MAPPING THE LEAF AREA INDEX IN VINEYARD USING A GROUND-BASED LIDAR SCANNER

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ABSTRACT

The leaf area index (LAI) is defined as the one-sided leaf area per unit ground area and is probably the most widely used index to characterize grapevine vigour. However, direct LAI measurement requires the use of destructive leaves sampling methods which are costly and time-consuming and so are other indirect methods. Faced with these techniques, vineyard leaf area can be indirectly estimated using ground-based LiDAR sensors scanning the vines and getting information about the geometry and/or structure of the canopy. In addition, LAI is spatially variable. In order to obtain a map of the LAI spatial distribution, a SICK LMS-200 laser scanner together with a RTK-GPS and an inertial sensor (IMU, Inertial Measurement Unit) were used to scan a vineyard plot. Specifically, the laser system was tested on a *Vitis vinifera* L. *cv*. Syrah vineyard in Raimat (Catalonia, Spain), with rows of 380 m length and 3 m row spacing. The total scanned ground area covered 0.70 ha. Having turned the resulting point vector map into a raster map by local block kriging, two classified maps with different LAI zones (two and three zones) were obtained using cluster analysis. Finally, to establish a protocol for the LiDAR use, the original maps were compared with maps obtained by progressively reducing the sample size. Concordance analysis between these maps showed that the LiDAR system could be used intermittently if the distance between scans along the row was separated not more than 15 m, and the scanned length was 1 m when the LiDAR system is scanning. The resulting map could be used for many purposes such as to optimize the applied doses of pesticides and canopy management.

Keywords: LAI, LiDAR, precision viticulture, vegetation maps, zone maps.

INTRODUCTION

The use of ground-based LiDAR sensors in viticulture has been reported by several authors (Rosell et al., 2009; Keightley and Bawden, 2010; Llorens et al., 2011a). Initially, LiDAR technology has been used to estimate certain grapevine characteristics such as vegetation height and canopy volume. The main advantages are the improved sensor accuracy and resolution. This feature makes possible a high sampling density and therefore the possibility of characterizing in detail the geometry of vines. The leaf surface and, above all, the leaf density are of great interest in viticulture because they are related to yield and grape quality. However, of the various indexes related to the characteristics of grapevine foliage, the Leaf Area Index (LAI) is probably the most widely used. Recently, LiDAR sensors have been used for predicting the LAI in tree crops (Sanz et al., 2011). To do this, it is normally assumed the relationship between the canopy volume obtained by LiDAR (or other geometric characteristics) and the tree leaf surface.

Precision Viticulture (PV) is a concept that is beginning to have an impact on the wine-growing sector (Arnó et al., 2009). Grape yield maps and remote sensing tools are used with varying success, being the management of spatial variability of grape quality the remaining challenge. Furthermore, the application of plant protection products also raises controversy about the risk of contamination by drift and residues in grapes due to overdosing. The use of vegetation maps (maps of LAI) might be interesting to assist in defining zones of different leaf surface. Then these zones could be managed differentially by applying the proper dose, or by separating the harvest if there is a relationship between vigor and grape quality.

So far, there are few references in relation to obtaining vineyard LAI maps using LiDAR sensors. Llorens et al. (2011b) used the information obtained by a terrestrial laser scanner to generate canopy density maps according to LiDAR returns. However, the proposed method does not generate a raster map, making it difficult the subsequent zoning of leaf surface. Faced with this methodology, this paper proposes a protocol to generate direct LAI raster maps using data from a terrestrial LiDAR sensor. The resulting surface map should allow later classification of LAI by applying cluster analysis and obtaining a zone map to optimize crop management.

MATERIAL AND METHODS

Field trial

The field trial was conducted in Raimat (Lleida, Spain). The field (denoted P44) was planted in 2002 with *Vitis vinifera* L. *cv*. Syrah on a total area of 17.74 ha and orienting rows N-S. However, the use of LiDAR sensor was limited to only 6 rows of an equivalent area of 0.70 ha. This area seemed ideal for generating a vegetation map due to the presence of a considerable spatial variation in the vine vigour along the rows, probably due to changes in topography within the plot.

Other interesting aspects were the use of vertical shoot position (VSP) as training system, and the use of partial rootzone drying (PRD) as irrigation strategy. The test took place in July 2011 at the 79 growth stage according to the BBCH-scale (Meier, 2001). Figure 1 shows the plot and the location of the scanned rows.

Fig. 1. Analysed plot of *Vitis vinifera* L. *cv*. Syrah (left) and location of the scanned rows (right).

Laser scanner

The LiDAR sensor used in this study was the LMS-200 model (SICK AG, Waldkirch, Germany). As basic features, the sensor operation is based on the time-of-flight (TOF) principle to estimate distances to the crop. A two-dimensional fan-shaped scan was obtained (sweep angle of 180º) since the laser beam was pulsed with an angular resolution of 1º. Thus, vines were scanned from both sides of the row and multiple vertical scans along the row were obtained as the laser sensor was mounted on a moving tractor (Fig. 2b). Possible deviations in the sensor position were corrected by an inertial sensor. On the other hand, and simultaneously with the scanning, the position of the LiDAR was recorded by a GX 1230 GG model GPS+RTK system (Leica Geosystems AG, St. Gallen, Switzerland) for later georeferencing and mapping the acquired information.

Data provided by the LiDAR sensor were the polar coordinates of each interception point according to the reference system shown in Figure 2a. LiDAR and GPS data were properly synchronized and transferred to an on-board central computer via the RS-232 protocol. In parallel, correction parameters from inertial sensor were sent via a USB port. A MATLAB-based program was used for sensor control and data acquisition.

LAI estimation

The calculation process was somewhat complex because of the different frequency of LiDAR sensor and GPS receiver, and the need to adjust the LiDAR readings from both sides of the row.

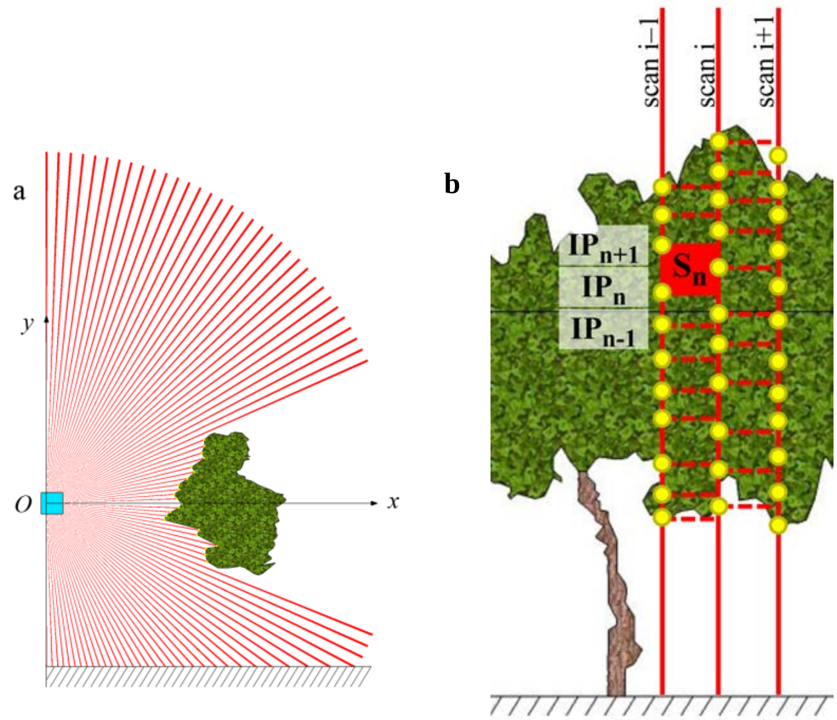


Fig. 2. a) Coordinate system of the sensor for a complete single scan (0º to 180º). b) Intercepted points (IP) generated by three consecutive scans, and surfaces assigned to each point (S_n).

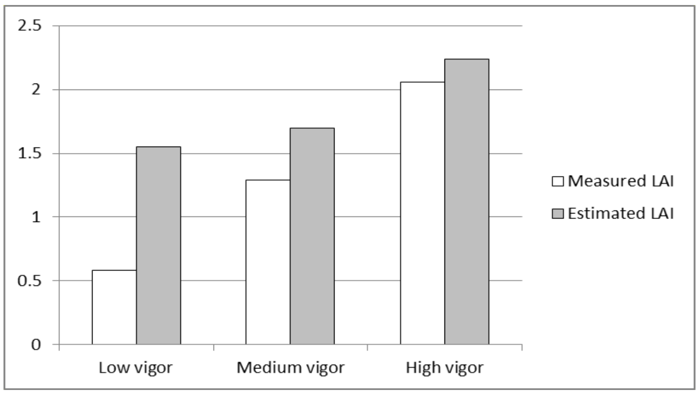
After applying the appropriate filters (MATLAB-based program), the UTM coordinates (X,Y) and Z coordinate of the intercepted points were calculated and then a projected surface was assigned to each point (Fig. 2b). The sum of surfaces was finally assigned to a representative point of the scan, i.e. with coordinates (X_m,Y_m) the average of points of interception. This procedure was repeated for each of the scans along the row and on both sides. The ultimate goal was to obtain the so-called envelope surface of grapevines. This surface consisted of the sum of lateral areas (leaf wall areas including gaps) and the area which encloses the top of the row. The Leaf Area Index was then calculated using the following expression,

$$LAI = \frac{(S_L + S_R + S_T)\cdot C}{d_r}$$

where S_L (m^2) and S_R (m^2) were the projected left and right surfaces respectively, S_T (m^2) the top surface, C the ratio leaf area/projected envelope area which is equal to 1.93 in vineyard ('unpublished report'), and d_r the row spacing (m). Since the surfaces were calculated for a row length of 1 m, the final result was the corresponding Leaf Area Index (m^2 m^{-2}). LAI values were then georeferenced on 1 m equidistant points placed on the line of grapevine trunks. The information generated (X,Y,LAI) allowed obtaining a LAI raster map by geostatistical interpolation.

LAI validation

Three vineyard blocks of different vigour (low, medium and high) were selected within the field covering each of them the distance between two consecutives trunks (2 m in length). After the LiDAR scanning, the three blocks were defoliated to measure the actual LAI and compare it with the estimated LAI from the sensor data. The result is shown in Graph 1.



Graph 1. Measured LAI and estimated LAI in three different vineyard blocks.

It is observed that LiDAR overestimates LAI in all cases. However, the differences decreased as grapevines had more leaf surface. Sensor configuration and tractor speed (~3.5 km h^{-1}) resulted in a vertical scan every 10-12 cm. According to Lee and Ehsani (2009), horizontal resolution about 10 cm negatively affects the accuracy in canopy volume estimation. This could explain the differences and the increase in the projected surface in vines with little vegetation. To compensate this overestimation, the initial values of LAI were corrected using the mean error of the three blocks analysed. After obtaining the corrected data (X,Y,LAI_C), the process conducted was the one shown in Figure 3.

RESULTS AND DISCUSSION

Figure 4 shows LAI maps (vector and raster) obtained using the initial data and the corrected data. Raster maps were obtained by VESPER software (Minasny et al. 2005), using a kriging in 5 m blocks and projecting interpolated data over a regular 2 m grid.

Both maps showed a very similar pattern of spatial variation, although the range of LAI values in the corrected map (0.7 to 2.1) was more reliable and adjusted to reality. Moreover, spatial variability of LAI was highly structured, allowing the delimitation of well-defined and compact areas within the field. Adopting the approach suggested by Fridgen et al. (2004), an unsupervised classification algorithm (fuzzy *c*-means) was applied to the interpolated data to classify the LAI and then generate LAI cluster maps (Fig. 5). Different maps were obtained based on the number of previously established classes. The process was performed by the software Management Zone Analyst (MZA) referred to in Fridgen et al. (2004).

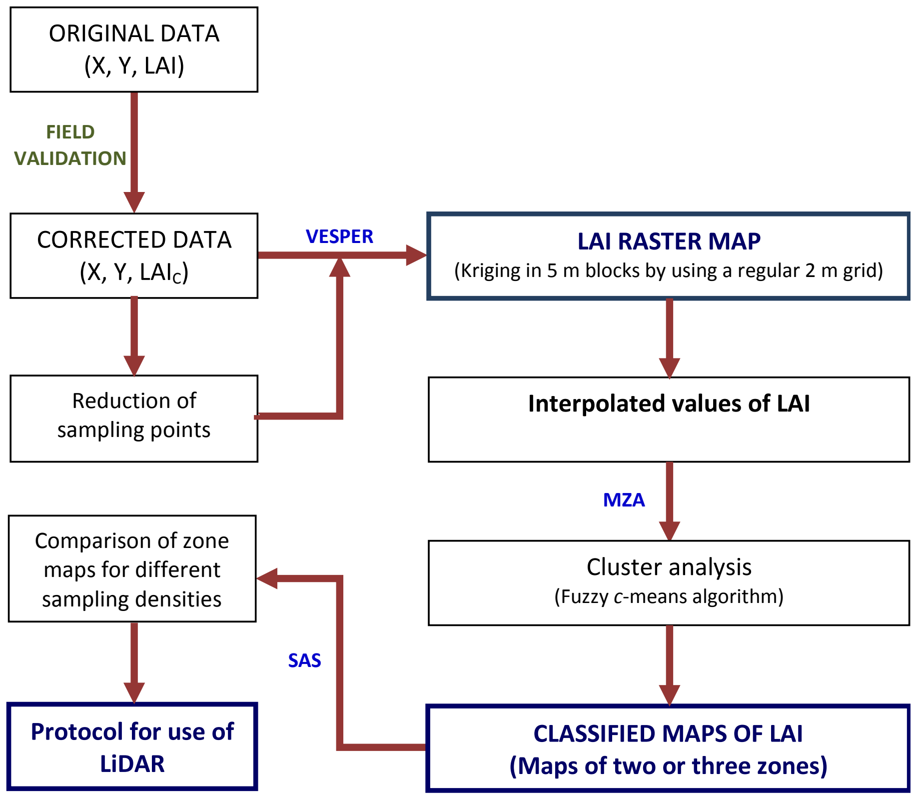


Fig. 3. LiDAR assessment method to obtain LAI maps in vineyard.

Maps of two and three classes showed the best properties. In fact, class maps directly provided maps of zones of different leaf area and, in this case, suitable for receiving a differential management. In short, the possibilities for LiDAR use in viticulture seem to be warranted. However, the main difficulty of laser sensors is the large amount of data they provide especially when scanning on-the-go all the rows of a plot. One possible strategy for a simplified use of LiDAR in field conditions is treated in the next section.

Optimization of sampling with LiDAR

The LiDAR in an on-the-go mode generated 2,145 sampling points (Fig. 5). Each of these points corresponds to a scanned length of 1 m. To reduce the acquired information, sampling points were progressively removed simulating the intermittent operation of the LiDAR. Table 1 shows that the resulting maps were in good agreement with the on-the-go map if the distance between scan points did not exceed 15 m.

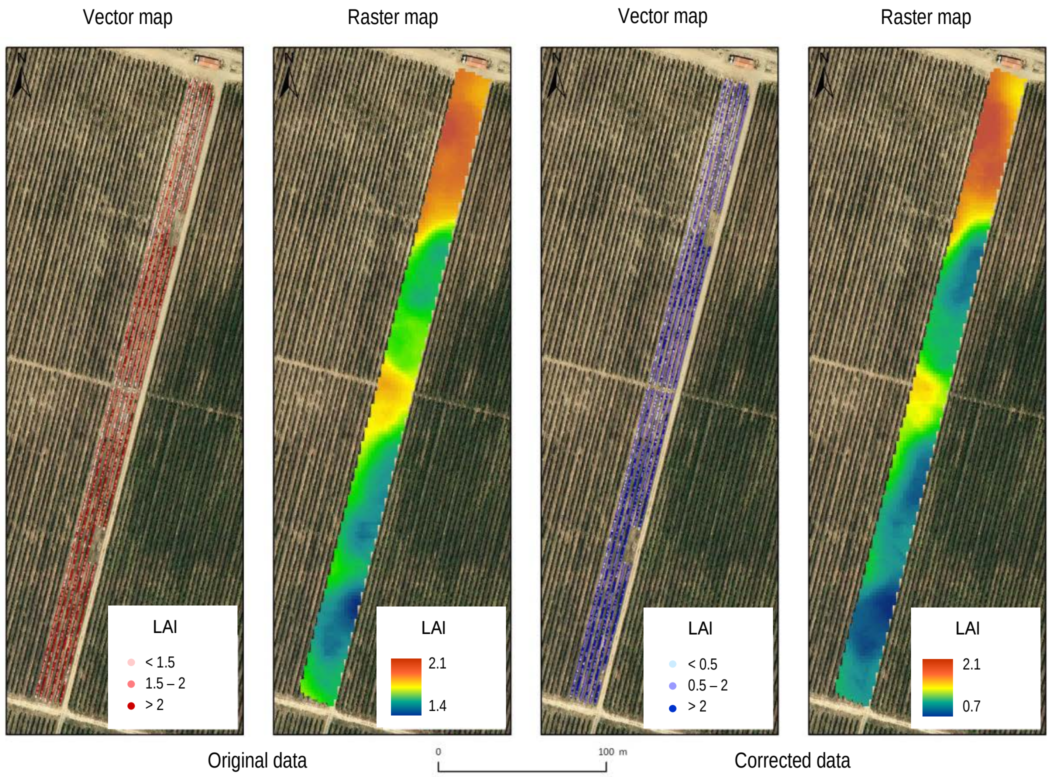


Fig. 4. Vector and raster maps of LAI using original data (left) and corrected data (right) from LiDAR sensor.

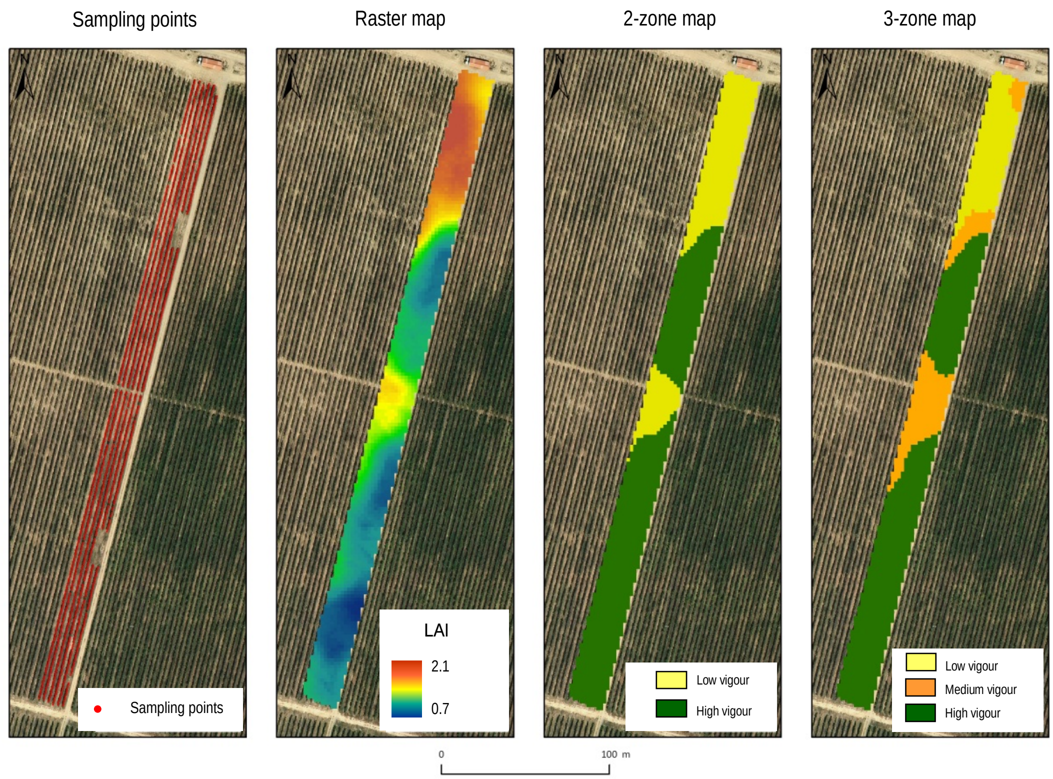


Fig. 5. Sampling points, LAI raster map, and maps of LAI zones.

Table 1. Concordance analysis between zone maps obtained with on-the-go and intermittent sampling using a LiDAR sensor

Distance between scan points (m)	Sampling points	Kappa coefficient. Maps of two zones	Kappa coefficient. Maps of three zones
1	1073	0.95	0.91
2	715	0.95	0.88
3	537	0.75	0.89
4	429	0.93	0.70
5	358	0.82	0.85
10	195	0.73	0.80
15	135	0.90	0.75
20	103	0.75	0.56
25	83	0.75	0.50
30	70	0.54	0.59

CONCLUSIONS

LiDAR technology can be used in viticulture to generate maps of Leaf Area Index. Faced to on-the-go use, LiDAR sensor can also be used intermittently resulting very similar maps if the maximum distance between scan points does not exceed 15 m. However, it is essential to increase the horizontal resolution of

LiDAR scanning to avoid overestimation of LAI. In short, further research is needed to optimize field sampling with LiDAR and simplify the data management process.

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