Electronic characterization of the phenological stages of grapevine using a LIDAR sensor.

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ABSTRACT

Canopy characteristics and their variation at all growth stages, together with the spatial distribution of plants in the field need to be considered in determining the application volume rate in fruit crops. Spray volume calculation in a vineyard needs to take into account concepts such as tree row volume (TRV), leaf wall area (LWA) and leaf area index (LAI). The objective of this work was to develop one protocol to characterize the canopy geometry of grapevine to determine BBCH stages using data sets measured manually and with LIDAR scanning. With this aim, a package called PROcess TO LIdar Data v.0.1 (PROTOLIDAR) was created in R environment to process the LIDAR scan information. Results showed a significant correlation between LIDAR impacts and LAI at each growth stage. The relationship between the estimated values of TRV or LWA, and the growth stage of the vine was statistically significant ($R^2 = 0.99$ and $R^2 = 0.95$, respectively). Finally, the geometry characterizations of the plants were represented in 2 or 3D maps in GRASS-GIS.

Keywords: LIDAR, grapevine, canopy characterization, PROTOLIDAR.

Introduction

In agreement with the European Directive 128 that calls for a sustainable use of pesticides, dose adjustment according to canopy characteristics represents one of the more effective improvements in the crop protection process. The geometric characterization of plants is useful in determining the optimal dose of pesticides. In recent years, studies have been reported (Gil et al, 2007; Koch, 2007; Gil and Escolà, 2009; Llorens et al, 2011) to characterize the sprayed area/target in order to reduce applied volume while efficacy values were maintained constant. Gil et al. (2007) showed that the total amount of liquid applied could be reduced by 58% by taking into account the variations of crop width with similar deposition on leaves. Furthermore, in recent years, LIDAR technology has been used for canopy characterization in fruits trees and vineyards (Rosell et al, 2009; Llorens et al, 2011). A LIDAR sensor is a remote-sensing technique based on the measurement of the time a laser pulse takes to reach a target. This sensor has a demonstrated accuracy in plant measurements; therefore, the grapevine was scanned along its cycle and the correlation between manual measurements and LIDAR were compared. According to previous research (Gil et al, 2011; Walklate et al, 2011; Toews & Friessleben, 2012), the leaf wall area (LWA) concept, expressed in $m^2\ ha^{-1}$, the tree row volume (TRV) method, measured in $m^3\ ha^{-1}$, have been calculated to give a better adjustment of the volume to be applied in an orchard. Gil (2003) showed that there is an interesting correlation between deposition and leaf area index (LAI). Llorens et al (2011) established a good correlation between LAI values and LIDAR impacts.

The main objective of this work was to develop a mathematic protocol able to predict the geometric parameters of the canopy after LIDAR scan measurements. A statistical comparison between estimated values of TRV, LWA and LAI calculated after LIDAR scan measurements was made with data obtained from manual measurements. With the data set of the grapevine characterization, a map was constructed using GRASS-GIS.

Material and Methods

Experimental Vineyard

A field experiment was located in a vineyard in Sant Pere Ribes (Barcelona, Spain) placed at 396.582 m (E), 4.566.477 m (N) UTM 31N-WGS84. The grapevine variety was Chardonnay and cordon was the trellis system. The distance between rows was 2.9 m and 1.4 m between plants on the row.

Geometric characterization

The height, width and surface of leaves in each phenological stage of the grapevine were measured manually and with a LIDAR sensor. Measurements were carried out randomly at four sites with three repetitions in each position. The measurement procedure started when the shoots were 10 cm long and five/six leaves were unfolded, corresponding to BBCH 15 (Lorenz et al, 1994), and continued during the whole growing season at different growth stages: inflorescences fully developed and flowers separating (BBCH 57), full bloom (BBCH 65), pea-sized berries (BBCH 75), the berries at 8° Brix (BBCH 78) and ended when the berries were ready to be harvested (BBCH 89).

Electronic canopy characterization at each phenological stage was developed using a LIDAR sensor. The laser scanner used was a LMS-200 model (Sick, Dusseldorf, Germany), a fully-automatic divergent laser scanner based on the measurement of time-of-flight (TOF) with an accuracy of ± 15 mm in a single shoot measurement in a range up to 8m. The time between the transmission and the reception of the pulsed near-infrared laser beam is used to measure the distance between the scanner and the reflecting plant surface (Rosell et al, 2009). The LIDAR scanner was placed at 1 m from the center of the plant line and at 0.9 m of height above the ground (Hg) (Fig.1). The total scan distance in each test was of 1.85 m on both sides of the plant (north and south positions). Three different measurements were taken on each side of each sampling point, with a total of 9 scans per plant at each phenological stage and the mean of each side was calculated. The configuration used was a continuous scan at ratio 38400 bps and angle 180° at 0.5° of angular resolution.

The dataset was processed using LidarScan v.1® software (Universitat de Lleida, Lleida, Spain). The output of the software is a dataset with x-y-z variables, where x is width (Fig.1: horizontal axis in the bottom left), y represents height (Fig.1: vertical axis in the bottom left) and z is the front view of the plant or path from the tractor (Fig.1: perpendicular axis to the graph or depth). The data files were analyzed with R Software® (2.15.1) (R Development Core Team, 2010) open source statistical software and a package called PROTOLIDAR (PROcess TO LIdar Data) version 0.1 was created.

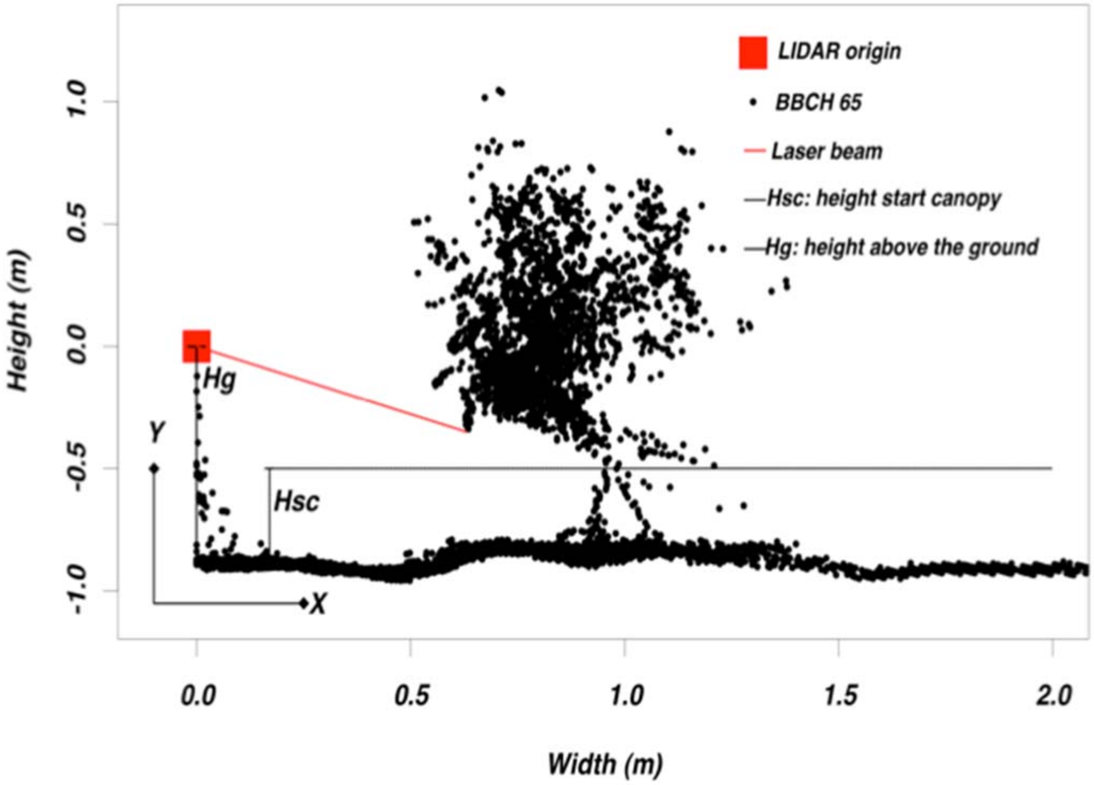

Figure 1. LIDAR position during the scan process (BBCH 65).

The methodology employed with R was to cut the surplus areas that do not correspond to the vegetation, because the LIDAR sensor reads 180° in a range up to 8 m and each scan performed in the orchard read more than one row.
The height of canopy was estimated from the point where the laser beam impacted the lower point of the canopy above the trunk (Hsc on Fig. 1) to the higher point. To analyze the data scan on each side, the maximum and minimum heights were extracted along of the z-axe (perpendicular axe to Fig.1) to calculate the mean of height of all plants.
The width of the plant was determined using the same methodology as for the height but using the x-axis (X axis in the bottom left corner of the Fig.1).
The number of LIDAR impacts into the canopy was computed at each phenological stage.

<u>Estimated indices</u>
Leaf area index (LAI) was determined using the manual counting of the number of leaves of each block; in our case, four plants were measured at each growth stage with three repetitions in each one. The mean surface of leaves was measured indirectly using four representative samples at each phenological stage. These samples were measured in the laboratory using a scan of the photograph of each leaf and then the images were processed with ImageJ® 1.45 open source software. With this method, the number of

leaves of each plant and the area of each leaf were used to calculate the leaf area index. The LAI was calculated as follows equation (1).

$$LAI = \frac{NL * LA}{RS * RD} \qquad (1)$$

Where *NL* is the number of leaves per plant; *LA* is the mean leaf area of leaves at each BBCH stage (m^2); *RS* is the row spacing in the orchard (m); and *RD* is the in-row distance between plants (m).
From manual and LIDAR measurements of the canopy, the Leaf Wall Area (LWA) in m^2ha^{-1} was calculated following equation (2).

$$LWA = \frac{2 * H * 10000}{RS} \qquad (2)$$

Where *H* is canopy height (m); 10000 is the ground area (m^2) and *RS* is the row spacing (m).
To adjust the volume rate applied at each phenological stage of the grapevine, the total volume of vegetation per unit of ground area was calculated according to the crop dimensions of each growth stage, by applying the TRV method.

$$TRV = \frac{H * W * 10000}{RS} \qquad (3)$$

Where *TRV* is the Tree Row Volume (m^3 ha^{-1}); *H* is canopy height (m); *W* is the canopy width (m); 10000 is the ground area (m^2) and *RS* is the row spacing (m).

<u>Development of PROTOLIDAR-package</u>
In order to process all data files generated after LIDAR measurements, LidarScan v.1® and PROTOLIDAR v.1.0 were used. This specific tool was created to be executed in R® over GPL 2 license. PROTOLIDAR is a package with a set of functions that helps to characterize the canopy of the grapevine (height, width, front view) from the LIDAR scan, performs statistical analysis on the outputs, plots and calculates LAI, LWA and TRV. The package was created in Windows® using Perl®, Latex®, Microsoft html compiler®, Rtools®, Rd.sty® file and WinZip®, as described by Frascati (2006).
The package comprises one example of LIDAR scan of grapevine (BBCH 65), called LIDAR_dataset, and ten functions that helped to analyze and characterize the canopy. Figure 2 describes all the processes where each function has one output such as a dataset or value. i.e., *Extract_plant* and *Extract_plant_3D* functions helped to extract all the plant from the entire dataset. This output helps to see the measurements of the plant in meters or to make plots. *Width_canopy*, *Height_canopy* and *Number_lidar_points* functions were constructed to characterize the canopy; here the plant was cut leaving only the area of measurement or interest (canopy).
TRV, LWA and LAI functions were developed to estimate these parameters from the data of the LIDAR scan and data measured manually such as the number of leaves or row distance. Finally, *Replicate_plants* and *Rotate* functions were made to construct 3D maps in GRASS. These last function allow rotation of plants in the direction of the planting framework of the orchard.

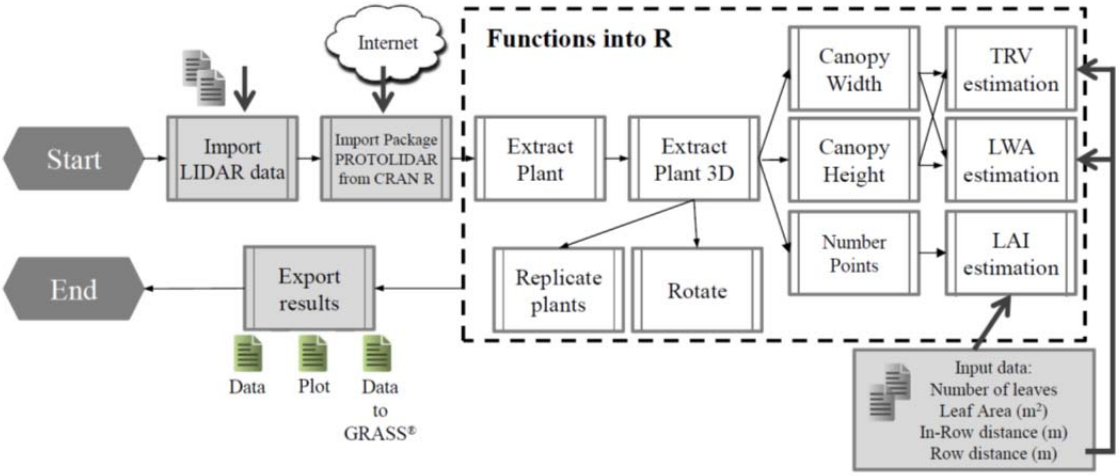

Figure 2. Process diagram of PROTOLIDAR package.

The package was published in R-project; it is available at http://cran.r-project.org/web/packages/PROTOLIDAR.

<u>Development of 3D Maps in GRASS with R environment.</u>

In this work, 3D maps were also developed in GRASS GIS (Neteler & Mitosova, 2008, Neteler et al, 2012) software in order to characterize the vegetation and, in the future, to help construct prescription maps for variable rate doses according to canopy variations. The process is explained in Figure 3 and could be visualized using the NVIZ 3-D GRASS interface. The latitude and longitude co-ordinates of each plant were obtained with TRIMBLE agGPS 332 used with differential correction. The antenna was located close to the trunk of the plant. The geo-positioning data obtained was overlapped with the orthophoto of the orchard downloaded from the Institut Cartogràfic de Catalunya (www.icc.cat) at 0.25 m x 0.25 m resolution. During the post-processing in GRASS, the latitude and longitude reference of each plant and the orthophoto were overlapped to create the planting line or the point maps to position the plants. The plants were positioned in the orchard using the *Rotate* function of PROTOLIDAR (Figure 3). The location projection in GRASS was created in Universal Transverse Mercator (UTM), zone 31 north – datum World Geodetic System (WGS84). The spatial resolution in this case was important because the plant, at BBCH 15, had 0.02 m^3 of canopy volume with 326.67 mean points and, at the final BBCH 89, had 0.57 m^3 of canopy volume with 2986.34 mean points. For that reason, the spatial resolution was first selected in 3D in GRASS, then it was selected in a Postgres SQL database for management of LIDAR datasets, and finally vector points maps in GRASS were developed.

Results

Results showed that LIDAR is a powerful tool that helps to characterize canopy. Statistical correlation with significance was found in each relationship between manual measurements and LIDAR scan measurements at each BBCH stage of the plant. i.e., regression analysis between: height manual measurements/height LIDAR scan or width manual measurements/width LIDAR scan revealed R^2 = 0.98, p-value = 2.2 e-16 and R^2 = 0.81, p-value= 1.764 e-09, respectively.

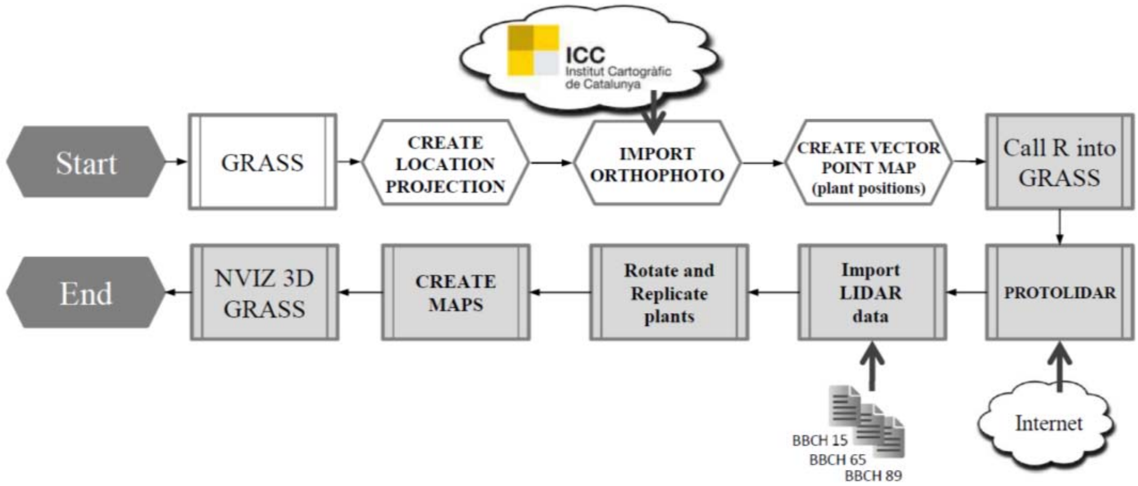

Figure 3. Process diagram of GRASS/R to construct 3D maps

These results show that, on the x-axis, the measurement of the width is less accurate than the height. This could be explained through the fact that the plant is measured from each side and the superposition of each scan could result in errors. The advantage of this last point is that, generally, the cordon system has a determinate width during the productive cycle due to plant pruning and LIDAR is able to characterize the total width of the vegetation.

From dataset obtained after the scanning of the grape and post-processed data with PROTOLIDAR functions, statistical correlation with significance between numbers of LIDAR impacts and LAI at each growth stage was constructed as shown in Figure 4. Here, more advanced phenological stages show a greater variability in the correlation between LAI and LIDAR impacts.

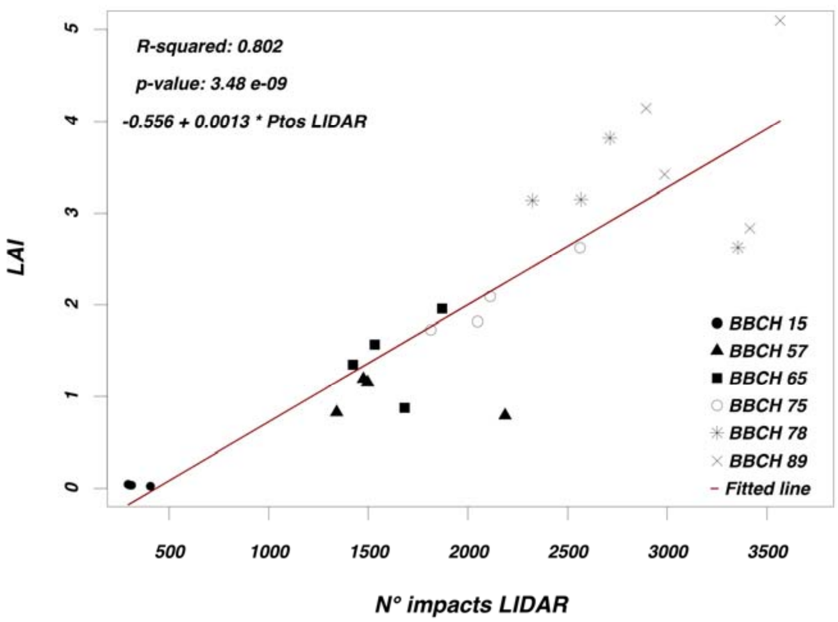

Figure 4. Relationship between the mean number of points of each side of the vine measured with LIDAR sensor in the canopy and LAI.

Other interesting correlations between LIDAR measurement values and canopy parameters were established. Figure 5 shows the relationship between the estimated TRV, LWA at every crop stage. It is interesting to highlight the accuracy of the relationship obtained and the possibility to use this relationship with the amount of LIDAR impacts generated in each BBCH for a quick canopy characterization.

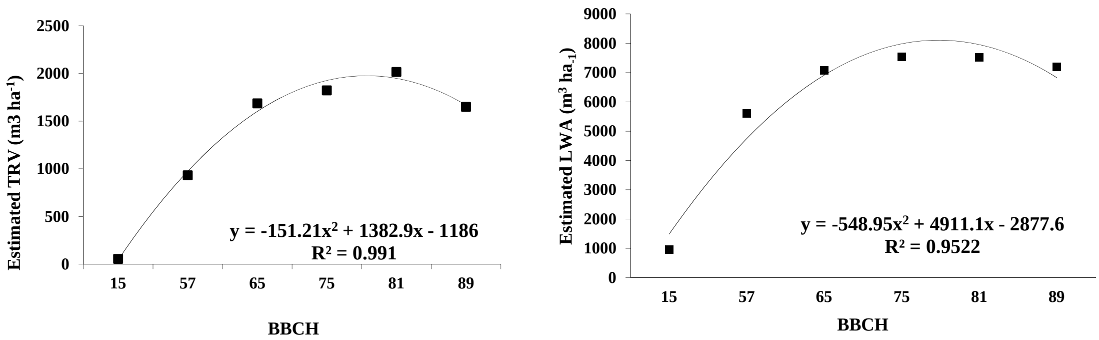

Figure 5. Relationship between TRW (left), LWA (right) at each BBCH stage.

The potential output of PROTOLIDAR package not only helps to calculate volumes of plants but also the output could be represented in two or three dimension (2D and 3D) canopy maps. Figure 6 (right) shows the 2D maps in GRASS environment overlapped with the orthophoto where the data was monitored and, on the left, 3D maps visualized with NVIZ tool. This methodology could be used to scan all plants and construct, with only the canopy points, variable rate dose maps. On the left (Figure 6), 3D view of the plants could be constructed.

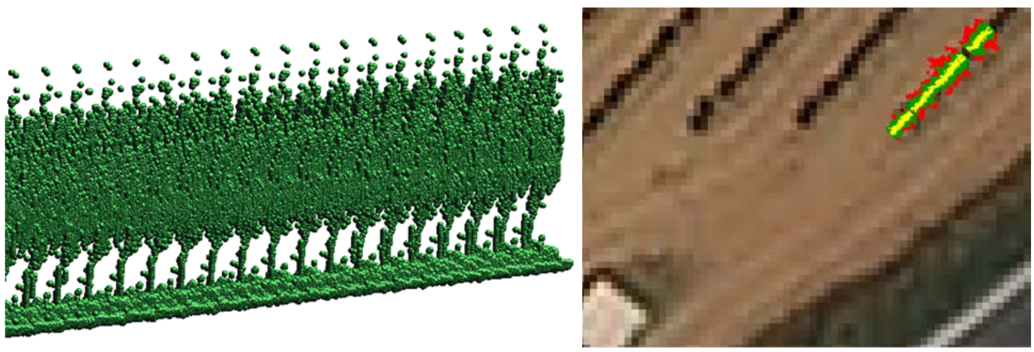

Figure 6. 3D Canopy view in NVIZ GRASS tool (left) and 2D Canopy view of each BBCH stage (BBCH 15: yellow points, BBCH 57: green points, BBCH 65: red points) in GRASS environment (right).

Conclusions

The high correlation found between manual and LIDAR scan measurements of canopy height and width ($R^2 = 0.98$ and $R^2 = 0.81$ respectively), confirm that LIDAR could be a useful tool for canopy characterization, maintaining an adequate level of accuracy of measurements. Canopy width is always linked with more imprecise data but, in the trellis system, where it is common to prune 2 or 3 times during the productive cycle, LIDAR scan can be used to describe the key parameters. Furthermore, canopy height and width measured with the proposed method show the variability of each vine in the trellis conductive system. This could be used to determine the TRV and LWA and, as a consequence, help in the calculation of the optimal spray volume.

This optimal spray volume applied could be adjusted using LIDAR data for every single phenological stage, and could be processed using the proposed PROTOLIDAR package.

Maps in two and three dimensions (virtual) could be an easy way to display this data for the growers and could be interpolated to obtain the prescription map in each plant.

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