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Short communication

A simple model for estimating leaf area of hazelnut from linear measurements

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Abstract

Simple, accurate and non-destructive models determining leaf area of plants are important for many experimental comparisons. Determining the individual leaf area (LA) of hazelnut (*Corylus avellana* L.) involves measurements of leaf parameters, such as length (L) and width (W), or some combinations of these parameters. Two-year investigation was carried out during 2005 (on 20 genotypes) and 2006 (on one cultivar) under open field conditions, respectively, to test whether a model could be developed to estimate leaf area across genotypes and environments. Regression analyses of LA versus L and W revealed several models that could be used for estimating the area of individual hazelnut leaves. A linear model having LW as the independent variable ($LA = 2.59 + 0.74LW$) provided the most accurate estimate ($R^2 = 0.982$, MSE = 29) of hazelnut LA. Validation of the model having LW of leaves measured in the 2006 experiment coming from other genotype grown under different environmental conditions showed that the correlation between calculated and measured areas was very high.

Keywords: *Corylus avellana* L.; Leaf area; Leaf parameters; Linear measurements; Non-destructive methods

1. Introduction

Accurate and simple measurements of leaf surface area are of special concern to plant scientists as well as to process engineers handling these materials. Sustainability of the leaves affect growth and bio-productivity, hence leaf area measurements assume a great significance in plant growth studies. Measurement of leaf area is of value in studies of plant nutrition, plant competition, plant soil–water relations, plant protection measures, crop ecosystems, respiration rate, light reflectance, and heat transfer in heating and cooling processes (Mohsenin, 1986).

Many methods have been devised to facilitate the measurement of leaf area. However, these methods, including those of tracing, blueprinting, photographing, or using a conventional planimeter, require the excision of leaves from the plants. It is therefore not possible to make successive measurements of the same leaf. Plant canopy is also damaged, which might cause problems to other measurements or experiments. Leaf area can be measured quickly, accurately, and non-destructively using a portable scanning planimeter (Daughtry, 1990), but it is suitable only for small plants with few leaves (Nyakwende et al., 1997). An alternative method to measure leaf area is to use image analysis with image measurement and analysis software. The capture of image by digital camera is rapid, and the analysis using proper software is accurate (Bignami and Rossini, 1996), but the processing is time consuming, and the facilities are generally expensive. Therefore, an inexpensive, rapid, reliable, and non-destructive method for measuring leaf area is required by the agronomists. If the mathematical relationships between leaf area and one or more dimensions of the leaf (length and width) could be clarified, a method using just linear measurements to estimate leaf area would be more advantageous than many of the methods mentioned above (Villegas et al., 1981; Beerling and Fry, 1990). Various combinations of measurements and various models relating length and width to area have been developed for several fruit trees, such as grape (Montero et al., 2000; Williams and Martinson, 2003), avocado (Uzun and Celik, 1999), pistachio (Ranjbar and Damme, 1999), cherry (Demirsoy and Demirsoy, 2003), peach (Demirsoy et al., 2004), and chestnut (Serdar and

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Demirsoy, 2006), while information on the estimation of hazelnut (*Corylus avellana* L.) leaf areas is still lacking.

The accuracy of the predictions is dependent on the variation of leaf shape between genotypes. Since leaf shape (length:width ratio) may vary among different genetic materials (Stoppani et al., 2003), we needed a good model of non-destructive leaf area estimation to use in physiological study of hazelnut plants independently of the genetic materials. Other factors can affect hazelnut leaf shape and morphometry, such as juvenility, rejuvenation and light (Tombesi and Cartechini, 1983; Kull and Niinemets, 1993). Nevertheless, juvenility is not relevant in the case of cultivated hazelnut, since juvenile phase is absent in agamically propagated plants. Differences induced by light and rejuvenation mainly in regard to the leaf size and specific leaf area and should not affect the validity of a predictive model if it is based on a correct sampling.

Therefore, the aims of this study were: (1) to develop a model for leaf area prediction from linear measurements of leaf length and width in hazelnut that was able to accommodate the effect of changes in leaf shape between genotypes and which could be used for hazelnut plants of all accessions without recalibration and (2) to assess the robustness of the model on an independent set of data from other genotype grown under different environmental conditions.

2. Materials and methods

Twenty-one genotypes including different Italian, Spanish, Turkish, French, German, and American genotypes of hazelnuts (*C. avellana* L.) were used to develop a leaf area prediction model. Wide varieties of fully expanded leaf samples collected on spurs and on the middle part of non-bearing shoots were used. Leaves varied in size from large to small for each genotype and were selected randomly from different levels of the canopy ranging between 1 and 2 m from the soil and all around the crown, during the summer growing season in 2005 and 2006. The age of the trees varied between 6 and 14 years.

A total of 3111 hazelnut leaves (about 150 leaves per genotype) were measured for leaf area (LA), length (L) and width (W) in the preliminary calibration experiment coming from 20 genotypes: Morell, Nocchione, Grifoll, Segorbe, Montebello, Barcelona, Palla Grossa, Negret, Tonda Gentile delle Langhe, Eynich, Daviana, Tombul, Tonda di Giffoni, Gunslebert, Closca Molla, Lunga di Spagna, Karidaty, San Giovanni, Merveille de Bollwiller, and Gironell under field conditions at the Experimental Farm of Caprarola (Lazio region). These genotypes were selected as a representative sampling of the many hazelnuts available throughout the Mediterranean region (Köksal and Celik, 2000). The single-trunk trees trained as free vase were spaced 4 m × 5 m giving a plant density of 500 plants ha^{-1}.

Immediately after cutting, leaves were placed in plastic bags and were transported on ice to the laboratory. Leaf L was measured from lamina tip to the point of intersection of the lamina and the petiole, along the midrib of the lamina, while leaf W was measured from end-to-end between the widest lobes of the lamina perpendicular to the lamina mid-rib. Values of L and W were recorded to the nearest 0.1 cm. The area of each leaf (LA) was measured using an area meter (LI-3100; LICOR, Lincoln, NE, USA) calibrated to 0.01 cm^2.

The dependent variable (LA) was regressed with different independent variables, including L, W, L^2, W^2, and the product $L \times W$. Mean square error (MSE) and the values of the coefficients (b) and constants (a) were also reported, and the final model was selected based on the combination of the highest coefficient of determination (R^2) and the lowest MSE. These statistics were applied to each individual genotype and to combined data points of all genotypes for each model. Moreover, using two measurements (i.e. L and W) introduces potential problems of collinearity, resulting in poor precision in the estimates of the corresponding regression coefficients. For detecting collinearity, the variance inflation factor (VIF) (Marquardt, 1970) and the tolerance values (T) (Gill, 1986) were calculated.

$$\mathrm{VIF} = \frac{1}{1 - r^2} \qquad (1)$$

$$T = \frac{1}{\mathrm{VIF}} \qquad (2)$$

where r, is the correlation coefficient. If the VIF value was higher than 10 or if T value was smaller than 0.10, then collinearity may have more than a trivial impact on the estimates of the parameters, and consequently one of them should be excluded from the model.

In addition to validate the developed model and to increase practical applicability in different environment conditions, a validation experiment was conducted in the summer 2006 on leaf samples of Tonda Gentile Romana grown at the Experimental Farm of Tuscia University, central Italy (latitude 42°25′N, longitude 12°08′E, altitude 310 m). This genotype was selected as one of the most representative hazelnut genotype cultivated in Italy. The trees were spaced at 5 m × 5 m giving a plant density of 400 plants ha^{-1}.

To validate the model, about 500 leaves of Tonda Gentile Romana actual leaf area and leaf width and length were determined by the previously described procedures. Leaf area of individual leaves was predicted using the best model from the calibration experiment and was compared with the actual leaf area. The slope and intercept of the model were tested to see if they were significantly different from the slope and intercept of the 1:1 correspondence line (Dent and Blackie, 1979). Regression analyses were conducted using the SigmaPlot 8.0 package (SigmaPlot, Richmond, California, USA).

3. Results and discussion

One of the leaf shape traits is the length:width ratio (L:W). In the current experiment, significant differences ($P < 0.05$) were recorded on L:W ratio among genotypes (Table 1). Morell, Grifoll, Segorbe, San Giovanni, and Merveille de Bollwiller produced the largest leaves (L:W ratio ranged from 1.15 to 1.19). Moreover, Palla Grossa, Tonda Gentile delle Langhe,