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LIDAR and non-LIDAR-based canopy parameters to estimate the leaf area in fruit trees and vineyard

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ABSTRACT

This paper is based on two initial hypotheses, firstly, it is proposed that the vegetation volume obtained with a LIDAR-based system or tree row LIDAR volume (TRLV) has a high correlation with the leaf area (LA). Secondly, it is proposed that the projected outer surface or projected tree row surface (PTRS), also LIDAR-based, is linearly related with the LA. The verification of these two hypotheses corresponds to the first two objectives of this work. The third objective is to propose an alternative method, without using LIDAR sensors, simpler and more economical, for *in situ* LA evaluation.

To achieve these objectives a total of 17 blocks of pear, 14 of apple and 26 of vine, in different phenological states, were LIDAR scanned and subsequently manually defoliated. After the field and calculation work, the TRLV and LA were compared. The logarithmic regressions obtained had high correlations. For apple and pear trees the equations are practically the same with R^2 of 0.85 and 0.84, respectively. The equation corresponding to vines is somewhat different and has an R^2 of 0.86. The regression without species differentiation is 3.66ln(x) +9.65 with R^2 = 0.90.

Based on the TRLV, the front and top projected surface areas of each block were then obtained and, using these variables, the PTRS. The linear regressions obtained between PTRS and LA have high correlations with R^2 of 0.88, 0.85 and 0.80 for apple trees, pear trees, and vineyard respectively. The three crops show very similar behavior. The straight lines are very close, with very similar slopes. With no species differentiation the linear regression model is y = 1.47x – 1.18 with R^2 = 0.93.

The starting point of the third objective is to obtain the projected surfaces, frontal and top, without using a LIDAR sensor. These surfaces are not as precise as those obtained with LIDAR and for this reason they are referred to as "estimated" projected surfaces. To calculate the estimated PTRS without a LIDAR sensor, the height and depth of the vegetation are measured with a tape measure. It is also necessary to make a visual estimation of the frontal gap-fraction. For this, a training method with known gap-fraction pictograms is proposed. The final results with this non-LIDAR method are very similar to those obtained with LIDAR. This method, although it needs human intervention, is simple, easy, economical and precise for *in situ* LA estimation.

1. Introduction

Determination of leaf area (LA) in fruit and vine cultivation is an important but difficult task. Important, because leaves are intrinsically related to evapotranspiration, radiation interception and CO_2 fixation (Hernandez-Santana et al., 2017), and difficult, because of the huge number of leaves and the complexity of the three-dimensional structure of the canopies of fruit trees and vines. It is also difficult to establish the necessary accuracy because it depends on other variables. Quick determinations with errors under 10% are a good starting point. Numerous research studies have required LA determination or estimation in fields such as irrigation (Du et al., 2017; Pereira et al., 2007), fertilization (Fernández et al., 2008), pruning (Ballesteros et al., 2015; Palmer et al., 1992), tree training (Kliewer and Dokoozlian, 2005), or the application of phytosanitary products (Arnó et al., 2015; Pascuzzi et al., 2017; Planas et al., 2013; Siegfried et al., 2007). All of these practices are related to canopy management, a key factor for plantation yield optimization (Cohen et al., 2005).

A review is conducted in Jonckheere et al., (2004) of different methods, both direct and indirect, for determination or estimation of

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Table 1
Tests conducted. Principal data.

Crop (Village) / Block	Test date (d/m/y)	BBCH scale	Length (m)	Height (m)	Depth (m)	Row Spacing (m)	Frontal Gaps (%)
Pear *Conference* (Gimenells) / BI	20/05/2004	71-75	1.50	3.00	1.05	4.00	20
Pear *Conference* (Gimenells) / BII	16/07/2004	76-89	1.50	3.00	1.30	4.00	10
Pear *Conference* 1-axis (Mollerussa) / BI	20/05/2008	71-75	2.93	3.10	1.70	4.00	25
Pear *Conference* 1-axis (Mollerussa) / BII	14/07/2008	76-89	3.12	3.30	1.55	4.00	25
Pear *Conference* 2-axis (Mollerussa) / BI	20/05/2008	71-75	2.00	3.80	1.15	4.00	10
Pear *Conference* 2-axis (Mollerussa) / BII	14/07/2008	76-89	1.85	3.70	0.95	4.00	10
Pear *Blanquilla* (Gimenells) / BI	20/05/2004	71-75	2.00	3.15	1.90	4.00	20
Pear *Blanquilla* (Gimenells) / BII	16/07/2004	76-89	2.00	3.10	1.70	4.00	15
Pear *Blanquilla* (Gimenells) / BIII	16/06/2008	76-89	1.90	2.90	1.40	4.00	10
Pear *Blanquilla* (Alfarrás) / BI	18/04/2005	71-75	2.00	2.50	0.85	4.50	50
Pear *Blanquilla* (Alfarrás) / BII	18/04/2005	71-75	2.00	2.50	0.90	4.50	40
Pear *Blanquilla* (Alfarrás) / BIII	03/05/2005	71-75	2.00	2.55	0.95	4.50	50
Pear *Blanquilla* (Alfarrás) / BIV	03/05/2005	71-75	2.00	2.50	1.00	4.50	40
Pear *Blanquilla* (Alfarrás) / BV	02/06/2005	71-75	2.00	2.60	1.10	4.50	20
Pear *Blanquilla* (Alfarrás) / BVI	02/06/2005	71-75	2.00	2.60	1.28	4.50	20
Pear *Blanquilla* (Alfarrás) / BVII	25/07/2005	76-89	2.00	2.60	1.10	4.50	30
Pear *Blanquilla* (Alfarrás) / BVIII	25/07/2005	76-89	2.00	2.60	1.13	4.50	20
Apple *Red Chief* (Gimenells) / BI	26/05/2004	71-75	1.60	3.40	2.60	4.00	0
Apple *Red Chief* (Gimenells) / BII	14/07/2004	76-89	1.50	3.40	2.60	4.00	0
Apple *Golden* (Gimenells) / BI	26/05/2004	71-75	1.52	3.40	1.60	4.00	20
Apple *Golden* (Gimenells) / BII	14/07/2004	76-89	1.49	2.40	1.50	4.00	5
Apple Gala Brookfield 1-axis (Mollerussa) / BI	20/05/2008	71-75	2.70	2.90	1.40	4.00	50
Apple Gala Brookfield 1-axis (Mollerussa) / BII	14/07/2008	76-89	2.30	3.40	1.25	4.00	50
Apple *Fuji* 1-axis (Mollerussa) / BI	20/05/2008	71-75	2.80	3.20	1.70	4.00	40
Apple *Fuji* 1-axis (Mollerussa) / BII	14/07/2008	76-89	2.65	3.35	1.60	4.00	50
Apple *Fuji* wall (Mollerussa) / BI	20/05/2008	71-75	2.75	3.07	0.95	4.30	40
Apple *Fuji* wall (Mollerussa) / BII	14/07/2008	76-89	2.62	3.10	0.85	4.30	40
Apple *Gala Brookfield* wall (Mollerussa) / BI	20/05/2008	71-75	3.03	3.40	0.65	4.50	60
Apple *Gala Brookfield* wall (Mollerussa) / BII	14/07/2008	76-89	2.78	3.00	0.55	4.50	60
Apple *Gala* 1-axis (Mollerussa) / BI	20/05/2008	71-75	3.04	3.45	1.65	4.00	15
Apple *Gala* 1-axis (Mollerussa) / BII	14/07/2008	76-89	3.15	4.00	1.68	4.00	20
Vineyard *Cabernet* (Caldes de Montbui) / BI	03/06/2004	71-89	2.00	1.08	0.42	3.00	50
Vineyard *Cabernet* (Caldes de Montbui) / BII	03/06/2004	71-89	2.00	1.36	0.35	3.00	60
Vineyard *Cabernet* (Caldes de Montbui) / BIII	26/07/2004	71-89	2.00	1.50	1.02	3.00	15
Vineyard *Merlot* (Caldes de Montbui) / BI	03/06/2004	71-89	2.00	1.06	0.31	3.00	50
Vineyard *Merlot* (Caldes de Montbui) / BII	03/06/2004	71-89	1.90	0.84	0.44	3.00	25
Vineyard *Merlot* (Caldes de Montbui) / BIII	30/06/2004	71-89	2.00	1.44	0.50	3.00	40
Vineyard *Merlot* (Caldes de Montbui) / BIV	26/07/2004	71-89	2.00	1.38	0.60	3.00	35
Vineyard *Merlot* (Raimat) / BI	10/05/2005	55-69	2.00	1.22	0.36	3.00	60
Vineyard *Merlot* (Raimat) / BII	10/05/2005	55-69	2.00	1.20	0.34	3.00	50
Vineyard *Merlot* (Raimat) / BIII	06/06/2005	71-89	2.00	1.24	0.58	3.00	25
Vineyard *Merlot* (Raimat) / BIV	06/06/2005	71-89	2.00	1.70	0.61	3.00	35
Vineyard *Merlot* (Raimat) / BV	07/07/2005	71-89	2.00	1.62	0.80	3.00	25
Vineyard *Merlot* (Raimat) / BVI	07/07/2005	71-89	2.00	1.62	0.98	3.00	30
Vineyard *Merlot* (Raimat) / BVII	24/08/2005	71-89	2.00	1.42	0.80	3.00	30
Vineyard *Merlot* (Raimat) / BVIII	24/08/2005	71-89	2.00	1.64	0.71	3.00	40
Vineyard *Syrah* (Raimat) / BI	24/07/2008	71-89	1.90	1.35	0.58	3.00	15
Vineyard *Syrah* (Raimat) / BII	24/07/2008	71-89	1.96	1.46	0.67	3.00	25
Vineyard *Syrah* (Raimat) / BIII	24/07/2008	71-89	2.12	1.46	0.60	3.00	30
Vineyard *Syrah* (Raimat) / BIV	24/07/2008	71-89	1.86	1.32	0.50	3.00	40
Vineyard *Syrah* (Raimat) / BV	24/07/2008	71-89	2.06	1.46	0.68	3.00	15
Vineyard *Cabernet* (Espiells) / BI	09/06/2008	71-89	1.82	1.38	0.62	3.00	40
Vineyard *Cabernet* (Espiells) / BII	02/07/2008	71-89	2.02	1.32	0.81	3.00	25
Vineyard *Cabernet* (Espiells) / BIII	21/07/2008	71-89	2.02	1.53	0.59	3.00	45
Vineyard *Tempranillo* (Espiells) / BI	09/06/2008	71-89	1.38	1.02	0.44	3.00	45
Vineyard *Tempranillo* (Espiells) / BII	02/07/2008	71-89	2.71	1.53	0.59	3.00	25
Vineyard *Tempranillo* (Espiells) / BIII	21/07/2008	71-89	2.54	1.60	0.61	3.00	35

LA. The direct methods are characterized by directly measuring the leaf surface area and the indirect methods by using other parameters which are related to LA but easier to obtain. The former methods are more precise, but entail a high cost in terms of labor and time, often making them unfeasible for commercial purposes. Nonetheless, they are indispensable for the validation and/or calibration of the indirect methods (Doring et al., 2014; Poblete-Echeverría et al., 2015). These latter methods are characterized by their rapidity and the fact that they can often be automated (Fuentes et al., 2014; Mora et al., 2016), making them suitable for the measurement of larger-sized areas. Many of these methods are based on differentiating between green and non-green areas (Diago et al., 2012), The latter are basically the woody material, fruit, flowers and gaps through which light passes. Many of the methods are based on quantification of the light that passes through the gap fraction in order to estimate the green fraction (De Bei et al., 2016; Liu et al., 2013aa). It is also important to bear in mind that, normally, distribution of the green and gap fraction is projected and analyzed in the horizontal plane of the ground, as for example, in a forest environment (Chianucci et al., 2014) or in extensive agricultural crops (Fang et al., 2014; Liu et al., 2013b). In contrast, there are other environments, no less important, like intensive fruit growing, where it is more interesting to project and analyze the green and gap fraction in a