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Two vegetation indicators from 2D ground Lidar scanner compared for predicting spraying deposits on grapevine

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ABSTRACT

Terrestrial 2D Light Detection and Ranging (Lidar) has been shown to be a useful sensor for sensing vegetation in vineyards and orchards and has applications in managing crop protection. In this paper, two crop structure parameters are evaluated in vines with the objective to predict the proportion of sprayed phytosanitary products that is actually deposited in target vegetation. The Tree Area index (TAI) is based on the estimation of light beam interception's probability within the plant cover. Leaf Wall Area by Point (LWApts) is derived from Pixelated Leaf Wall Area, a high resolution measurement applying the Leaf Wall Area concept. Repeatability at measuring these indicators has been assessed by analyzing their Relative Standard Deviations (RSD) for twenty cases with 5 repetitions in each. Spraying deposits on vineyard plots have been measured in order to study the relationships between deposits and the two crop indicators TAI and LWApts. Field trials were performed on five plots and at four times. Deposits were measured for two sprayers: a pneumatic arch and an air assisted face to face sprayer. For each time, plot and sprayer, Lidar measurements were performed on a 15m long section of two adjacent rows. The crop structure indicators were calculated from data acquired at frequency of 50Hz by the Lidar moved at 5km/h forward speed. Spray deposition was measured using a tracer (Tartrazine E102) sprayed on PVC collectors disposed according to a grid within 4 vigorous trees selected on the sections measured by Lidar. Both indicators were found to be repeatable and useful to predict deposits. These promising results lead to the perspective of using Lidar systems to tune dose sprayed in the vineyards.

Keywords: Measurement, Ground-based Lidar, Crop structure, Tree Area Index (TAI), Spraying deposits.

1. INTRODUCTION

Impacts of plant protection products (PPP) on environment and human health have been highlighted for many years. New environmental policies and social demand prompt for the development of new strategies to reduce the amount of PPP used in agriculture in general and viticulture in particular. One such strategy is to adjust the spraying dose rate according to parameters of the crop to protect. Yet, manually acquired indicators of grapevine crop structure are tedious to measure and uncertain.

M. Bastianelli, V. de Rudnicki, S. Codis, X. Ribeyrolles, O. Naud "Two vegetation indicators from 2D ground Lidar scanner compared for predicting spraying deposits on grapevine". EFITA WCCA 2017 Conference, Montpellier Supagro, Montpellier, France, July 2-6, 2017.

Paper number: 125

So, in recent decades, several researchers have developed sensing systems to improve the characterization of crop structures in orchards (Berk & al. 2016). Lidar 2D sensors mounted on a tractor can be used to rapidly reconstruct a point cloud describing the vegetation's shape with a good precision and for a reasonable cost. From this point cloud, crop structure indicators can be calculated.

Among these indicators, the Tree Area Index (TAI) was introduced by Walklate and al. (2002) to predict deposits of axial fan sprayers in orchards. In the same paper, TAI was shown to account for most of deposit variations and thus to be a reliable indicator in orchards. An adaptation of the TAI calculation method for vineyards was suggested by Arnó and al. (2013) to estimate the Leaf Area Index (LAI) of 1 to 4m long row sections at 1km.h⁻¹ forward speed. Comparisons of the TAI with LAI were also carried out to evaluate the effects of the scan side of the vineyard rows in Arnó and al. (2015) and of the length along a row that is required to obtain one value in Arnó and al. (2017).

Del-Moral-Martínez and al. (2015) introduced the Pixelated Leaf Wall Area (PLWA) as the area obtained by projecting the vineyard rows detected by a Lidar on a vertical plane. The indicator discards vegetation gaps and considers only, in the cloud of points generated by the Lidar, the points which are situated on the half row width which is closest to sensor. The limit of this half row width inside vegetation is given by the so called line of trunks (LoT) at the center of the row. The research presented here aims to evaluate two crop structure indicators from 2D Lidar for their capability to predict deposits at a 5km.h⁻¹ forward speed. The first one is TAI (Arnó, 2013, 2015, 2017). The second one has been named Leaf Wall Area by Point (LWApts) and was derived by ourselves from PLWA. The LWApts is geometry based, as is the PLWA, but it considers the entire row width and was designed not to require high precision for sensor positioning. Thus, it does not require extra-equipment such as an Inertial Measurement Unit (IMU) and a RTK-GPS. LWApts was designed to be a high resolution variant of classic Leaf Wall Area (LWA). One motivation to investigate this type of indicator is that LWA is going to be used for homologation trials of new PPP for grapevine and other perennial crops in Europe. Specifically, trials were conducted to compare and assess the two indicators for predicting actual spraying deposits of sprayers at vineyards. Two sprayers were used: a pneumatic arch and an air assisted side by side sprayer. The pneumatic sprayer was used in a "spray every 4 rows" setting which means that only on side of the row receives the spray. Besides deposit prediction, repeatability of Lidar indicators was also studied.

The studied indicators were calculated to characterize the vegetation on areas of 15m long inter-rows sections. They were calculated from Lidar data synchronously measured on one side of the two rows of the considered areas.

2. MATERIALS AND METHODS

A LMS100 Lidar, a RTK-GPS (TERIA GSM correction)¹ and a processing unit (Effibox from Effidence society²) were mounted on a tractor. The tractor forward speed was set at 5km.h⁻¹. Lidar data was acquired at a frequency of 50Hz each 0.5° of angle from 0° to 270° in plane around it. It was placed orthogonally to the inter-row in order to obtain vertical cuts of both adjacent rows' shape. The processing unit stamped the acquired data with time information. Cuts

¹ <http://www.reseau-teria.com/>

² <http://www.efdidence.com/>

were aggregated to generate a 3D reconstruction of the rows assuming a straight trajectory and using the data' recorded times of perception and the average speed measured by the RTK-GPS. The positions given by RTK-GPS weren't used for point cloud reconstruction, in order to assess the feasibility of not using an accurate GPS in farming practice.

The 3D reconstruction of the rows from the points cloud was then calculated with reference to a (O, x, y, z) Cartesian coordinate system. The chosen origin of the coordinate system was the first position of the Lidar during the measurement on the studied rows. The chosen x-axis corresponded to the Lidar movement direction (along the rows). The z-axis was chosen for height and y-axis was chosen for row thickness. Lidar raw data are angle θ (between 0 to 270°) and distance ρ from sensor to interception point. The time stamp t in μs was given by the processing unit. For each point of the cloud, the x coordinate was calculated by multiplying the time t by the average speed and the y and z coordinates were obtained by a polar (ρ, θ) to Cartesian (y,z) coordinates transformation using `pol2cart` Matlab function.

The points measured just below the Lidar were used to estimate the z position of the ground. Points too close to the ground were filtered out thanks to a threshold on z of 30cm. The remaining points were considered as part of the grapevine vegetation.

2.2 Crop structure indicators

2.2.1 Calculating LWA_{pts}

For each Lidar scan of the 541 angles from 0° to 270° (0.5° of angle increment) and for each adjacent row (left and right of the tractor), vegetation points were projected on the height axis. LWA_{pts} was calculated from the total amount of intercepted point measured on each vegetation row at a distance shorter than the inter-row spacing. This setting differs from the PLWA method (Del-Moral-Martínez and al. 2015).

The distance d_x between two consecutive Lidar scans was calculated from the average speed U measured by the RTK-GPS and the Lidar frequency f as follows:

$$d_x = (1/f) * U$$

For each row's Lidar scan, the following distances d_i were calculated for each point i :

$$d_i = \min((z_i - z_{i-1}), \text{maxInterval})$$

where:

- z_i is the z-coordinate of point i
- z_{i-1} is the z-coordinate of the highest point of the row's scan under point i
- maxInterval is a threshold value used to take into account the main vegetation gaps.

The maxInterval value was defined as follows:

$$\text{maxInterval} = \sin(0,5^\circ) * D_{ir}$$

where D_{ir} is the inter-row spacing.

When point i was the lowest point of the row's scan, then d_i was assumed to be equal to d_{i+1} .

Subsequently a rectangle surface s_i was associated to each point i using the following equation:

$$s_i = \frac{(d_i + d_{i+1})}{2} \cdot d_x$$

When point i was the highest intercepted point of the row, then d_{i+1} was assumed to be equal to d_i .

The LWA_{pts} of an inter-row section is expressed in $m^2 \cdot ha^{-1}$. LWA_{pts} is obtained by summing the surfaces s_i of the points in the rows on each side of the sensor and by dividing this sum by the total ground area occupied by the rows on the length l considered for providing one LWA_{pts} measurement ($l \times 2 \cdot D_{ir}$).

The value chosen for l was 15 m.

2.2.1 TAI

TAI (dimensionless) is based on probability of light interception at different depths along the conical light beam of the LIDAR system. The method used to calculate the TAI in this paper is very similar to the method explained in details in Arnó et al. (2013).

The point cloud is studied in the cylindrical coordinates (ρ, θ, x) and projected in a polar grid. Figure 1 illustrates this polar grid. It is defined by its dimensions on the three axis of the cylindrical coordinates $\Delta\rho$, $\Delta\theta$ and Δx . Except for the scan length (Δx), the grid dimensions adopted are the same than in Arnó et al. (2013): the angle increment was $\Delta\theta = 3^\circ$ and the radial increment was $\Delta\rho = 10\text{cm}$. In Arnó et al. (2017) three different values of the scan lengths of the row (0.5m, 1m and 2m intervals on x-axis) were considered and compared for determining TAI. The 0.5m length of row seems too short to calculate a reliable TAI value. Arnó et al found that 1m and 2m were both acceptable but did not identify what is the optimal length. Considering these results from literature, a 3m scan length was chosen ($\Delta x=3\text{m}$). Thus, each TAI value was calculated with more than one hundred laser beam interceptions for each angle of the Lidar (from 0° to 270°), with a 5km/h forward speed.

The studied rows sections were divided in 3m long subsections. An individual TAI value was determined for each subsection.

The average of the N calculated values was then calculated to obtain a single TAI indicator on the studied row section:

$$TAI = \frac{1}{N} \sum_{i=1}^N TAI_{\Delta x_i}$$

where N is the number of subsections on studied portion of row and $TAI_{\Delta x_i}$ is the TAI value calculated for the i -th Δx long subsection ($\Delta x = 3\text{m}$).

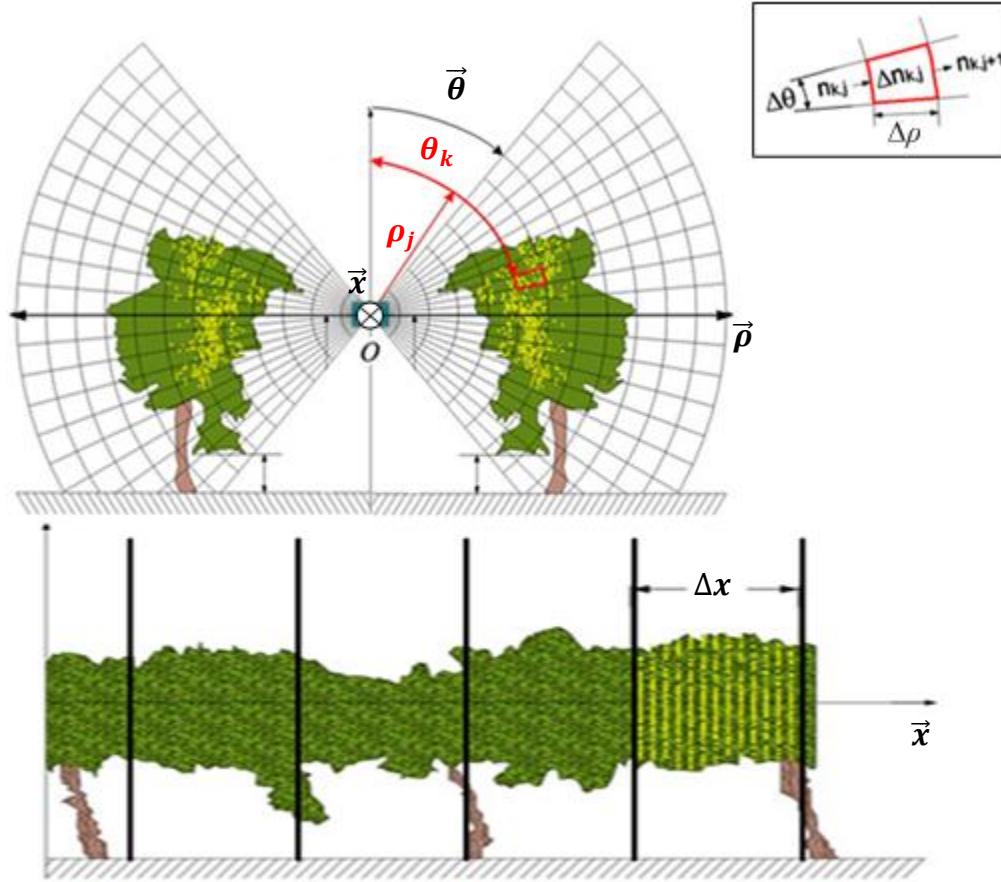


Figure 1: Method for TAI measurement (derived from Arnó et al. (2013))

A mesh element of the grid is defined by its radial distance, ρ_j , and its angle, θ_k , with $j \in \{0, 1, 2, \dots, J\}$ and $k \in \{0, 1, 2, \dots, K\}$. J is the number of $\Delta\rho$ long intervals between 0 and D_{ir} . K is the number of $\Delta\theta$ intervals between 0° and 270° .

For each Δx long section, $TAI_{\Delta x_i}$ was estimated from the laser beam interception rate of each mesh of the grid using the formula proposed by Walklate and al. (2002) and adapted for two rows:

$$TAI_{\Delta x} = -\frac{\Delta\theta}{2 \cdot D_{ir}} \sum_{k=0}^K \sum_{j=0}^J \rho_j \cdot \delta_{k,j} \cdot \ln\left(1 - \frac{\Delta n_{k,j}}{n_{k,j}}\right)$$

Where

- $\Delta n_{k,j}$ is the number of intercepted laser beam in the mesh element (ρ_j, θ_k) .
- $n_{k,j}$ is the number of laser beams which reach and or go through the mesh element.
- $\delta_{k,j}$ is a coefficient with a value of 1 if $(\Delta n_{k,j} / n_{k,j}) < 0.01$, 0 otherwise.

In order to process the case where all the laser beam reaching a mesh element are intercepted ($\Delta n_{k,j} / n_{k,j} = 1$), the maximum laser beam interception rate ($\Delta n_{k,j} / n_{k,j}$) was assumed to be 0.99.

M. Bastianelli, V. de Rudnicki, S. Codis, X. Ribeyrolles, O. Naud “Two vegetation indicators from 2D ground Lidar scanner compared for predicting spraying deposits on grapevine”. EFITA WCCA 2017 Conference, Montpellier Supagro, Montpellier, France, July 2-6, 2017.

Paper number: 125

In the present work, as the TAI was directly calculated on two rows (figure 1), the term D_{ir} was multiplied by two so as to consider total ground area.

2.3 Field trials

Experiments were performed on a vine estate from Languedoc, at four times distributed from April (2 to 3 leaves unfolded) to July (bunch closure). On this estate, 5 plots of different vine varieties were selected for their distinct vigor (parcels' names : Collection, LeMas, FranqCa, Verdot and FaysseH). The two sprayers used are illustrated by figure 2.

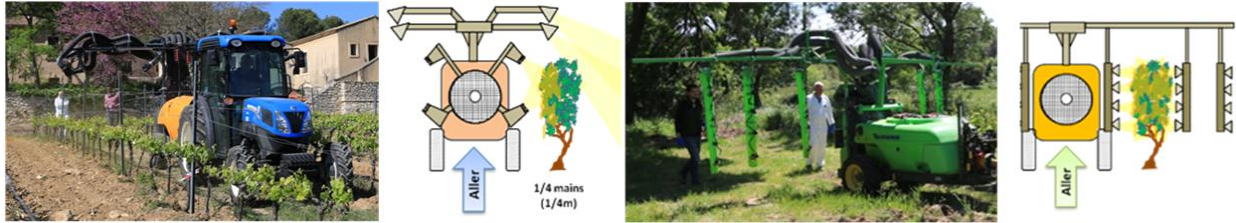


Figure 2: Pneumatic arch (left) and air assisted side by side sprayer (right) used for field trials.

For each plot, date and sprayer, acquisition of Lidar data was done on a 15m long section of inter-rows. Five acquisition repetitions were done at each date and plot (on sections corresponding to one of the tested sprayers). Due to the working force and time necessary to process, Lidar and deposit measurements couldn't be carried out the same day. Lidar measurements occurred on the 27th of April, the 20th of May, the 17th of June and the 21st of July, 2016. Spraying deposits measurements were made the 28th of April, the 25th of May, the 23rd of June and the 18st of July, 2016.

For each 15m long inter-row section, four vigorous trees were selected on one row. On each tree, 10cm² PVC collectors were positioned on leaves within the canopy according to a profile perpendicular to the row and a grid with elements 20cm high and 10cm wide. A collector was installed in each grid element. A Tartrazine E102 water solution was then sprayed. The mass of Tartrazine deposits on collectors was measured by rinsing collectors with a known water volume and measuring concentration with a spectrometer. Deposit masses were normalized by the Tartrazine quantity sprayed by hectare (unit: ng.dm⁻² for 1 g.ha⁻¹). A total amount of 3077 collectors were analyzed individually. .

The sections selected for each plot had to change with each date in order to ensure that the Tartrazine measurement on the collectors wasn't contaminated by previous trials.

3. RESULTS AND DISCUSSION

3.1 Repeatability

The repeatability of the Lidar based indicators was assessed by calculating the standard deviation (SD) and the relative standard deviation (RSD) of the five measurement repetitions for each of the 20 (date, plot) couple.

SD varied between 4.77 m²/ha and 66.69 m²/ha, with an average of 21.35 m²/ha, for the repetitions of LWApTs measurements, and between 9.25e-04 and 8.59e-02, with an average of 2.72e-02, for the repetitions of TAI measurements.

RSD varied between 0.1% and 2.5%, with an average of 0.6%, for the repetitions of LWApTs measurements, and between 0.6% and 7.8%, with an average of 2.7%, for the repetitions of TAI measurements. The LWApTs appears to be more repeatable than the TAI.

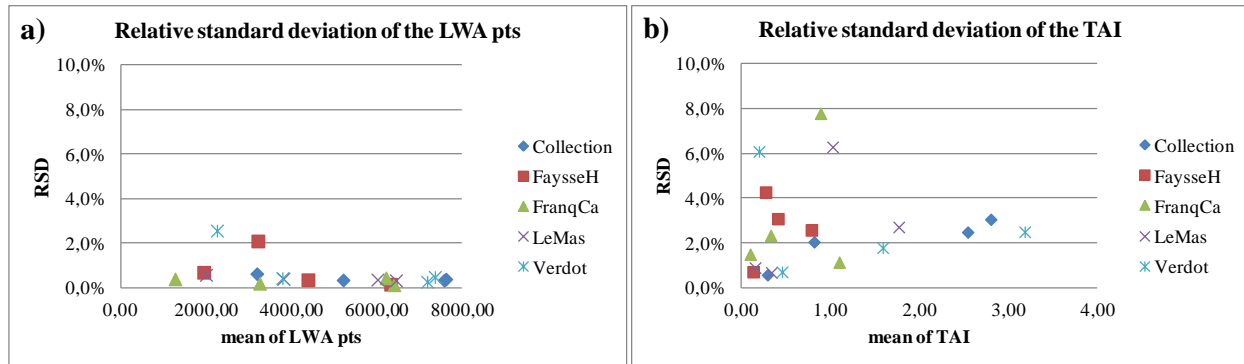


Figure 3: Relative standard deviations and Standard deviation of the Lidar indicators.
a) RSD of LWApTs ; b) RSD of TAI

Figure 3 shows the calculated RSD values for LWApTs (a) and for TAI (b) depending on the average indicators of the measurement repetitions. Except for two particularly high values, LWApTs deviation was quite low (RSD < 1%) and regular (low sensitivity to the average values). Overall, highest RSD values of the TAI occurred for low average values (figure 2.b). Both indicators SD tended to increase with the average values and for TAI in particular. TAI values are low and close to 0 and consequently RSD values could be more sensitive to average values' variations.

3.2 Comparison of crop structure indicators with spraying deposits

In figure 4, Pneumatic arch sprayer's deposits on y axis are given respectively with regards to LWApTs (a) and TAI (b). Face to face sprayer's deposits are also given with regards to LWApTs (c) and TAI (d). The prediction for pneumatic sprayer is very good for both indicators (a and b), which is consistent with Walklate and al (2002) findings. Indeed, the pneumatic sprayer technology has some similarities with airblast spraying technology which is common in fruit orchards.

TAI calculation lays out the analogy of the interception by the vegetation of the laser beam emitted by the Lidar being the same as interception of the solution emitted by sprayer. As the face to face sprayer emits the solution from several nozzles that are directed perpendicularly to the surface of the row, the analogy between spray and light interception is less consistent as far as spray geometry is concerned. A prediction of lower quality was then expected. However figure 4.d) brings out a good correlation. The highest point of this figure results from a case setting in which only one nozzle was open, which resulted in a lower sprayed Tartrazine volume and then a higher normalized deposit. This observation highlights the importance of sprayer setting when analyzing results.

However, despite higher prediction difficulty for face to face sprayer and TAI values lower than 0.5, the worst case for this sprayer is better than for pneumatic sprayer cases. In practice, this may allow farmers to consider that higher efficiency means that lesser dose rates can be applied.

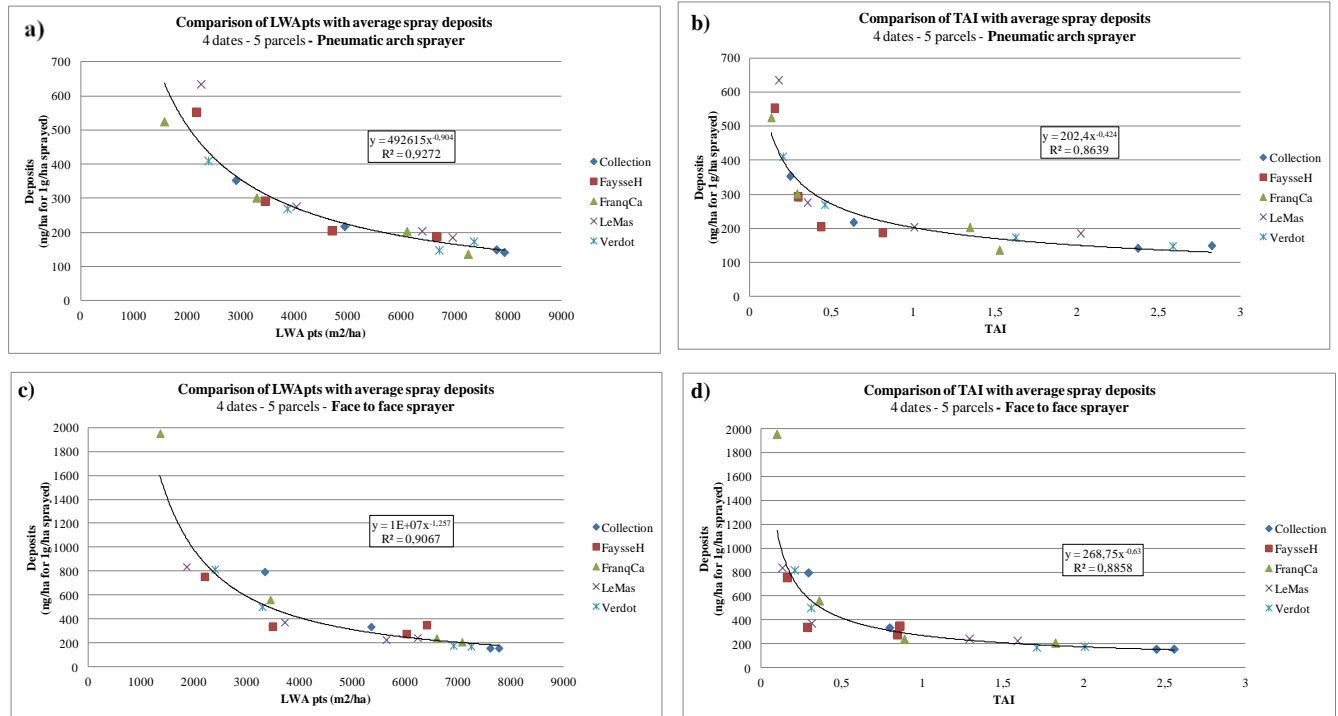


Figure 4: Evolution of the average spraying deposits with crop structures' indicators measured with a LIDAR-LMS100

Comparison of Pneumatic arch sprayer's deposits with LWAp_{ts} (a) and TAI (b);
Comparison of face to face sprayer's deposits with LWAp_{ts} (c) and TAI (d);

The form of the curves obtained with regard to the TAI is very similar to the mean leaf deposit curves related to the leaf area index (LAI) presented in Siegfried and al. (2007). This similarity consolidates the good correlation between LAI and TAI mentioned in Arnó, J (2015, 2013) even if the TAI calculation used in this paper differs slightly.

Observed trends appear steadier for LWAp_{ts} but highest values of LWAp_{ts} are grouped.

Figure 5 shows the comparison of LWAp_{ts} with TAI. For lower values (TAI from 0,09 to 0,5), LWAp_{ts} appears to grow faster but proportionally to the TAI. Then LWAp_{ts} appears to saturate whereas TAI still grows. TAI is considered a reliable indicator of the grapevine leaf development (Arnó, J, 2015, 2013), but LWAp_{ts} seems not to be as well correlated to leaf surface for the full growth stage. Yet this LWAp_{ts} saturation observed in our trials occurred after the first pruning operation (generally from end of May or middle of June). Although of high resolution, LWAp_{ts} is mainly related to vegetation height. It takes into account the main gaps of the vegetation but does not represent width variation of the crop structure as does TAI. Our hypothesis is that pruning would stop the height development of the crop structure and by consequence evolution of LWAp_{ts}. TAI may better take into account foliage growth that occurs within the trimmed volume.

M. Bastianelli, V. de Rudnicki, S. Codis, X. Ribeyrolles, O. Naud "Two vegetation indicators from 2D ground Lidar scanner compared for predicting spraying deposits on grapevine". EFITA WCCA 2017 Conference, Montpellier Supagro, Montpellier, France, July 2-6, 2017.

Paper number: 125

These observations may explain the differences between the average deposits curves obtained with regards to LWAp_{ts} (figure 4.a and c) and with regards to TAI (figure 4.b and d).

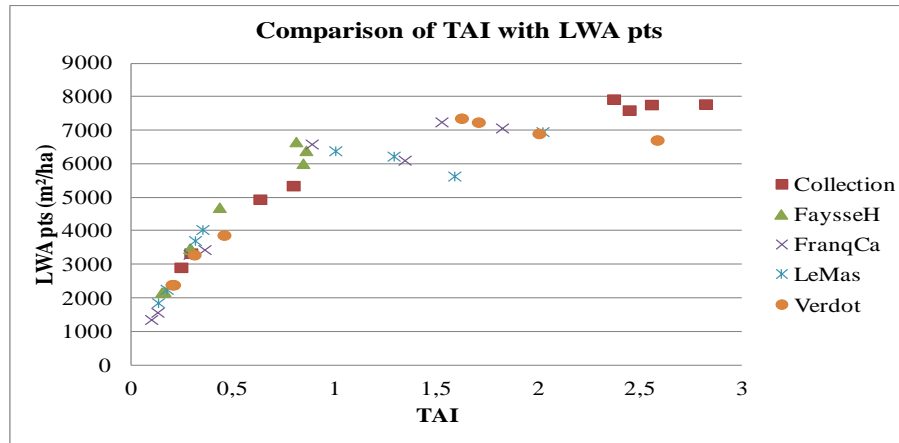


Figure 5: Evolution's comparison of LWA pts and TAI

For both sprayers, average deposits (figure 4) tend to reach a kind of saturation for high indicator values (TAI > 0,5 and LWA pts > 6000 m²/ha). These values correspond to full growth stage in June and July measurements. This phenomenon may be related to the experimental protocol and the scale differences between TAI and deposit measurements. In order to make “safe” prediction of deposits, 4 vigorous trees were chosen within one side of the section covered by the Lidar. It is likely that the chosen vigorous trees had reached a final growth stage whereas other trees within the section covered by Lidar were still evolving. The scale used for Lidar measurement and the scale used for deposits were, as a consequence of the protocol, different. This protocol issue may have little practical incidence, as main product savings are expected before full growth is reached

Finally, from these results, the main potential reduction of applied PPP may be achieved for growth stage where TAI and LWAp_{ts} are lower than 0.5 respectively 6000 m²/ha.

3.3 Discussion

Various indicators proposed in previous works (Walklate and al. 2002, Rosell-Polo and al. 2009, Palleja and al. 2010 and Sanz and al. 2013) or tested by the authors estimate the vegetation volume. Vegetation volume indicators represent a great interest compared with vegetation surfaces or TAI as they contain vegetation width information and they are easy for growers to grasp. However the estimation of the vegetation width is complex and lead to uncertainties compared to the TAI or the vegetation surface indicators. Reaching accuracy and reliability for vegetation volume indicators requires high precision in the knowledge of the Lidar position relatively to the rows during trials. TAI and LWAp_{ts} are much less sensitive to this positioning precision.

Previous works suggest coupling Lidar with additional sensors (such another Lidar for more perspectives (Bietresato, 2016) or IMU (del-Moral-Martínez, 2015)...), and coupling the Lidar

M. Bastianelli, V. de Rudnicki, S. Codis, X. Ribeyrolles, O. Naud “Two vegetation indicators from 2D ground Lidar scanner compared for predicting spraying deposits on grapevine”. EFITA WCCA 2017 Conference, Montpellier Supagro, Montpellier, France, July 2-6, 2017.

data obtained for the two sides of the same row (Arnó, 2015). These methods may result in significant improvements of information on the crop at fine spatial scales (1-3m). Nevertheless, they also imply additional costs for the system and more complicate measurements. This may hinder effective transfer to winegrowers of the Lidar technique.

In the present study, our method and designs aimed at transfer of Lidar techniques to winegrowers in a context in which current spraying technologies used at the farms don't allow real time spraying dose rate adjustment. In this sense, a spatial resolution of a 15m long section comprising two rows may be sufficient to exhibit differences between plots and zones within a plot, yet using only Lidar equipment.

4. CONCLUSION

Overall, the study showed promising results for predicting spray deposits in the vine with regards to a geometry based indicator (LWA_{pts}) and an interception probability based indicator (TAI) from a 2D Terrestrial Lidar moved one out of two inter-rows and on 15m long rows sections.

Results shows average deposits two to three times greater for early and medium growth stage than for full growth stage. There may be a potential reduction of applied PPP dose rate for these growth stages.

For five measurements repetitions, the Relative Standard Deviation was in average lower than 1% for the LWA_{pts} and than 3% for the TAI. Both indicators were found to be repeatable. Using these indicators, and by measuring actual deposits within different plots, the study has shown the possibility to predict deposits, using either one of TAI or LWA_{pts} indicators, for two different types of sprayers.

Deposits from face to face sprayers seem to be more difficult to predict using these Lidar indicators than deposits from pneumatic arch sprayers. In particular for the face to face sprayer, the machine set-up has an important impact on deposits. It was observed that TAI allows a better differentiation between plots than LWA_{pts} does.

Overall, the trials and data analysis presented in this study indicate that Lidar sensing technology could be transferred to growers for effective use in applying doses that would depend on growth stage and foliage quantity.

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