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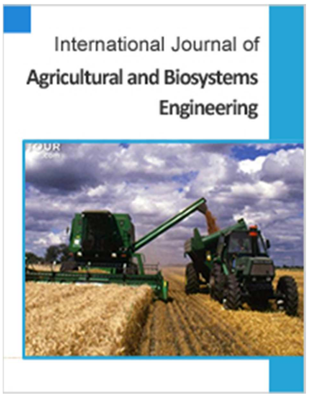

Non-destructive Estimation of Leaf Area Index in Sweet Cherry Trained as Tatura-Trellis

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Abstract
Knowledge of the Leaf Area Index (LAI) of sweet cherry orchards is crucial for diagnosis about their production potential. The objective of this research was to develop simple, precise and non-destructive methods for estimating LA/tree (and based on that the LAI, dividing LA/tree by the area allocated to each tree) in orchards trained as tatura-trellis. Therefore, four models were evaluated: two simple linear regression models using as explanatory variables the Trunk Cross-Sectional Area (TCSA; dm^2) (30 cm above the floor) or the Wood Volume of the Central Leader (WVCL; dm^3) (considering the trunk as a cone: WVCL = $\pi \cdot r^2 \cdot h/3$) and two multiple regression models combining Mean Leaf Area (MLA; dm^2) with the two previously mentioned variables. In all cases, LA/tree was the dependent variable. The TCSA and WVCL of 27 'Sweetheart'/'SL64' trees conducted as tatura-trellis were registered, covering a wide range of tree sizes. At full canopy, all leaves of each tree were counted and 2% of them were randomly taken as a sample, from which the MLA was estimated. Leaf Area (LA) per tree was calculated multiplying the number of leaves by MLA. The best models to explain LA/tree variability were multiple linear regression equations combining WVCL and MLA (LA/tree = -9.18 + 37.31 · MLA + 0.83 · WVCL), or TCSA and MLA (LA/tree = -11.23 + 37.2 · MLA + 15.91 · TCSA), with R^2 of 0.83 and 0.84, respectively. The R^2 of simple linear regression models utilizing WVCL or TCSA were also high (0.69 and 0.70, respectively). However, the non-inclusion of MLA in these models, would limit their applicability in cultivars with different leaf morphology. The multiple regression equation including WVCL and MLA as explanatory variables seems to be the most robust model to be applied in other situations, because it considers two dimensions of the trunk and the leaf morphology.

1. Introduction

In South Patagonia (Argentina), most of the sweet cherry orchards installed in the last decade are intensive, trained as tatura (one tree alternatively tilted to each side of the row), drip irrigated and frost-protected with sprinkling irrigation systems. However, so far, yields and fruit quality have not been as good as expected. The reason of this depends of various factors, but probably the main causes are the low value of Leaf Area Index (LAI) and the inadequate fruit number to leaf area ratio (FNLAR) in most commercial orchards [1].

For a specific variety, the FNLAR of the current year is the most important factor affecting inter-annual variation in fruit weight [2, 3]. Leaf area (LA) per fruit itself is not important, but represents the production potential through its photosynthetic capacity, and a high value is essential for production of high-quality sweet cherries [4]. Results reported by Roper and Loescher [4], Whiting and Lang [5], Cittadini *et al.* [1, 6, 7], Cittadini [8] and Szlápelis and Cittadini [9] showed a negative relationship between fruit quality and FNLAR.

Besides the importance of FNLAR, the LAI of commercial orchards is crucial, because determines light interception and this is the main driver for dry matter production. Raffo and Iglesias [10] determined that trees with higher LAI intercepted more light and had more green leaves weight and trunk cross-sectional area (TCSA). According to Gil Salaya [11], a good level of light interception in fruit-tree crops ranges between 70 and 75% of the incident PAR (Photosynthetic Active Radiation) at full canopy. This situation allows a good level of sugars' production for obtaining high yields [12] with no compromise of the viability of spurs and reproductive buds. With low light levels, both the formation of floral buds and the growth of the fruit can be affected [13] and early death of buds and spurs may occur. On poorly illuminated branches, fruits ripen more slowly, are softer, their color is lighter and their soluble solids content (SSC) is lower than those on well illuminated branches [14]. Thus, LAI is a critical parameter in plant physiology for models related to growth, photosynthetic activity and evapotranspiration. It is also important for farm management purposes [15].

The availability of a simple and non-destructive method for LAI estimation can support decision making for optimal management of the canopy in commercial orchards. However, measuring LAI or LA per tree in commercial orchards is not a common practice, because is tedious and time-consuming [16]. Several indirect methods have been proposed for non-destructive estimation of leaf area in tree species, with the objective of reducing sampling effort. Some of them are based on light interception, like the use of digital luximeters [17], ceptometers, hemispheric photographs [18, 19, 20] or light detection and ranging (LiDAR) sensors [21]. These methods, however, require sophisticated and expensive instruments, and need calibration for each orchard type. Villalobos *et al.* [22] reported up to 30% underestimation of plant area index (PAI) of olives using a commercial sensor for LAI determination (Plant Canopy Analyzer LI-COR LAI-2000). There are other methods for LAI estimation based on biometric variables, such as the trunk or branch diameter as used in apple [23, 24, 25, 26].

The utilization of the TCSA as explanatory variable for the different quality parameters and for yield estimation has been utilized in 'Bing' sweet cherries [27] and could also be useful for estimating leaf area. In forest species, measurement of TCSA has been reported as one of the best estimators of leaf area [28]. However, these estimations based only in that variable are very specific to the tree-type (and shape) from which the data for model development are taken.

In sweet cherry orchards the knowledge of LAI or LA/tree (and based on that FNLAR) could be used as a tool for diagnosis of situations with excessive or insufficient canopy, allowing performing corrective practices (e.g. fruit thinning, winter or summer pruning, bending, etc.).

Mora *et al.* [15] used a modified cover photography method based on specific image segmentation algorithms to exclude contributions from non-leaf materials. Poblete-Echeverría [16] tested a similar method to estimate LAI in apple trees using conventional digital photography and instantaneous measurements of incident radiation and transmitted radiation through the canopy. Hochmaier *et al.* [29] developed several non-destructive methods for estimation of leaf area index in vase-shape sweet cherry trees. They concluded that the model that combined pragmatism, objectiveness, reliability and accuracy was a multiple regression model including MLA and TCSA as explanatory variables. However, there are not citations of reliable methods for tatura-trellis orchards.

The objective of this work was to develop simple, precise and non-destructive methods for indirect estimation of LAI in sweet cherry orchards trained as tatura-trellis.

2. Materials and Methods

During the 2008/2009 season a sampling was performed in a commercial sweet cherry orchard in the Lower Valley of Chubut River (43° 17' S. L.; 65° 19' W. L.), South Patagonia (Argentina). Planting was done in 2002 with trees of the cv. 'Sweetheart' grafted on the rootstock 'Santa Lucia 64' (*Prunus Mahaleb*) at 4.4 m x 2 m (2273 trees/ha), trained as tatura (Figure 1).

The radius (r) of the trunk 30 cm above the floor and the length of the central leader were registered in 27 trees (experimental units). Trees were selected trying to get a wide tree-size range. The TCSA was calculated as:

$$\text{TCSA (dm}^2) = \pi \cdot r^2;$$

while the Wood Volume of the Central Leader (WVCL) was estimated considering the radius and the length (L) of the leader:

$$\text{WVCL (dm}^3) = \pi \cdot r^2 \cdot L/3$$

From each experimental tree, all leaves were counted immediately after harvest and 2% of them were randomly taken as a sample, from which the length (without petiole) and the width of each leaf were measured. Leaf area (dm^2) was estimated multiplying length times width times 0.6612 [30]. Leaf area (LA) per tree was calculated multiplying the number of leaves times the mean leaf area. Based on the experimental data, four statistical descriptive models to estimate LA/tree were adjusted and evaluated. Two of them were simple linear regression models using as independent variable the TCSA or the WVCL. The other two were multiple linear regression models combining mean leaf area (MLA) with either WVCL or TCSA. Regression analyses were performed with InfoStat 2008 (Grupo InfoStat, Facultad de Ciencias Agrarias, Universidad Nacional de Córdoba, Argentina), with a significance level of 0.05.

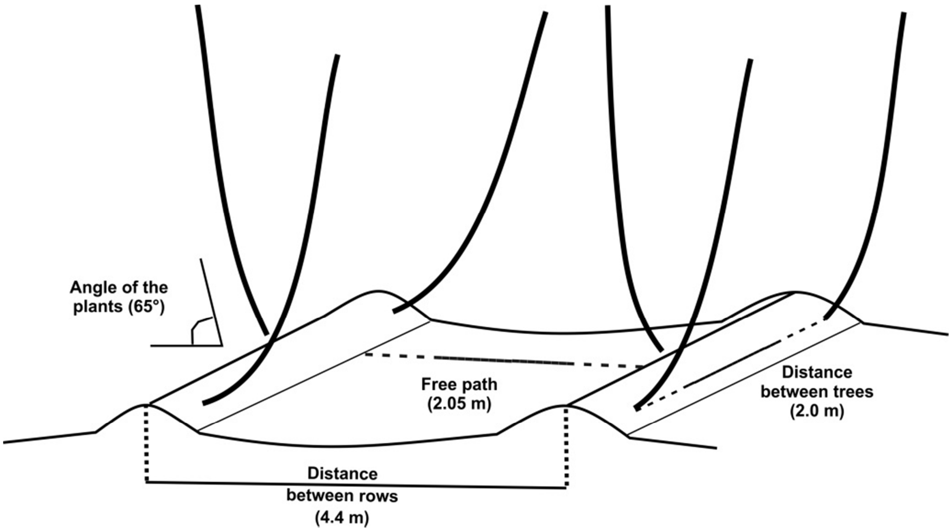

Figure 1. *Planting scheme of the commercial orchard used for sampling.*

LAI was calculated by dividing the estimated LA/tree by the area allocated to each tree (distance between rows times distance between trees in the row) (LAI = [LA/tree] / [area allocated per tree]).

3. Results and Discussion

The measured LAI of the experimental trees varied between 3 and 6. A wide range like this is a condition to be able of developing robust models.

The simple linear regression models to estimate the LA/tree utilizing TCSA or WVCL as independent variable showed a good fit (R^2 = 0.70 and 0.69, respectively) (Table 1; Figure 2). However, not including MLA as an explanatory variable would limit the usefulness of these models for cultivars with different leaf morphology. The models that better explained LA/tree variability were multiple linear regression equations combining TCSA and MLA (LA/tree = -11.23 + 37.2 • MLA + 15.91 • TCSA), or WVCL and MLA (LA/tree = -9.18 + 37.31 • MLA + 0.83 • WVCL), attaining a R^2 of 0.84 and 0.83, respectively (Table 1). From the perspective of the authors, utilizing the wood volume of the central leader in combination with the mean leaf area seems to be the most recommendable option for situations with conditions different to those of the experiment.

Table 1. *Statistical models for estimation of the Leaf Area per Tree (LA/tree) in sweet cherry cv. 'Sweetheart'.*

Model	R^2	Model probability	Standard error
LA/tree = 5.33 + 1.23 WVCL	0.69	*P*<0.0001	1.60
LA/tree = 2.07 + 23.25 TCSA	0.70	*P*<0.0001	1.98
LA/tree = -9.18 + 37.31 MLA + 0.83 WVCL	0.83	*P*<0.0001	3.46
LA/tree = - 11.23 + 37.2 MLA + 15.91 TCSA	0.84	*P*<0.0001	3.28

Note: WVCL: Wood Volume of the Central Leader (dm^3); TCSA: Trunk Cross-Sectional Area (dm^2); MLA: Mean Leaf Area (dm^2).

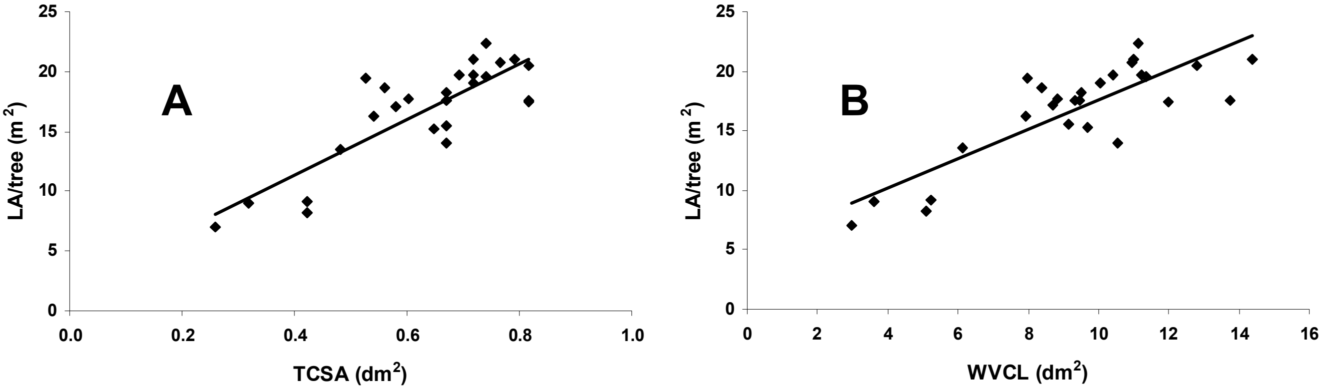

Figure 2. *(A): Estimation of LA/tree as a function of the Trunk Cross-Sectional Area (TCSA): LA/tree = 2.07 + 23.25 TCSA; P<0.0001; R^2 0.70. (B) Estimation of LA/tree as a function of the Wood Volume of the Central Leader (WVCL): LA/tree = 5.33 + 1.23 • WVCL; P<0.0001; R^2 0.69.*

The models presented in this work could be used in orchards in which the training system involves the presence of a central leader (e.g. tatura, central leader, solaxe, etc.); although for recommending the general use of these models, validation in other cropping situations is still required, especially in relation to other combinations cultivar-rootstock and different training systems.

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