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Model for estimating red mulberry leaf area using a genetic algorithm

Corresponding author
Alejandra Semiramis Albuquerque
Universidade Federal de São João del-Rei
alejandra@ufsj.edu.br

Leandro Mendes de Souza
Universidade Federal de São João del-Rei

Kassilio José Guedes
Universidade Federal de São João del-Rei

Gabriella Roberta Silva Oliveira
Universidade Federal de São João del-Rei

Abstract. The success of sericulture depends directly on the quality and quantity of mulberry leaves, as it is essential for the feeding and development of silkworm caterpillars and, consequently, influences the quality of the silk thread manufactured. The estimation of mulberry leaf area is important to have plant development and growth indicators, such as transpiration intensity, net assimilation rate, leaf area ratio, specific leaf area and leaf area index, which allow predicting crop productivity. Thus, the objective of this study was to develop and test a model capable of estimating the red mulberry leaf area using a genetic algorithm. The model was adjusted with the proposed stochastic optimization method. The mean error found for the tested dataset was approximately 228.17 mm^2 in sample space with mean leaf area of 6515.55 mm^2. The information generated allows applying the model to estimate red mulberry leaf area in future studies.

Keywords: *Morus rubra*, artificial intelligence, optimization.

Introduction

Sericulture is an agro-industrial activity aimed at the production of silk threads and fabrics and involves mulberry cultivation (*Morus* spp.), a fundamental food for silkworm caterpillars (*Bombyx mori*), and the zootechnical breeding of this insect. This activity has been developed in Brazil since the end of the nineteenth century and continues to the present day due to the good edaphoclimatic conditions for silkworm breeding and mulberry cultivation in several regions (Porto, 2014). In addition, it does not require large investments in labor and cultivation area, which makes the activity viable for small and medium-sized producers and an alternative for agriculture diversification (Guimarães Filho, 2016).

The success of sericulture depends directly on the quality and quantity of mulberry leaves, as it is essential for the feeding and development of silkworm caterpillars and, consequently, influences the quality of the silk thread manufactured.However, studies indicate that there are alternations in leaf mass production, impairing the development, feasibility and production of cocoons (Purohit & Kumar, 1996).

In this sense, measuring the mulberry leaf area is important to have plant development and growth indicators, such as transpiration intensity, net assimilation rate, leaf area ratio, specific leaf area and leaf area index, which allow predicting crop productivity (Schmildt et al., 2014).

Leaf area estimates can be obtained both destructively and non-destructively, directly or indirectly. As it is a non-destructive, low-cost, high-precision and fast evaluation method, the indirect method is the most used to estimate leaf area in agricultural crops, allowing successive evaluations on the same plant (Azevedo et al., 2019).

One of the ways to estimate leaf area is through artificial intelligence techniques (Azevedo et al., 2015), highlighting genetic algorithms (GAs) due to their ability to solve optimization problems. Genetic algorithms are computational techniques, inspired by genetics and Darwin's principle of species evolution, which have the ability to determine the best answer to the problem. The algorithms act to optimize the coefficients of the proposed mathematical model, so that the input patterns correspond to the output patterns (Pinto et al., 2022). In view of these perspectives, the objective was to develop and test a model capable of estimating red mulberry leaf area using a genetic algorithm.

Material and Methods

A total of 900 leaves were harvested from four red mulberry trees (*Morus rubra*) at different development stages. Leaves were scanned and their length and greatest width were measured with a ruler. The leaf area was obtained from scans with the aid of the Image Pro Plus 4.5 software. The proposed mathematical model took into account the leaf length and greatest width measurements, which values are the input patterns. The model output was the leaf area obtained from scans (output pattern). The following model has been proposed:

$$\mathrm{A} = \mathrm{M} \times \mathrm{C}^{\mathrm{n}} \times \mathrm{L}^{\mathrm{p}} \quad \text{eq. 1}$$

in which:
A: leaf area (mm^2);
C: leaf length (mm);
L: leaf width (mm);
M: proportionality adjustment coefficient;
n: exponent length adjustment;
p: exponent width adjustment.

M, n and p values were adjusted with the genetic algorithm in order to reduce the error in the leaf area calculation. The values of variables were adjusted through a process in which the model "learned" how to calculate the area from leaf length and greatest width values. In addition to the learning stage, the performance testing process was carried out, which is a statistical evaluation of the model's functioning. This step consisted of comparing the actual result of the problem and the result obtained through data provided by the model in the test step. After the completion of the learning and performance testing stages, the information learned could be generalized (Haykin, 2001).

A binary coding genetic algorithm was used with 10 individuals, with mutation rate equal to 0.1 and 5000 generations. The input elements of patterns were the largest leaf width and length measured at the midrib. The output values of patterns were the areas of each leaf, obtained by the Image Pro Plus 4.5 software. In the problem, the objective function, which was minimized, was the mean error of the calculated area when compared to the actual area (equation 2). After adjustment, the dataset was used to verify the model reliability and general application, evaluating its efficiency by means of equation 2 and calculation of the standard deviation of the error.

$$Em = \sum_{i=1}^{n} \frac{|S_C(i) - S_R(i)|}{n} \quad \text{eq.2}$$

in which:
Em: average validation error (mm^2);
$S_C(i)$: output calculated for standard i (mm^2);
$S_R(i)$: Actual output for standard i (mm^2);
n: number of standards used for validation.

Results and discussion

The mean error of the model, obtained by equation 2, was approximately 228.17 mm^2 for the dataset analyzed, whose mean leaf area was 6515.55 mm^2. The standard deviation of the error between areas was 6.94 mm. In figure 1, the real and calculated leaf areas were compared, making it possible to observe the small magnitudes of the average error and the standard deviation of the error, since the curves of the real and calculated value of leaf areas tended to overlap. The values found for coefficients were M= 10.255, n=1.055 and p=0.862, and the model was established in equation 3. $\mathrm{A} = 10.255 \times \mathrm{C}^{1.055} \times \mathrm{L}^{0.862}$ eq. 3

As in this model, several authors have also estimated leaf area based on linear leaf dimensions of various crops (Goergen et al., 2021;Hernandéz-Fernandéz et al., 2021;Junges&Anzanello, 2021; Leite et al., 2017;Leite et al., 2019; Leite et al., 2021;Zanetti et al., 2017; Silva et al. 2017); however there are no works of this nature in literature for red mulberry tree.

The prediction efficiency using artificial intelligence techniques depends on leaf shape variation (length/width) and genetic materials used in the adjustment (Azevedo et al., 2017; Queiroga et al., 2003). Thus, the use of the four different genotypes and the different leaf development stages evaluated in this study contributed to the fact that the adjusted model is generalist for various shapes and dimensions of red mulberry leaves. In addition, Monteiro et al. (2005), working with cotton, obtained three different models, one for each leaf size, and concluded that there is no need for using these different models due to the small improvement obtained in leaf area estimation. Maldaner et al. (2009) also reported that unique equations are calibrated for different leaf sizes and ages with excellent accuracy.

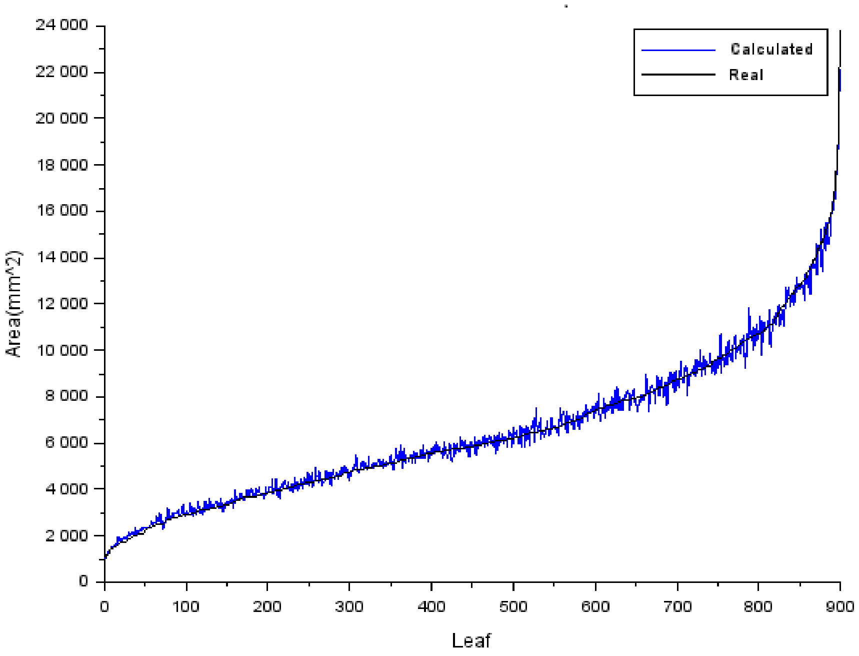

Figure 1. Real and calculated leaf areas of red mulberry

Conclusion

It was demonstrated that it is possible to estimate red mulberry leaf area by means of the model presented in equation 3, with mean error of approximately 228.17 mm² for the dataset analyzed, whose average leaf area was 6515.55 mm². The mean error was approximately 3.5% of the average leaf area, showing that the model allows obtaining accurate red mulberry leaf area estimates. The information generated allows applying the model to estimate red mulberry leaf area in future studies.

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