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Non-destructive Estimation of Leaf Area in Tea (*Camelia sinensis*)*

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Abstract: Leaf area parameters routinely measured in physiological studies provides researchers many advantages in horticultural experiments. In the present study a leaf area prediction model was developed for tea (*Camelia sinensis*) by using different tea cultivars namely, Derepazari-7, Fener-3, Tuglali-10, Pazar-20, Muradiye-10, Komurculer-1 and Gundogdu-3. Leaf lamina width, length and leaf area were measured to develop the model. The actual leaf areas of the cultivars were measured by PLACOM Digital Planimeter and multiple regression analysis with Excel 7.0 computer package program was performed for the cultivars. The produced leaf area prediction model in the present study were formulized as $LA = -0.66 + (0.348\times L) - (0.155\times L^2) - (0.133\times W^2) + [1.084\times(L\times W)] + \lfloor 0.0062\times(L^2\times W)\rfloor - \lfloor 0.033\times(W^2\times C)\rfloor$ where LA is leaf area, W is leaf width, L is leaf length and C is cultivar. R^2 value was 0.99 for the equation. The model had also a biological meaning such as cultivars were found to be significant as a parameter in the model.

Key words: *Camelia sinensis*, leaf area, modeling

Introduction

Tea (*Camelia sinensis* L.) is an evergreen shrub that widely cultivated throughout the tropics and subtropics especially in hilly or mountainous regions for its tender leaves that are dried and used for a mildly stimulating beverage (Hodgson *et al*., 1999). Today, tea is one of the most widely used beverages in the world, second only to water and an important cash crop throughout different production areas of the world. Planted area for this plant has reached 2.461 million ha resulting in 3.196 million ton production in world-wide during 2005 (Anonymous, 2006). Also, this plant has received considerable interest in recent years as a medicinal agent with its well-documented anti-bacterial (Vijaya *et al*., 1995), anti-ulcer (Maity *et al*., 1995), anti-cancer (Okai *et al*., 1998; Weisburger and Chung, 2002; Joshua *et al*., 2003) and anti -inflammatory (Chattopadhyay *et al*., 2004; Chaudhuri *et al*., 2005) effects. These figures clearly demonstrate the importance of tea, as well as the potential economic benefits possibly realised from productivity increases.

Tea leaves contain a number of substances including caffeine, tannins, amino acids, proteins, trace elements, minerals and vitamins, all contribute to flavour and fragrance as well as medicinal properties of tea (Liang *et al*., 2001). Therefore, leaves are the most important organ of this plant. Leaf area is routinely measured in experiments interesting crops where some physiological phenomenon such as light, photosynthesis, respiration, plant water consumption and transpiration is being studied (Rieger and Duemmel, 1992; Horsley and Gottschalk, 1993; Gottschalk, 1994; Kersteins and Hawes, 1994; Picchioni and Weinbaum, 1995; Uzun, 1996; Centritto *et al*., 2000). In addition, leaf number and leaf

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area of a plant are important in terms of cultural practices such as training, pruning, irrigation, fertilization etc. The leaf area estimation models that aim to predict leaf area non-destructively can provide researches with many advantages in agricultural experiments. Moreover, these kinds of models enable researchers to carry out leaf area measurements on the same plants over the course of a study, resulting in reduced experimental variability (Gamiely *et al*., 1991; NeSmith, 1991, 1992). Leaf area can be determined by using expensive instruments and/or predictive models. Recently, new instruments, tools and machines such as hand scanners and laser optic apparatuses have been developed for leaf and fruit measurements. These are very expensive and complex devices for both basic and simple studies. Furthermore, non-destructive estimation of leaf area saves time as compared with geometric measurements (Robbins and Pharr, 1987). For this reason, several leaf area prediction models were produced for some plant species in previous studies. But, to the authors' knowledge, there are no published reports concerning leaf area prediction model for tea. Due to the lack of such information, in the present study, we aimed to develop reliable equation that allow for the non-destructive estimation of leaf area through linear measurements of leaf dimensions.

Materials and Methods

Experimental Procedures

Seven tea cultivars (Derepazari-7, Fener-3, Tuglali-10, Pazar-20, Muradiye-10, Komurculer-1 and Gundogdu-3) were used. In the present study, leaf samples were randomly taken from different locations of the canopy of 20-25 years old tea plants during the summer growing season in 2004 at a five time intervals. In this period, 250 leaf samples for each cultivar and a total of 1750 leaves for seven cultivars were processed at the same day as they were collected in the following manner. First, they were placed on the photocopier desktop by holding flat and secure and copied on A3 sheet (at 1,1 ratio). Second, a Placom Digital Planimeter (Sokkisha Planimeter Inc., Model KP-90) was used to measure actual leaf area of the copy. Selection of leaf dimensions for measurement was governed by variation in leaf characteristics (e.g., size, shape and symmetry) and practical constraints (e.g., ease and accuracy of measurements under field conditions). Given these concerns, we chose maximum leaf width

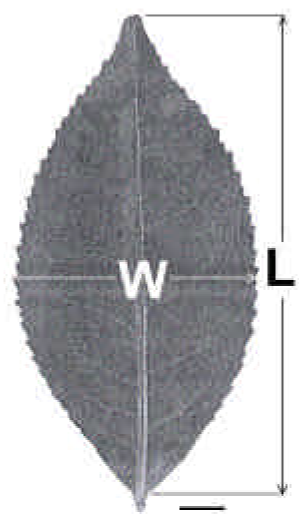

Fig. 1: Leaf diagram of tea showing the position of leaf length (L) and leaf width (W). Bar seen at the lower right corner represent 1 cm

(W) and length (L) to relate with leaf area. Leaf width (cm) was measured from tip to tip at the widest part of the lamina and leaf length (cm) was measured from lamina tip to the point of petiole intersection along the midrib (Fig. 1). The leaf positions were selected with regard to points that could be easily identified and used to facilitate the measurement of leaf length and width.

Model Constructions

Multiple regression analysis of the combined data was performed for all the cultivars. A search for the best model for predicting leaf area was conducted with various subsets of the independent variables, namely, length (L), (L^2), width (W), (W^2), (L×W) and (L^2×W) and cultivar (C). The best estimating equations for the Leaf Area (LA) of the cultivars tested were determined with the Excel 7.0. Multiple regression analysis was carried out until the least sum of square was obtained.

Results

Multiple regression analysis used for determination of the best fitting equation for estimation of leaf area in tea cultivars evaluated here showed that most of the variation in leaf area values was explained by the selected parameters (Length, Width and Cultivar). The variation explained by the parameters was 99% for all cultivars tested. The produced leaf area prediction models in the present study were

$$LA = -0.66 + (0.348\times L) - (0.155\times L^2) - (0.133\times W^2) + [1.084\times(L\times W)] + \lfloor 0.0062\times(L^2\times W)\rfloor - \lfloor 0.033\times(W^2\times C)\rfloor$$

where LA, leaf area, L, leaf length, W, Leaf width, C, cultivar. C values in this equation are 1 for cv. Derepazari-7, 2 for cv. Fener-3, 3 for cv. Tuglali-10, 4 for cv. Pazar-20, 5 for cv. Muradiye-10, 6 for cv. Komurcular-1 and 7 for cv. Gundogdu-3 respectively (Table 1). When the data for actual leaf area was plotted against the leaf area values predicted by the present model, it was found that the model estimated leaf area for all cultivars examined with a high determination (Fig. 2).

Table 1: The equation of leaf area for tea

LA[1] =	$-0.66 + (0.348\times L) - (0.155\times L^2) - (0.313\times W^2) + [\ 1.084\times(L\times W)\ ] + [0.0062\times(L^2\times W)] - 0.033\times(W^2\times C)\ ]$, ($R^2$=0.99)
SE[2] =	(0.33)* (0.088)*** (0.011)*** (0.053)*** (0.048)*** (0.00093)*** (0.0044)***

[1]leaf area, [2]standard errors, R^2 and all SE values are significant at $p<0.001$ level

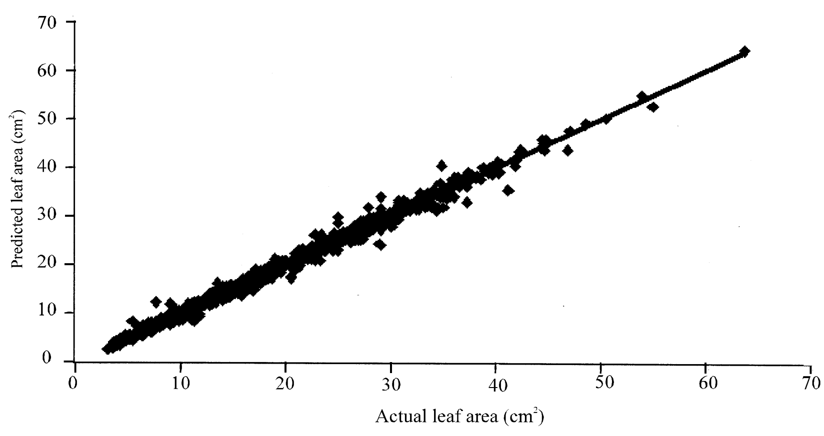

Fig. 2: Relationship between actual leaf area (cm^2) and predicted leaf area (cm^2) in tea

Discussion

Investigations on estimation of leaf area by using leaf length and width are most common (Smith and Kliewer, 1984; Elsner and Jubb, 1988), but some studies also include petiole length (Manivel and Weaver, 1974) and leaf weight (Montero *et al*., 2000). However, regression equations including leaf length and/or width as selected parameters are generally chosen due to their easiness and reliability and because these measurements are non-destructive. Thus, many studies have been carried out to estimate leaf area by linear measurements of leaf width and length in the following plants, soybean (Lieth *et al*., 1986), cucumbers (Robins and Pharr, 1987), orange (Arias *et al*., 1989; Ramkhelawan and Brathwaite 1992), French bean (Rai *et al*., 1990), coconut (Mathes *et al*., 1990), banana (Potdar and Pawar, 1995), Grape (Uzun and Çelik, 1999; Willams and Martinson, 2003), miscanthus (Vargas *et al*., 2002), broad bean (Odabaş 2003), cherry (Demirsoy and Demirsoy, 2003; Pinto *et al*., 2004), peach (Demirsoy *et al*., 2004), strawberry (Demirsoy *et al*., 2005), summer snowflake (Çırak *et al*., 2005a), nettle and lemon balm (Çırak *et al*., 2005b). The same authors found that there were close relationship between leaf area value, leaf length and leaf width for these plants ($R^2 = 0.94$ for soybean, $R^2 = 0.76$ to 0.99 for cucumber, $R^2 = 0.89$ to 0.93 for orange, $R^2 = 0.99$ for French bean, $R^2 = 0.95$ to 0.98 for coconut, $R^2 = 0.96$ for banana, $R^2 = 0.98$ and 0.99 for grapes, $R^2 = 0.91$ for miscanthus, $R^2 = 0.99$ for broad bean, $R^2 = 0.95$ and 0.99 for cherry, $R^2 = 0.99$ for strawberry, $R^2 = 0.99$ for peach, 0.97 for summer snowflake, $R^2 = 0.97$ for nettle and $R^2 = 0.98$ for lemon balm). We found that there was very close relationship between actual and predicted leaf area for cultivars tested and our results were consistent with those of other studies mentioned above that used linear measurements of leaves from different plants for estimating leaf area.

Conclusions

Here, the simple model for predicting leaf area was developed for tea. As the understanding of plant growth and development has been increasing, such mathematical models as this shown in Table 1 will be very useful tools for prediction of leaf area for many plants without using of expensive devices. Because maximum leaf width and length are dimensions that can be easily measured in the field, use of these equations would enable researchers to make non-destructive measurements or repeated measurements on the same leaves. Such equations would also allow researchers to estimate leaf area in relation to factors like crop load, drought stress and insect damage. Therefore, the models produced in the present study can be used safely by tea researchers for the cultivars used in this research. On the other hand, different models can be developed by researches studying on tea cultivars different from those used in the present study.

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