Leaf Area and Its Relationship with Leaf Descriptors Elements in *Liquidambar styraciflua* L.

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Bulletin UASVM Horticulture 75(1) / 2018

Print ISSN 1843-5262, Electronic ISSN 1843-536X

DOI:10.15835/buasvmcn-hort: 005117

Abstract

This study aimed at determining the leaf area in *Liquidambar styraciflua* L. and at characterising the relationship between leaf area and leaf descriptors. The biological material was the species *Liquidambar styraciflua* L. We determined leaf area in 100 leaves (Figure 1) based on the size of median rib (L), leaf width at higher (W_1) and lower (W_2) lobe level, and on area constants (K_A). The size of elements L, W_1 and W_2 were found by measuring with a precision of ± 0.5 mm. Area constants in the species *Liquidambar styraciflua* L. were $K_{A1} = 0.63$, determined depending on leaf width at upper lobe width (W_1), and $K_{A2} = 0.81$ in relation to the width W_2 of the lower lobes. Between the scanned leaf area (SLA) and measured leaf area (MLA) and leaf descriptors (L, W_1 and W_2) we identified relations of interdependence statistically ensured: $r = 0.960$ to $r = 0.971$ for SLA; $r = 0.951$ to $r = 0.981$ for MLA W_1 , and $r = 0.933$ to $r = 0.972$ for MLA W_2 , respectively. Leaf descriptors L, W_1 and W_2 had a differentiated contribution in determining SLA and MLA. SLA was influenced by leaf length (L) with higher statistic safety ($R^2 = 0.963$, $p < 0.001$, $F = 1277.2$) than leaf width at upper lobe width W_1 ($R^2 = 0.943$; $p < 0.001$; $F = 797.7$) and leaf width at the extremities of the lower lobes W_2 ($R^2 = 0.927$, $p < 0.001$, $F = 620.59$).

Keywords: leaf area, LAC Model, *Liquidambar*, descriptors, leaves

Introduction

Leaf area is a morphological and physiological parameter in plants of interest for the reception of solar energy, the process of photosynthesis, relationship with the environment, ornamental issues, etc. Determining leaf area to characterise different plant species was done through different models, methods and techniques (destructive and non-destructive) (Jonckheere *et al.*, 2004; Behera *et al.*, 2010; Kirk *et al.*, 2009; Fascella *et al.*, 2009, 2013; Sala *et al.*, 2015).

The Genus *Liquidambar* has four tree species: *Liquidambar orientalis* L., *Liquidambar formosana* Hance., *Liquidambar styraciflua* L., and *Liquidambar acalycina* L. (Adams *et al.*, 2015; Lingbeck *et al.*, 2015). The species *Liquidambar styraciflua* L. has various uses: ornamental,

pharmaceutical, and medical (Lingbeck *et al.*, 2015). Several studies have assessed the antioxidant and antimicrobial effects of some compounds and the quality of volatile oils (Sađdic *et al.*, 2005; Carson *et al.*, 2006; Wang *et al.*, 2010; El-Readi *et al.*, 2013).

The species has different types depending on leaf or other organs morphological parameters that have been studied and characterised in different studies (Gilman and Watson, 1993).

They have also carried out studies on productivity depending on leaf area and photosynthesis rate in *Liquidambar styraciflua* L. under different conditions of fertilisation, irrigation and pest control (Samuelson *et al.*, 2001).

Figure 1. Leaf of *Liquidambar styraciflua* L.

Table 1. Values of area constants K_{A1} , MLA and safety parameters in *Liquidambar styraciflua* L.

Values of area constants (K_{A1})											
SLA	46.93										
KA	0.58	0.59	0.6	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68
MLA	43.02	43.76	44.51	45.25	45.99	46.73	47.47	48.21	48.96	49.70	50.44
ME	-3.91	-3.17	-2.43	-1.68	-0.94	-0.20	0.54	1.28	2.03	2.77	3.51
RMSE	5.4581	4.8111	4.218	3.7047	3.3086	3.0426	3.0753	3.2164	3.5669	4.0483	4.6199

Note: K_{A1} – constant of leaf area to determine leaf area based on leaf width at upper lobe termination; K_A – constant of leaf area; MLA – measured leaf area; ME – minimal Error; RMSE – Root Mean Square Error

This study aimed at determining the leaf area in *Liquidambar styraciflua* L. and at characterising the relationship between leaf area and leaf descriptors.

Materials and methods

The biological material was the species *Liquidambar styraciflua* L. We determined leaf area in 100 leaves (Fig. 1) based on the size of median rib (L), leaf width at higher (W_1) and lower (W_2) lobe level, and on area constants (KA). Results were compared with leaf area determined through scanning (SLA) as reference, based on the model proposed by Sala *et al.* (2015). The size of the elements L, W_1 and W_2 was obtained by measurements with a precision of ± 0.5 mm.

Experimental data were analysed and statistically processed through correlation analysis and regression, and the interdependence between descriptors and MLA and SLA thus obtained was described by 2nd degree polynomial

functions. The precision MLA assessment element was the mean of minimum errors (MME) and statistic safety parameters were represented by the correlation coefficients R^2 , p, F and RMSE.

Results and discussion

Based on individual values of the median vein length (L) and of upper lobe width (W_1) and lower lobe width (W_2), we obtained the mean values of these elements. Area constants for the species *Liquidambar styraciflua* L. were $K_{A1} = 0.63$ determined depending on upper lobes width (W_1) and $K_{A2} = 0.81$ and on lower lobe width W_2 . Based on leaf size (L, W_1 and W_2) and on area constants K_A , determined based on the model proposed by Sala *et al.* (2015), we calculated leaf area with high precision. Compared to the scanned leaf area, the mean of minimum error mean of measured leaf area was -0.20 cm^2 (RMSE = 3.0426) when calculating based on upper lobe width (W_1) and -0.06 cm^2 (RMSE = 4.3826) when

Table 2. Values of area constants K_{A2} , MLA and safety parameters in *Liquidambar styraciflua* L.

Values of area constants (K_{A2})											
SLA	46.93										
KA	0.76	0.77	0.78	0.79	0.8	0.81	0.82	0.83	0.84	0.85	0.86
MLA	43.97	44.55	45.13	45.71	46.29	46.87	47.45	48.02	48.60	49.18	49.76
MME	-2.96	-2.38	-1.80	-1.22	-0.64	-0.06	0.52	1.09	1.67	2.25	2.83
RMSE	5.5359	4.9886	4.7158	4.5177	4.4045	4.3826	4.4534	4.6127	4.8517	5.1594	5.5243

Note: K_{A1} – constant of leaf area to determine leaf area based on leaf width at upper lobe termination; K_A – constant of leaf area; MLA – measured leaf area; ME – minimal Error; RMSE – Root Mean Square Error

Table 3. ANOVA test for single factor

Source of variation	SS	df	MS	F	P-value	F. crit
Between groups	226061	5	45212.2	207.9989	5.9E-128	4.16402
Within groups	129116.3	594	217.3675			
Total	355177.3	599				
Alpha = 0.001						

calculating based on leaf width at lower lobes (W_2). Based on the leaf dimensions (L and w) and the surface constants K_{A1} and K_{A2} , the foliar surface was determined by the relation (1).

Data are shown in Tables 1 and 2 below.

$$MLA = L \times w \times K_A \quad (1)$$

Where: MLA – Measured Leaf Area; L – leaf length; w – leaf width; K_A – constants of leaf area, K_{A1} and K_{A2} .

We identified statistically ensured interdependence relations between scanned leaf area (SLA) and measured leaf area (MLA) and leaf descriptors (L, W_1 and W_2): $r = 0.960$ to $r = 0.971$ for SLA; $r = 0.951$ to $r = 0.981$ for MLA W_1 , and $r = 0.933$ to $r = 0.972$ for MLA W_2 , respectively.

We identified interdependence relations between leaf descriptors and scanned leaf area (SLA) and measured leaf area (MLA), respectively.

The interdependence between SLA and individual leaf descriptors (L, W_1 and W_2) was described by 2nd degree polynomial functions (relations 2, 3 and 4), with statistic ensurance.

$$SLA_L = 0.8669x^2 - 0.8305x + 1.515 \quad (2)$$

$$SLA_{W1} = 0.405x^2 + 1.851x - 8 \quad (3)$$

$$SLA_{W2} = 0.297x^2 + 5.038x - 6.279 \quad (4)$$

Thus, leaf descriptors L, W_1 and W_2 had a different contribution to the calculus of SLA and MLA. Scanned leaf area (SLA) was influenced by leaf length (L) with higher statistic ensurance

($R^2 = 0.963$, $p < 0.001$, $F = 1277.2$) than upper lobe width W_1 ($R^2 = 0.943$; $p < 0.001$; $F = 797.7$) and leaf width at the extremity of lower lobes W_2 ($R^2 = 0.927$, $p < 0.001$, $F = 620.59$). Independence relations are shown in Figures 2-4, where: SLA_L – leaf area based on leaf length, SLA_{W1} – leaf area based on upper lobe width, SLA_{W2} – leaf area based on lower lobe width; x – parameter depending on which we determined leaf area.

Measured leaf area (MLA) depending on upper lobe width (W_1), was differently influenced by leaf length (L) under statistic safety conditions $R^2 = 0.971$, $p < 0.001$, $F = 1598.7$ (relation 5) and by leaf width (W_1) under statistic safety conditions $R^2 = 0.974$; $p < 0.001$; $F = 1789.7$ (relation 6). The distribution of interdependence relations between MLA_{W1} and leaf length (L) and W_1 , respectively, are shown in Figures 5 and 6.

$$MLA_{W1} = 0.69x^2 + 1.167x - 3.183 \quad (5)$$

$$MLA_{W2} = 0.3834x^2 + 1.888x - 6.549 \quad (6)$$

Measured leaf area (MLA) depending on lower lobe width (W_2) was differently influenced by leaf length (L) under statistic safety conditions $R^2 = 0.969$, $p < 0.001$, $F = 1526.2$ (relation 7) and by leaf width (W_2) under statistic safety conditions $R^2 = 0.984$; $p < 0.001$; $F = 2956.4$ (relation 8). The interdependence relations between MLA_{W2} and leaf length (L) and W_2 , respectively, are shown in Figures 7 and 8.

Figure 2. Distribution of the interdependence relation between SLA and L

Figure 3. Distribution of the interdependence relation between SLA and W_1

Figure 4. Distribution of the interdependence relation between SLA and W_2

$$MLA_{W_2} = 0.9988x^2 - 1.772x + 0.6835 \quad (7)$$

$$MLA_{W_2} = 0.4888x^2 + 3.355x - 5.055 \quad (8)$$

Determining leaf area based on leaf descriptors is non-destructive, quick, enough accurate and low cost. To determine leaf area, we use direct relations between leaf length and correction coefficients or area constants (Sala *et al.*, 2015) or different software applications and models (Kumar *et al.*, 2017). We can also use linear or polynomial regression models to calculate leaf area based only on independent descriptors of the

leaf between which there are not such relations (Blanco and Folegatti, 2003; Mokhtarpour *et al.*, 2010; Rouphael *et al.*, 2010).

The study of leaf area was carried out on different horticultural species depending on nutrition (Jivan and Sala, 2014) to characterise tree species (Sala *et al.*, 2017).

In *Liquidambar*, leaf specificity made possible determining leaf area based on L, W_1 and W_2 . Leaf area in *Liquidambar* was studied by Kuers and Steinbeck (1998) depending on N fertilisation

Figure 5. Distribution of the interdependence between MLA_{W1} and L

Figure 6. Distribution of the interdependence between MLA_{W1} and W_1

Figure 7. Distribution of the interdependence relation between MLA_{W2} and L

Figure 8. Distribution of the interdependence relation between MLA_{W2} and W_2

and on vertical and temporal leaf distribution. They identified an increase of the leaf area and of the total leaf weight in trees fertilised with N due rather to an increase of leaf size than to an increase of leaf number and of specific leaf weight.

Conclusions

Leaf geometry in *Liquidambar styraciflua* L. facilitated the measurement of leaf area based on

the length of the median vein and on the upper and lower lobe width (W_1) and (W_2), respectively.

Leaf area calculated based on lower lobe width was more accurate than that calculated based on lower lobe width compared to scanned leaf area (SLA).

We identified interdependence relations between the values of scanned leaf area and of

measured leaf area, which confirms the accuracy of the measurement based on leaf descriptors.

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