross-section, by using the physical principle of emission of acoustic waves, in which the values of propagation speed of the waves are affected by the influence of some factors. The density of the wood, damage or anomalies (Costa, 2013), moisture content and temperature (Balmori et al., 2016). Basterrechea (2016) explains that in areas damaged by fungi or termites, the propagation of the acoustic wave crosses a different medium from that of the intact wood, affecting its speed and direction, because it tends to deviate from the hole, increasing its path.

The control and follow-up mechanisms in the crops and plantations monitoring are of great importance to carry out adequate management. Currently, the use of Remotely Piloted Aircraft System (RPAS) plus remote sensors such as RGB and multispectral cameras are used for the study of eco-forestry processes. They enable the acquisition of information with high spatio-temporal resolution. González et al. (2020) identified them as potential tools for health monitoring and rapid phenotyping. This multispectral imaging technology allows us to calculate vegetation indices using different spectral bands. These are algorithms with mathematical combinations of wavelength-specific spectral reflectance (Barzin et al., 2020), used for crop health or stress monitoring, as reported by García-Ruiz et al. (2013) in citrus plantations.

The general aim of this research was to establish evaluation methodologies to identify avocado trees affected by pests/diseases or abiotic stress, using different non-destructive technologies in order to take the necessary control measures. The specific objectives were to determine the number of trees with rotting or damaged wood and to compare the morphological and dasometric information obtained with the Field-Map technology and the data from RGB and multispectral images.

MATERIALS AND METHODS

Description of the study area

This study was carried out in an avocado commercial field of 0.7 ha located in La Molina Research Center (CELM, for its acronym in Spanish) of the National Institute of Agrarian Innovation (INIA) in the district of La Molina, Lima, Peru (Fig. 1A,B), between the UTM coordinates WGS84, 18S zone; 288625.284 X

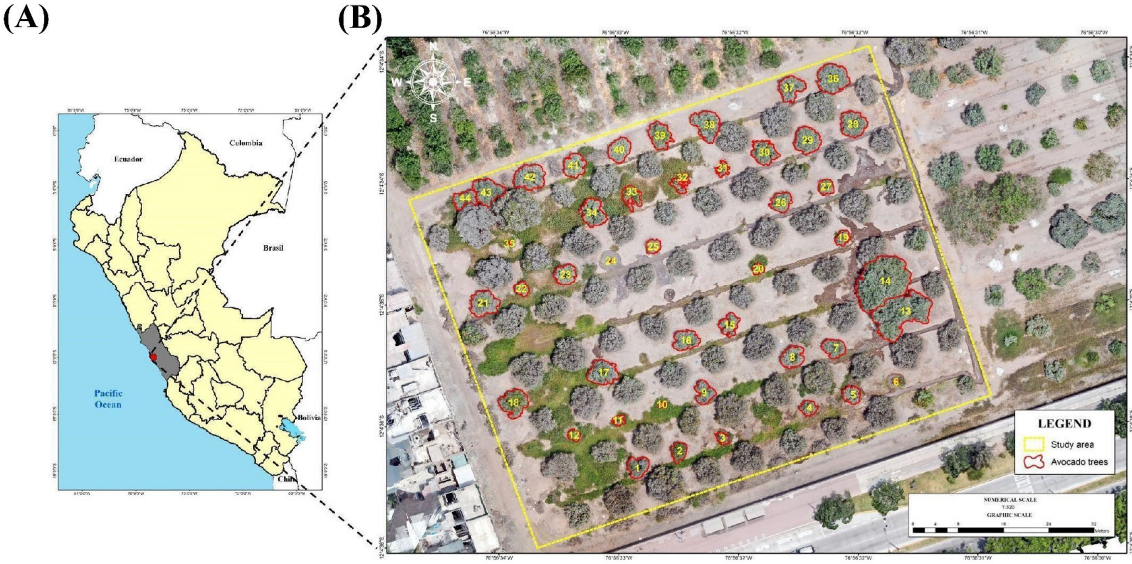

Fig. 1. Location of the study area in Lima - Peru (A). Composite true-color image (red, green, and blue bands); the yellow rectangle indicates the study area and the red polygons indicate the intervening avocado trees (B).

and 8664235.562 Y, at an altitude of 241 m.a.s.l. The evaluations were performed in September-October 2021.

Evaluation with acoustic tomography

The ArborSonic 3D tomography (Fakopp Enterprise Bt, Hungary) is a device used to determine the location and percentage of rotten or hollow areas in the trunk in a non-destructive way. Its operation is based on the measurement of the acoustic speed between six sensors around the trunk; if there is a hole or other defect inside, the speed will decrease between the sensors and the sound waves will surround it, causing an increase in the reception time (Fakopp Enterprise Bt, 2020). Fig. 2A shows the equipment made up of amplifier boxes, sensors, battery box, rubber hammer, steel hammer, tape measure, connection cables, sensor removal tool and a field computer with ArborSonic 3D software.

The initial step to evaluate with tomography was to measure the circumference of the trunk and enter the data into the ArborSonic 3D software, where six sensors (SD02 low noise sensor) were selected, and the program determined the distance between them. The sensors are placed equidistant with a rubber hammer, then they are connected to the transmitter boxes and they are linked by connection cables to the battery box. The information is transmitted to the Getac T110 Tablet (Getac, China) by Bluetooth. Other devices such as a computer or smartphone can be used (Fig. 2B). Then, each sensor is hit three times with the same force intensity. Finally, the program records the time and a tomogram is obtained as a result (Fig. 2C) that is interpreted according to a color scale and acoustic velocity. For the evaluations with the tomograph, 15 avocado individuals were selected, and the following characteristics were considered: lack of bifurcation from the base and having a diameter greater than 15 cm.

Evaluation with Field-Map Technology Field-map

Field-Map (FM) software (X16 version) was created by IFER- Institute of Forest Ecosystem Research, (Czech Republic) It integrates a set of modern devices, and consists of: (i) a robust getac T800 tablet field computer (Getac, China), (ii) a Trupulse 360R laser hypsometer (Laser tech, Japan) with leaf filter, and (iii) an IFER dendroscope and support accessories (tripod, L brackets and reflector rod), which allows to make individual measurements of the trees, as well as calculations of trunks and crown parameters, data control, mapping, preliminary analysis of the obtained data in the field and it is flexible to any methodology. There were two stages for gathering information: i) the project is developed in the Field-Map Project Manager extension where the variables and vectors (points, lines, polygons, etc.) are defined, and ii) the data collection is carried out in the Field-Map Data Collector

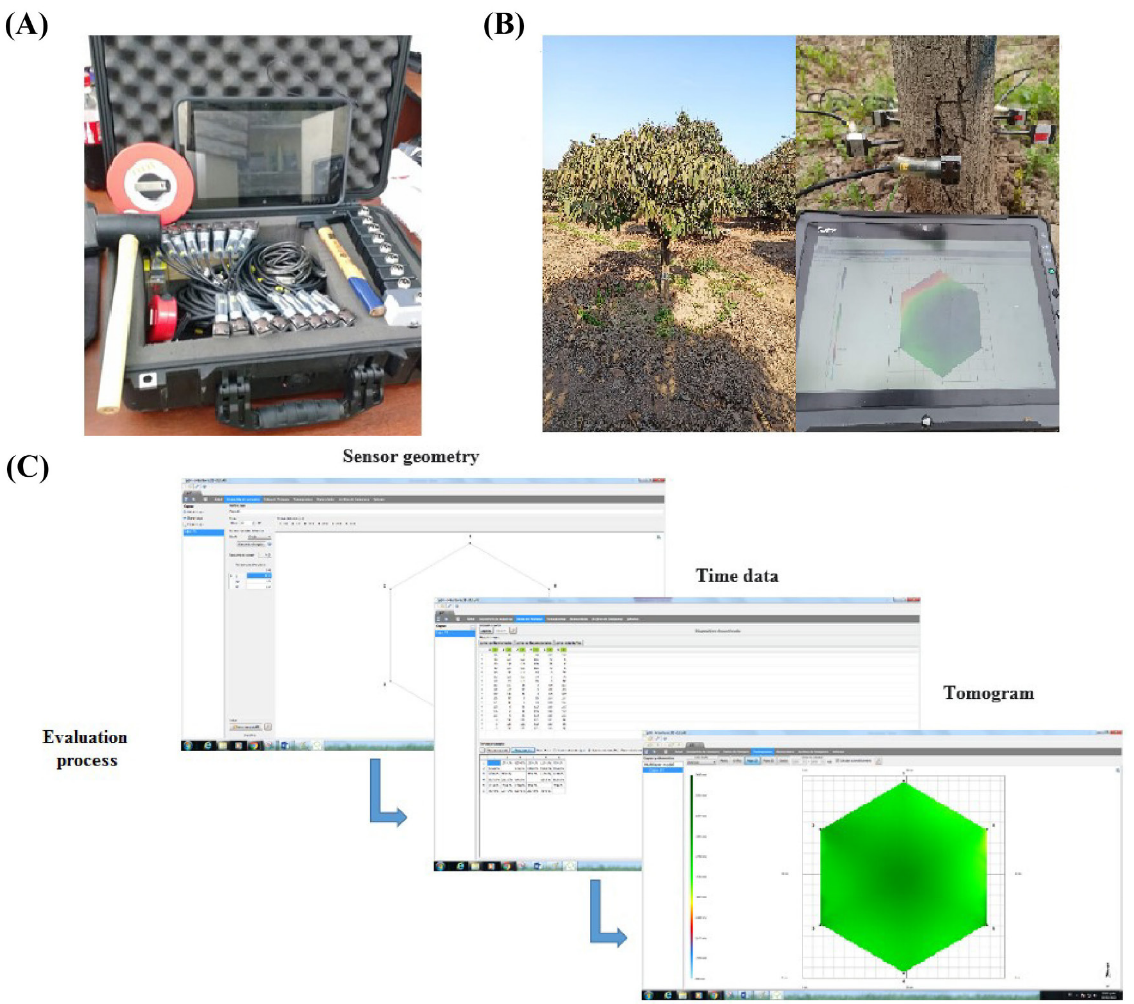

Fig. 2. ArborSonic 3D acoustic tomography (Fakopp Enterprise BT., Hungary) (A), wood evaluation (B). Processing views in ArborSonic 3D program (C).

extension where the initially created project was loaded, combining electronic measurement equipments. They are installed in the field. After that, the georeferenced starting point is defined and the tripod is placed to verify the leveling and, the accessories for the assembly and calibration of the Trupulse 360R. Then, the laser and the computer (Getac Tablet) connections are verified and begin to georeference each individual avocado. This action is carried out using the laser Hypsometer (Trupulse 360R) and a pole with a reflector, which is placed at the base of the tree, so the laser emits a signal that is received and automatically stored by the system (Field-Map Data Collector interface) as a tree-like vector and it can be displayed on the computer in real-time. Then, the electronic form is filled out with the morphological characterization (phenological stage, trunk type, canopy type, canopy size, bifurcation). The extension of the FM system is used for the dasometric evaluation (heights and projection of the canopy), and it automatically performs the calculations, using the distance and the angle formed between the tree and the equipment. To do this, from the position of the FM, we made a shot at the trunk base and at the apex, in this way the total height is obtained. For the height, at the base of the treetop the same procedure is followed. To measure the projection of the treetop, we used a laser hypsometer and the shots were made at the reflector, locating four to six points following the shape of the treetop. Fig. 3 shows the workflow; from the design, collection and analysis of the information obtained in the field.

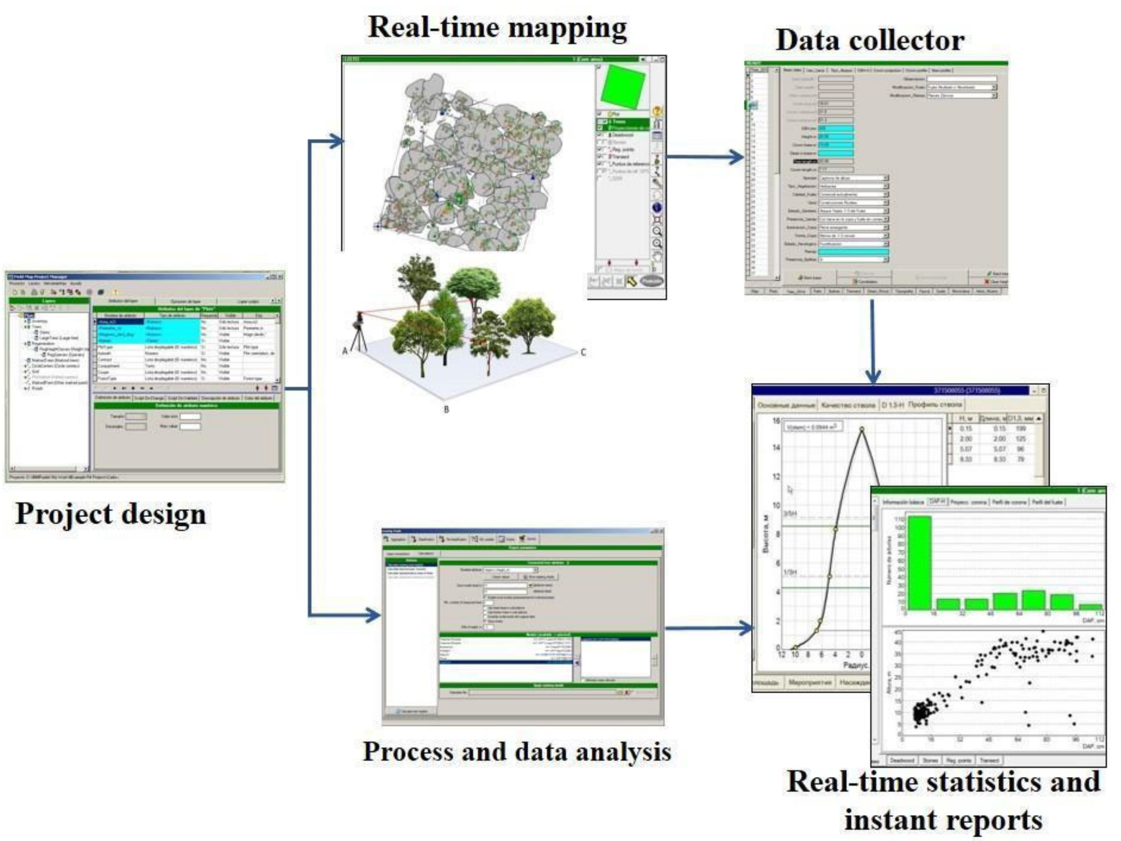

Fig. 3. Scheme of workflow with Field-Map Version X16 technology (software created by IFER (Institute of Forest Ecosystem Research, Czech Republic).

Evaluation with Remotely Piloted Aircraft System (RPAS) using RGB and multispectral sensors

Acquisition and calculation of vegetation indices with RPAS multispectral images

A quadcopter-type industrial platform RPAS, DJI Matrice 300 RTK (Shenzhen Dajiang Baiwang Technology Co., Ltd., Shenzhen, China), was used to perform the flight in the avocado plot. Ten-band multispectral sensor with 3.6 megapixels (MP) global shutter, MicaSense Dual RedEdge-Mx + RedEdge-MX Blue (MicaSense, Inc., United States) was coupled to the RPAS; it captures images in coastal blue 444 (28), Blue 475 (32), Green 531 (14), Green 560 (27), Red 650 (16), Red 668 (14), Red Trim 705 (10), Red Trim 717 (12), Red Trim 740 (18) and near-infrared 842 (57). Image capture was made in the period of September-October 2021, with an approximate temperature of 16 °C and wind speed of less than 12 m/s, under clear and sunny sky conditions (without clouds) from 11:00 a.m. to 1:00 p.m. following the methodology used by Lu et al. (2020). The flight plan was carried out with RPAS control, considering a frontal and lateral overlap of 80%, flight height of 50 m, speed of 2.5 m/s and the camera was focused on the nadir plane (perpendicular to the ground surface), allowing a 3.47 cm/pixel resolution to obtain the images that were stored on a 128 GB SD card. The processing was carried out with the Pix4Dmapper Pro software (V4.3.33, Pix4D SA, Prilly, Switzerland), where the necessary parameters for the processing were introduced, the configuration for the multispectral camera was selected and the reflectances were generated using the inverse distance weighted method. A DRTK 2 Mobile station was used to improve the georeferencing of the data obtained and the radiometric calibration of the multispectral images was carried out with the MicaSense reflectance calibrator panel and a DLS 2 sunlight sensor that has an integrated a GPS, and it automatically adjusts the images to ambient light as used by Han et al. (2019).

With the reflectances obtained for each spectral band, the vegetation indices were calculated in the QGIS software (V 3.16.8, free software). This study used the following procedure to obtain the vegetation indices with the multispectral images: (1) A combination of bands was made with the *composite bands* in which the red, green and blue bands were selected to obtain an RGB image that allows to carry out a supervised classification and elaborate the cut masks. (2) The supervised classification was carried out using the RGB image and the *image classification*, which allows selecting and differentiate the soil vegetation, shadows and other elements that exist in the research plot, then this classification is edited to eliminate some stubble and thus to be able to obtain the area of interest of the study. (3) Six vegetation indices were calculated; they are displayed in Table 1. (4) Finally, with the masks obtained in step 2, the raster images of each generated vegetation indices were cut. This allowed to calculate the statistical parameters (min, max, sum, sd, range and mean) of each plant using the zonal statistics and thus to obtain the values for each evaluated avocado tree.

Calculation of perimeter, canopy cover and plant height using RGB images from RPAS

For the acquisition of RGB images, the same RPAS was used with the D-RTK 2 Mobile station and a Zenmuse H20T RGB sensor (Shenzhen Dajiang Baiwang Technology Co., Ltd., Shenzhen, China) was attached to it. The images were captured around noon to minimize the shadows of the plants and specular lighting, following the methodology used by Jurado et al. (2020). The flight plan was carried out with the RPAS radio control, considering a frontal and lateral overlap of 80%, flight height of 50 m, 3 m/s speed and the sensor was configured to perform an oblique flight, getting a greater number of images at different angles and directions (four side views and one front view) that allowed to build a better orthomosaic and 3D model. The full-frame RGB camera takes photos with 20 MP, thus it can observe the study area with a spatial resolution of 1.99 cm/pixel.

The procedure was performed with the Pix4Dmapper Pro software, it was used to build the orthomosaic, the digital surface model (DSM) and the digital terrain model (DTM). With the inputs obtained, we proceeded to calculate the height of the plant, the perimeter and canopy coverage in the QGIS software. This study used the following procedure: (1) a supervised classification was carried out with the orthomosaic of the RGB image, it allowed to identify the avocado trees and create a mask in raster format (.tiff), (2) the layer was converted from raster to vector format to have a shapefile format (.shp). The attributes of the perimeter (m) and canopy cover for each avocado tree (m^2) were added to this layer, and (3) the DSM and DTM layers were loaded into QGIS; both layers were cut with the generated mask to obtain only the values of the avocado trees, which were considered in the present study. The calculation of the Digital Height Model (DHM) was performed to obtain plant height (m), using the following formula:

$$\text{Plant height} = DSM - DTM \quad (1)$$

Data processing and multivariate analysis

The data obtained by the combination of different methodologies employed in this research, allowed to create a database with qualitative and quantitative variables. They were organized in data frame format that was loaded into the R software platform (R Core Team, 2022). We used *ggplot2* library (Wickham, 2016) to create boxplots, observing the variability and dispersion of the data. Multivariate analysis such as principal component analysis (PCA) was conducted with *FactoMineR* (Le et al., 2008) and *factoextra* (Kassambara and Mundt, 2020) libraries

Table 1. Vegetation indices calculated by reflectance using multispectral images.

Abbreviation	Definition	Type	Reference
NDVI	(NIR−RED)/(NIR+RED)		
GNDVI	(NIR − GREEN)/(NIR + GREEN)	Multispectral	
NDRE	(NIR-RED EDGE)/(NIR+RED EDGE)		(Qi et al., 2020)
SAVI	[(NIR − RED)/(NIR + RED+L)](1+L)		
CIG	(NIR / GREEN) - 1		
RVI	(NIR / RED)		

considering only quantitative data. Function *famd* was used to conduct PCA for quantitative and qualitative variables together. The r-Pearson correlation was obtained using *GGally* (Schloerke et al., 2021) and *Hmisc* (Harrell Jr., 2022).

RESULTS AND DISCUSSION

Evaluations with acoustic tomography

Of a total of 15 trees, evaluated with the tomograph, only one tree presented wood rot with a 14% affected area; this agrees with the morphological evaluation since the tree was defoliated and had visible cracks in the trunk. There are different studies where the results of the tomography are compared with the real data, finding favorable results for this technology (Li et al., 2014; Barrios, 2016; Ostrovský et al., 2017; Kobza et al., 2022). In Fig. 4A it can be observed the variation of acoustic speed per evaluated tree. The affected trees showed lower speed values (1251.6±186.1 m/s), which is related to the damage of the wood due to the time of sound propagation is greater when presenting a defect or hole (Basterrechea, 2016; Fakopp Enterprise Bt, 2020). The path of the sound measured in speed between sensor 1 to sensor 2 (Fig. 4B) showed a different coloration because it presented a lower speed (677 m/s) and in the tomogram, the region with wood damage is observed in blue (Fig. 4C).

Evaluations with Field Map technology

A total of 44 individuals were evaluated. The total average height was 1.9 m, maximum height was 4.5 m, and minimum was 0.54 m. The average area of the crowns was 11.50 m^2 (Table 2). In Fig. 5, it can be observed the analysis of the qualitative morphological variables evaluated in avocado. A total of 80% of the individuals presented straight, trifurcated trunk, medium treetop size and a phenological stage in flowering.

FM technology can effectively handle dasometric and morphological data. A significant advantage compared to conventional evaluations is that data collected with FM in the field is stored directly in the system, facilitating data processing. These new measurement techniques have shown to be effective in crop plots where measurements are periodically carried out, and thus they could be able to develop growth prediction models. Similarly, Tomao et al. (2012) mentioned this tool allows the field evaluation with high-precision topographical surveys and it is a need to face problems in forest management, however, the expansion of its use could be also useful for historical parks and crops inventories.

Evaluations with RGB and multispectral images

From the processing of the multispectral images obtained with RPAS, six vegetation indices were calculated; they are described in

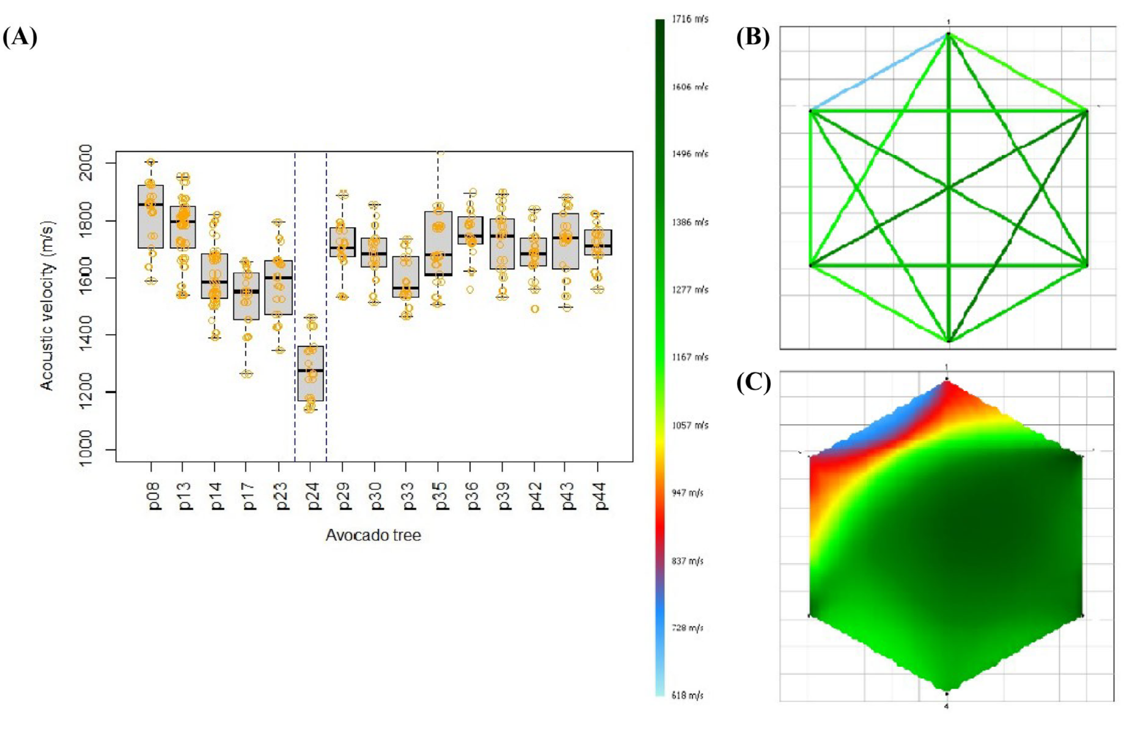

Fig. 4. Acoustic velocity per tree (A). Velocity propagation path (B) and tomogram (C) for tree 24.

Table 2. Dasometric evaluation results in avocado trees.

Statistics	Total height (m)	Crown base height (m)	Crown projection (m^2)
Minimum	0.540	0.140	1.201
Maximum	4.500	4.100	78.273
Rank	3.960	3.960	77.072
Average/SD	1.902±0.823	1.040±0.726	11.497±12.394
C.V.	43.265%	69.831%	107.801%

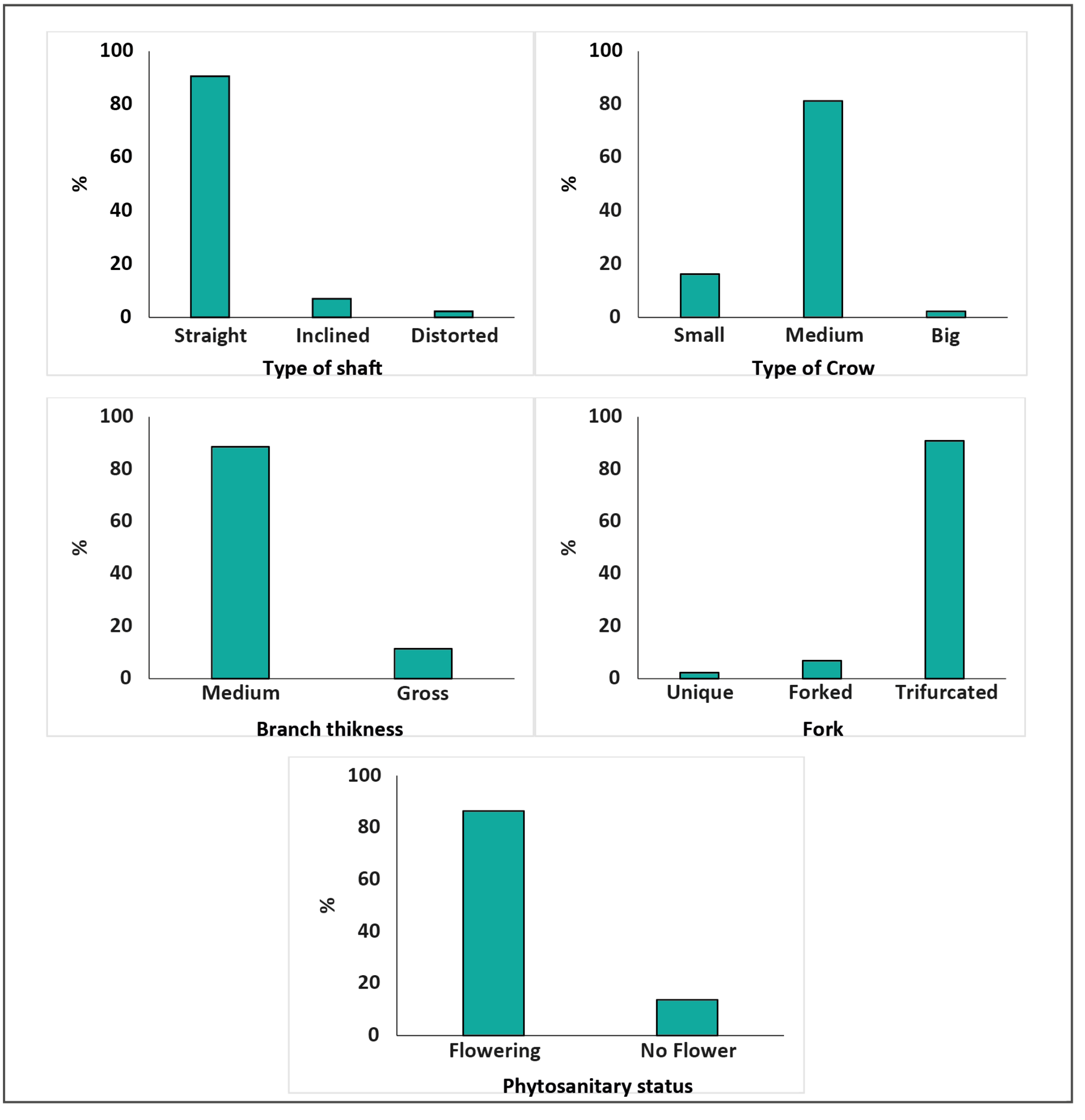

Fig. 5. Qualitative morphological evaluation of avocado trees loaded to the project designed in the Field-Map.

Table 1. In the scale of values of the indices, the NDVI varies from 0.1 to 0.9, but a higher percentage of trees (70%) shows values between 0.4 to 0.6 (Fig. 6). This could be attributed to the fact that the crop was at the beginning of flowering period, with a greater number of physiologically mature leaves covered on their surface with dust particles and with few new leaves. These values are similar to those obtained in the GNDVI and SAVI indices. NDRE values ranged from 0.2 to 0.4. It is not possible to establish a relationship between the vegetation indices and the presence of wood rot because the affected plant had no canopy cover and had been drastically removed before taking the images.

On the other hand, with the RGB images it was possible to estimate the perimeter and the canopy coverage area through the supervised classification method. This methodology was used since a small plot was evaluated and the high resolution of 1.99 cm/pixel allowed us to identify and differentiate avocado trees from other crops or weed. A total of 44 avocado trees were identified with an accuracy of 99%. The small patches of weed that resembled the coloration of the avocado trees were corrected manually in the QGIS software. For larger areas, it is suggested to use the methodology of Ampatzidis and Partel (2019), which allows training a learning convolutional neural network for the direct identification of trees through the rectangle technique or image segmentation shape technique, as well as correcting the results through a refinement process. We calculated the height of the avocado trees by using the digital height model (1) which represents the relative height of each object that was found on the evaluated surface. In our case the images were cut with the generated mask to avoid the presence of other crops or weed within this model. de Oliveira et al. (2022) obtained similar results evaluating citrus crops and mentioned that adding ground control points (GCP) did not have influence when calculating the DHM.

The perimeter, plant height, canopy cover and vegetation indices showed variability as well as biometric evaluations (Fig. 6). The trees with the greatest dimension are located as outliers in the

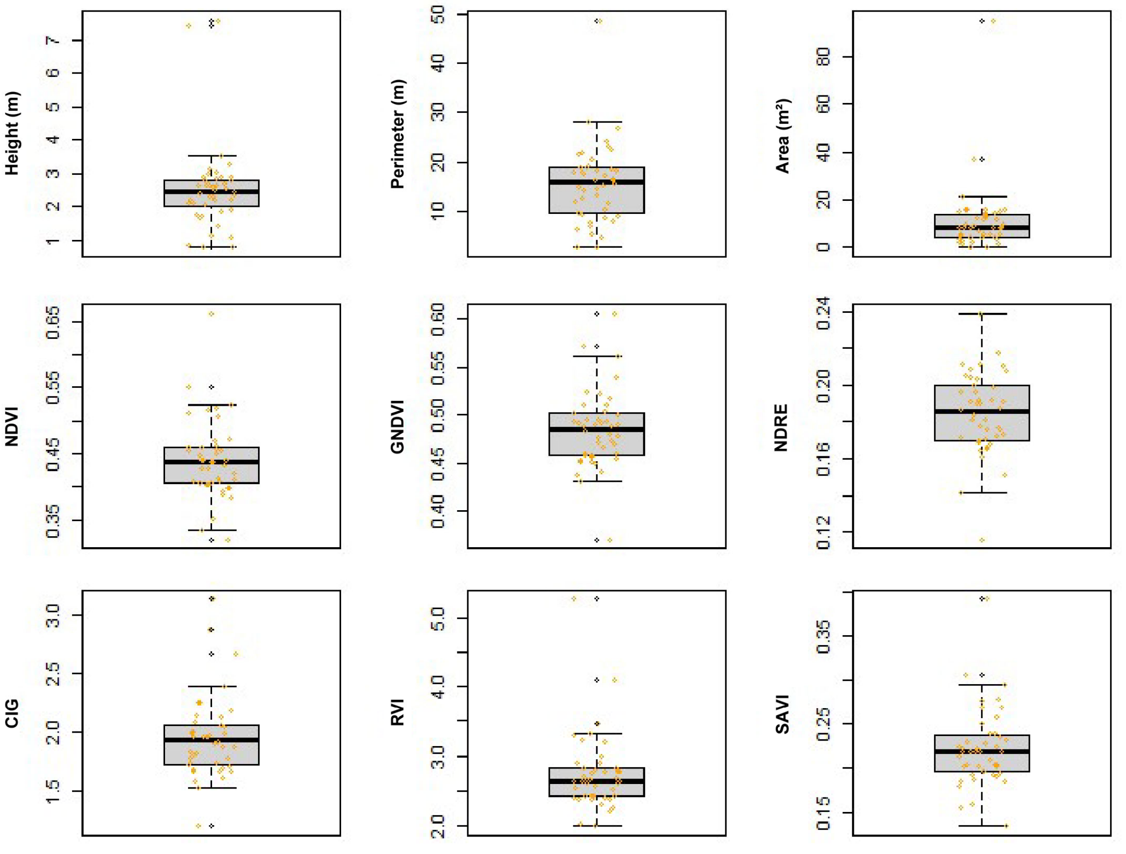

Fig. 6. Boxplot of biometric variables (height, perimeter and area) and vegetation indices (NDVI, GNDVI, NDRE, CIG, RVI and SAVI) evaluated with RPAS and RGB cameras (H20T) and multispectral (Micasense Dual) in avocado trees.

box plots, reflecting the variability of the images with the data generated by these methodologies.

Multivariate analysis with the technologies used

A factor analysis of mixed data analysis (FAMD) was carried out in order to analyze the data as a whole and to obtain the quantitative and qualitative data, obtaining a variability of 46.5% (Fig. 7); it is explained by the two dimensions of the FAMD (Dim 1 = 24.8% and Dim 2 = 21.7%). From the FAMD of quantitative variables (Fig. 7A) a high correlation of the dasometric variables

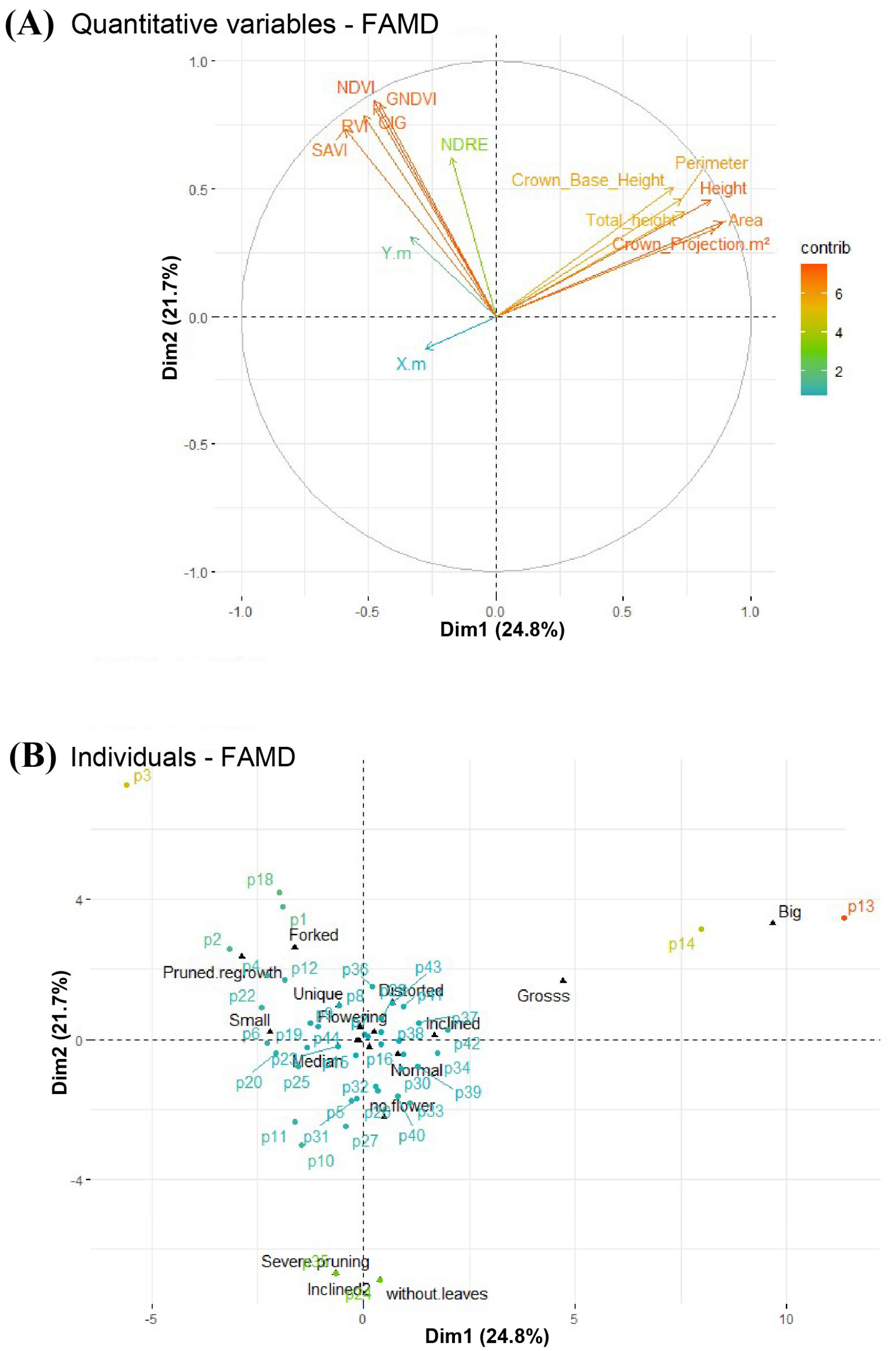

Fig. 7. Factor analysis of mixed data (FAMD) of the dasometric evaluations with Field Map and DJI Matrice 300 drone with RGB and multispectral cameras in avocado trees at CELM-INIA. FAMD with quantitative variables (A) and individual FAMD of avocado trees (B).

(*r-Pearson* from 0.63 to 0.98) estimated with FM technology (crown base height, crown projection, and total height) is observed, and those obtained with RPAS (height, perimeter and area), contributed between 5 to 7% to the observed variability. These variables are shown in the same quadrant and with sharp angles between them, evidencing their high correlation. On the other hand, the six vegetation indices (NDVI, GNDVI, NDRE, SAVI, CIG and RVI) are oriented to another quadrant with a similar contribution to the total variability of the analysis, with the NDRE index, being the one with the least contribution (approx. of 3%). The individual FAMD (Fig. 7B) of the avocado trees showed clear discrimination between the evaluated individuals, with the p13 and p14 trees, being the greatest in dimension and size, while the vegetation indices with the highest values were for the p3 tree. Trees without cover and wood damage are in an opposite quadrant to the direction of the vegetation indices based on the canopy. These indices do not have a direct correlation with the dasometric variables of growth and dimensions of the trees since they are estimated from the reflectance (vegetation indices) of the leaves of each individual. Current methods for detecting damage caused by fungal pathogens are based on microbial and molecular techniques, and their application on a small scale are still limited as indicated by Pérez-Bueno et al. (2019). Multispectral imaging techniques have been applied to analyze trees health, through machine learning methods, using vegetation indices such as the NDVI (Romero et al., 2018). Therefore, this study about avocado trees may promote the use of this type of methodology.

Another multivariate analysis performed in this research was the principal component analysis (PCA). There were 15 avocado trees evaluated with the acoustic tomography. PCA explains 69.3% of the observed variability (Fig. 8) with the first two dimensions (Dim 1 = 48% and Dim 2 = 21.3%). The acoustic speed of the tomography sensors and the observed variability are not directly influenced by the dasometric characteristics such as height, diameter and crown projection. Avocado trees with larger dimensions (p13 and p14) and trees of average size presented similar values of acoustic velocity (Fig. 8). Similarly, Ostrovský et al. (2017) found

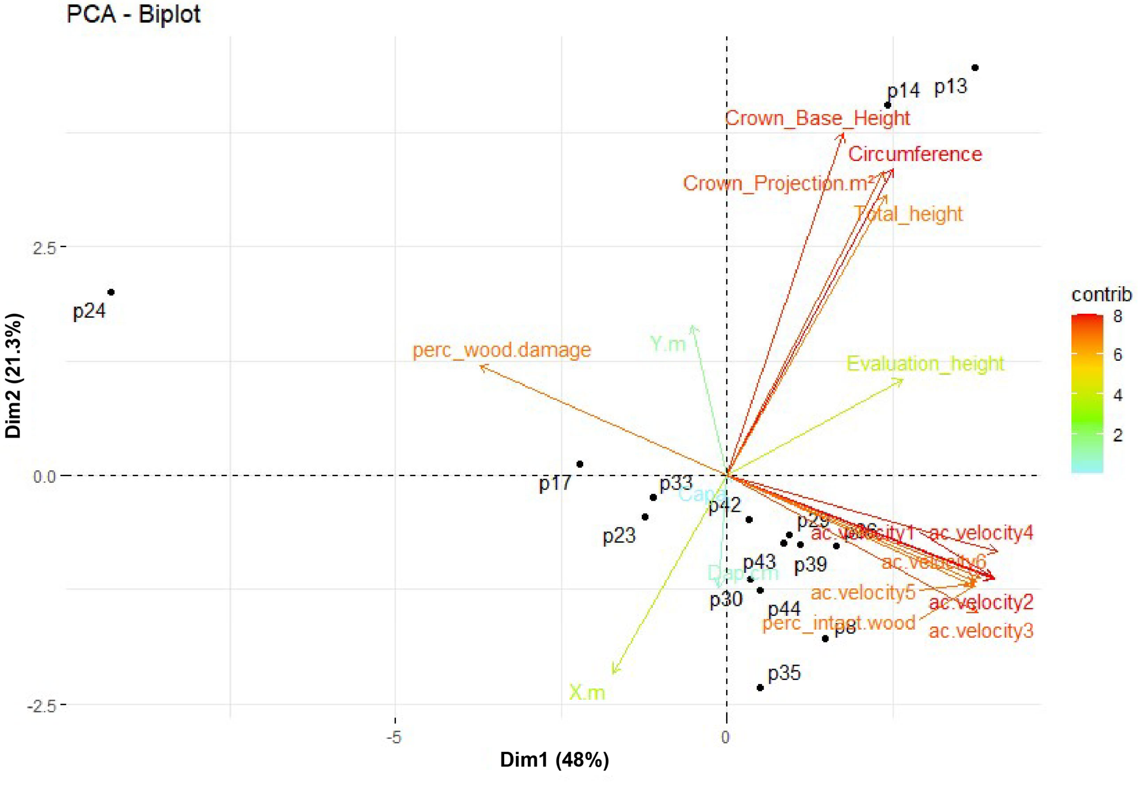

Fig. 8. Principal component analysis (PCA) of the trees evaluated with the tomography for wood damage as a function of acoustic velocity, sensor evaluation height and biometric variables estimated with Field-Map (total height, crown base, crown projection, and circumference of avocado trees).

that the diameter of the tree does not influence the accuracy of the tomograph.

Regarding the dasometric variables evaluated with FM and RPAS (plant height and tree canopy cover), they had a high and very high degree of correlation (R^2=0.68 and R^2=0.96) in these two variables (Fig. 9A and 9B). In Fig. 9C, the canopy cover calculated with the Field-Map is compared with that obtained from the supervised classification of the RGB images, getting a better representation in the case of the latter procedure. Data collection time with RPAS was approximately 15 minutes, and measurement of the tree canopy with the FM was around 5 hours. However, the images obtained from sensors + RPAS require more processing time in high-performance computers (16 hours approx.), while the data taken with the FM in the field can be exported at the end of the evaluation.

CONCLUSIONS

Of the avocado trees evaluated with tomography, one affected individual was identified, while a high degree of correlation was obtained in measurement of dasometric variables, by using Field-Map and RPAS methodologies. In the multivariate analyses, it was concluded that the vegetation indices do not present a direct relationship with the dasometric variables. Measurement methodologies raised in the present study allow carrying out evaluations with a greater number of reliable and precise data with respect to information obtained in a

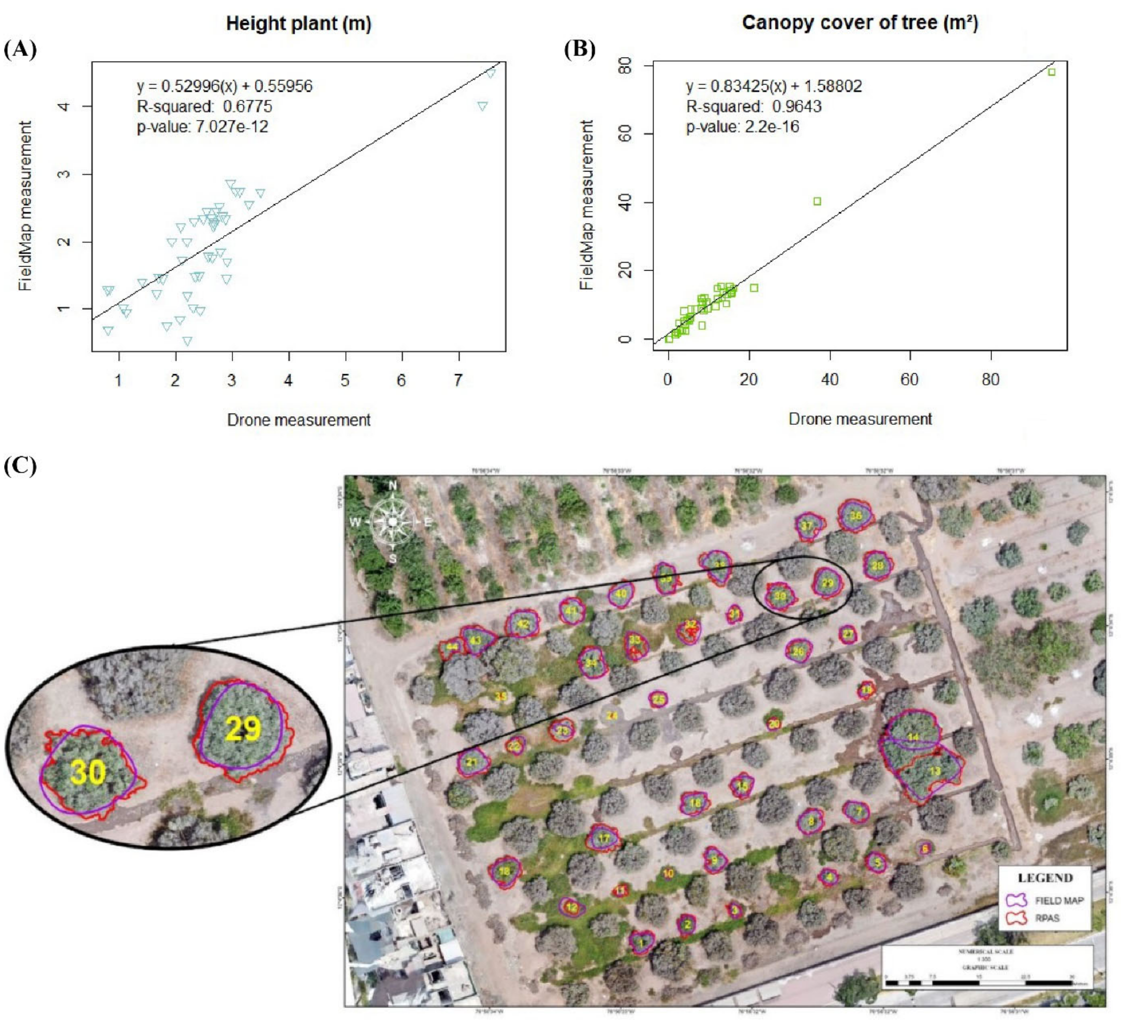

Fig. 9. Linear regression of measurements made with field map and drones for plant height (A), for avocado tree canopy cover (B) and supervised classification of canopy cover polygons from the images generated by RPAS (drone) and those obtained with Field Map (C)

traditional way, while they can be replicated in commercial plots or research work of different perennial crops, generating precise information for management decisions and evaluations.

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