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Leaf area constant model in optimizing foliar area measurement in plants: A case study in apple tree

Florin Sala[a,b,*], Gicu-Gabriel Arsene[a,c], Olimpia Iordănescu[a,d], Marius Boldea[a,e]

[a] Banat University of Agricultural Sciences and Veterinary Medicine, "Regele Mihai I al României", Timisoara, Calea Aradului 119, 300645 Timişoara, Romania
[b] Soil Science and Plant Nutrition
[c] Biology Plant Protection
[d] Horticulture
[e] Mathematics and Statistics

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ABSTRACT

Non-destructive methods of determining plant leaf area are useful instruments in physiological, ecological and agronomic research. Determining individual leaf area (ILA) in plants based on leaf size parameters – length (L) and width (W) – suppose the use of an area constant (K_A) as a factor of correction in increasing calculus precision. These studies suggest a model for the high accuracy calculus of the area constant (K_A) and of leaf area in plants based on leaf size on five apple tree cultivars. Measuring leaf area was done in parallel with for each leaf through measured leaf area (MLA) and scanned leaf area (SLA) in 1,500 leaves. Area constant (K_A) was calculated and validated through the comparison of measured leaf area (MLA) and scanned leaf area (SLA) under minimum error (ME) and minimum value RMSE conditions. Based on research, was obtained a Leaf Area Constant Model (LAC Model) to calculate K_A whose optimum value facilitated the accurate prediction of leaf area based on L and W in the five apple tree cultivars we studied (R^2 = 0.987 to R^2 = 0.995). The suggested LAC Model was used with high precision to calculate K_A in apple tree making possible its extension to other plant species also.

1. Introduction

Plant leaves and leaf area are an important variable within land ecosystems mainly in relation to the interception of solar light and its conversion into biochemical energy (Blanco and Folegatti, 2005; Pandey and Singh, 2011; Fascella et al., 2013). The importance of plant leaves was emphasized from different perspectives: botanical for the identification and characterization of plant species and phytocenoses (Cope et al., 2012); morphometric for the characterization of leaf topography and leaf features from the perspective of the interception of pathogens and of the solutions sued in foliar treatments (Mechaber et al., 1996); physiological for the study of the photosynthetic potential and of primary production in plants (Sestak et al., 1971; Smart, 1974; Tieszen, 1982; Bleasdale, 1984; Williams, 1987; Hoad et al., 1996; Guo and Sun, 2001; Balan, 2010 Tieszen, 1982; Bleasdale, 1984; Williams, 1987; Hoad et al., 1996; Guo and Sun, 2001; Balan, 2010); ecologic for the evaluation of symbiotic, nonsymbiotic or competitive relationships in plants (Harper, 1977; Mercier and Lindow, 2000); plant-environment relation for the evaluation of plant nutrition and stress state in certain environmental factors (Mohsenin, 1986; Stevens and Baker, 1987; Clayton et al., 1995; Meziane and Shipley, 1999; Vile et al., 2005; Hunsche et al., 2006; Jivan and Sala, 2014); ideotype definition for the analysis and computerized modeling of ideotypes to optimize production (Da Silva et al., 2014).

Among the characterization parameters of the leaves, leaf area and the parameters derived from them – leaf area index (LAI), net assimilation rate (NAR), specific leaf area (SLA), specific leaf weight (SLW) and leaf area duration (LAD) – are among the most representative and express plant and crop state in relation to environmental and technological factors (Smart, 1974; Mohsenin, 1986; Williams, 1987; Mokhtarpour et al., 2010 Mohsenin, 1986; Williams, 1987; Mokhtarpour et al., 2010). The leaf area can be measured by destructive methods based on leaf detachment –

* Corresponding author. Fax: +40 256 200296
E-mail addresses: florin_sala@usab-tm.ro (F. Sala), botanix.timagro@yahoo.com (G.-G. Arsene), olimpia.iordanescu@yahoo.com (O. Iordănescu), marius_boldea@usab-tm.ro (M. Boldea).

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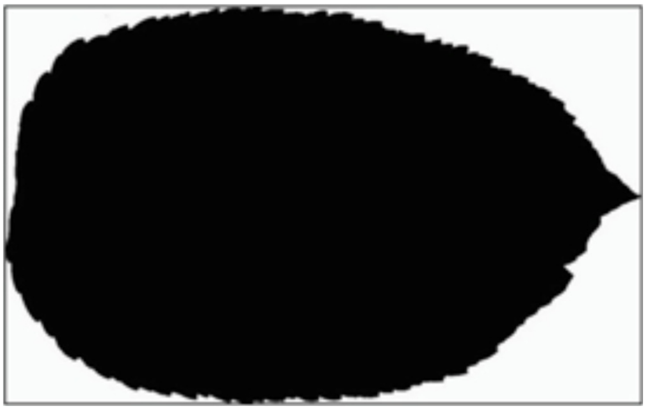

Fig. 1. Graph of area covered by a leaf in relation to the area calculated based on leaf dimensions (L, W).

planimetric, gravimetric, etc. – and non-destructive methods based on measurements or on imagery – calculation method, scanning method, imaging method, etc., (Sestak et al., 1971; Jonckheere et al., 2004; Kirk et al., 2009; Behera et al., 2010). Measuring leaf area is time-consuming and costly depending on work methods and/or precision (Marshall, 1968). Using quicker, simpler, non-destructive, enough accurate methods, with lower costs in order to measure leaf area in plants is very useful particularly in the case of a large number of measurements or of repetitive analysis focusing on the dynamics of leaf area (Spitters, 1990). Such methods have been of particular interest for researchers (Blanco and Folegatti, 2003; Pandey and Singh, 2011).

One of the most accessible methods supposes leaf area determination based on leaf dimensions (length and width) but for high accuracy it is necessary to be used an optimal correction factor. Starting from these considerations, the goal of this study was to develop a model for the calculus of the area constant (K_A) that are very useful to increase calculus accuracy of leaf area; the case study focused on apple tree.

2. Material and methods

2.1. Hypothesis

Based on leaf dimensions (L, W), it follows a regular geometric area (most frequently rectangular) which circumscribes the leaf (Fig. 1).

Since the leaf does not cover the entire area calculated based on leaf dimensions (L, W), it has to be corrected and area constant (K_A) has been proposed for this.

Leaf dimensions (L, W) can be obtained by high precision measurement. The area constant K_A is specific to each leaf type, variety, cultivar, plant species whose value influences significantly the level of accuracy in the calculus of leaf area through this method. One determined K_A can be used in an unlimited series of studies on this biological material.

2.2. Biological material

The study was carried out on the species Malus domestica Borch., on five cultivars with specific leaf morphological features that are well defined and differentiated: Generos, Pionier, Jonathan, Florina, and Delicios de Voineşti. The leaves were randomly sampled from tree canopy: five cultivars, three repetitions on each cultivar (5 trees per repetition), randomized 100 leaves collected from each repetition, i.e. a total of 1,500 leaves.

2.3. Conceptual model, work methods and work stages

In order to carry on the research, was proposed the Leaf Area Constant Model (LAC Model) (Fig. 2), which contains the work methods and stages to obtain optimum value of the area constant K_A and measure with high accuracy leaf area based on leaf dimensions.

According to the conceptual model (LAC Model), measuring the leaf area was done through two methods: measuring leaf area based on leaf dimensions (measured leaf area – MLA) and scanning leaf area (scanned leaf area – SLA) considered as a reference due to the high work precision. Measured leaf area (MLA) relied on leaf dimensions (L, W) and on area constant (K_A) according to the relation (1) from which has been deducted the relation (2) for area constant K_A.

$$MLA = L \times W \times K_A \tag{1}$$

$$K_A = \frac{MLA}{L \times W} \tag{2}$$

where: MLA – measured leaf area, L – leaf length, W – leaf width, K_A – area constant.

The length and width of leaves were measured with a ruler, with an accuracy of 0.5 mm, and constant KA received values in the range [0.69–0.79]. The MLA was determined for each leaf and after that the average was calculated for each cultivar.

In parallel, for the compared analysis of the results, was measured, for each leaf, scanned leaf area (SLA) with the software ImageJ (Rasband, 1997), which facilitated the measurement of the leaf area with high precision (99.95–100%). The values of leaf areas obtained with the two methods (MLA and SLA) were analyzed in parallel for each leaf to determine area constants, K_A. Area constant is sub-unitary: its optimal value depending on the difference between MLA and SLA as calculus error, it is minimal (minimal error – ME) relation (3):

$$K_A = \frac{MLA}{L \times W};\text{when}: MLA - SLA = ME \tag{3}$$

where: K_A – area constant, MLA – measured leaf area, L – leaf length, W – leaf width, SLA – scanned leaf area; ME – minimal error.

2.4. Statistical calculus of the results

The experimental results were calculated to obtain the foliar surface, and the surface constant for each leaf, and then the average for each cultivar. The relations between scanned leaf area (SLA) and predicted leaf area (PLA) based on area constant (K_A) were assessed. Regression analysis was used to obtain leaf area prediction functions based on the dimensions of the leaves.. The safety of the results and work accuracy were evaluated based on parameters: standard error (SE) – minimum value was the best; correlation coefficient R^2–maximum value was the best; $p < 0.01$ and RMSE, the lowest value was the best, relation (4). For this, the mathematical module in EXCEL 2007 and the software PAST (Hammer et al., 2001) were used.

$$RMSE = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(y_j - \hat{y}_j\right)^2} \tag{4}$$

3. Results

Based on the Leaf Area Constant Model proposed (LAC Model), the area constants - K_A, were determined and the leaf areas for the five apple tree cultivars were studied. Based on preliminary calculus and on general values for Malus established by Rubin and Danilevskaya (1957) and Gladyshev (1969), the theoretical interval