VALIDATION OF AN EMPIRICAL MODEL FOR GRAPEVINE LEAF AREA ESTIMATION WITH DATA FROM THE VARIETIES 'CANNONAU' AND 'VERMENTINO' GROWN IN SARDINIA

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ABSTRACT

The performance of two mathematical models for non-destructive estimation of primary and lateral leaf area per shoot of Tempranillo grapevines was tested in Sardinia using independent datasets from two main traditional varieties. One collected on Cannonau grapevines from Nurra wine region, and another from Vermentino grapevines grown in Gallura wine region. The models presented good fit between observed and estimated values with high modeling efficiency.

For primary leaf area estimation the mean absolute percent error for both varieties was lower than 10%. Both linear regressions between observed and estimated primary leaf area had high and significant R^2 but while Vermentino fitted line presented a slope not significantly different from 1, Cannonau fitted line showed a slope significantly < 1, indicating that the model overestimated the primary leaf area per shoot.

The validation of the model for lateral leaf area presented lower goodness of fit as that reported for primary leaf area. Linear regressions had a very high and significant R^2 but the slopes were significantly <1 indicating that the model overestimated lateral leaf area per shoot.

The positive validation shows that these models can accurately predict leaf area per shoot independently of ecological conditions, variety, year, growth stage and training system. Low goodness of fit for lateral leaf area model may be avoided building the model on each variety data. The generalized use of this type of model represents a powerful tool for grapevine research, for consultants and advanced growers, allowing the evaluate vine leaf area more frequently and with low cost.

Key words: grapevine, leaf area, statistical model, Tempranillo, Cannonau, Vermentino.

1. INTRODUCTION

The knowledge of foliar area, its density and distribution within the canopy is a fundamental basis of viticulture research. It can provide valuable information for characterizing light microclimate and understanding the responses of grapevine to environment, training systems and canopy management strategies (Smart, 1985; Murisier, 1996). Although, monitoring grapevine leaf area is a laborious task.

Different techniques of measuring or estimate leaf area have been proposed and they can be grouped on destructive and non-destructive methods (Mabrouk and Carbonneau, 1996). The use of empirical models for estimating leaf area per shoot is one of the most important non-destructive methods developed recently (Barbagallo *et al*, 1996; Mabrouk and Carbonneau, 1996; Lopes and Pinto, 2005). These models are based on empirical relationships between leaf area and other parameters easily measured on the canopy, without the use of expensive devices. In fact, due to their simplicity empirical models are also a powerful tool for common use.

Lopes and Pinto (2000) developed two accurate and simple models for easily estimate primary and lateral leaf area per shoot. For primary leaf area estimation they included 4 variables: shoot length, number of primary leaves, area of the largest and smaller leaves. The lateral leaf area model considers each lateral shoot as a composed leaf.

Further developments of this approach (Lopes and Pinto, 2005) lead to an improvement of the two models, allowing them to estimate primary and lateral leaf area independently of the vine growth stage. However, in order to test their potential applicability it's necessary to validate the models with independent datasets from other varieties, regions and training systems.

This paper aims to test the performance of the two mathematical models proposed by Lopes and Pinto (2005) for non-destructive estimation of primary and lateral leaf area per shoot of Tempranillo grapevines using independent datasets from two varieties grown in Sardinia.

2. MATERIAL AND METHODS

2.1 Validation datasets

Two datasets were used in the validation tests. The first dataset was collected in ‘Cannonau’ vines from a mechanical hedge pruned vineyard located in Nurra wine region, Alghero, Italy (40º 38’ N; 8º 18’ E). Cannonau vines, grafted on 1103P rootstock, were spaced 2.5 m between rows and 1.0 m along rows, trained to a unilateral cordon 1.2 m height, head-trained and mechanical hedge spur pruned. In 2008, periodically, from 19 June (pea size) till 17 September (ripening) a sample of 20 fruiting shoots was randomly collected, from the internal and external parts of the canopy, inserted into plastic bags and transported to the laboratory. From each shoot, primary leaves and laterals were separated and numbered according to node insertion and the length of the mid, left and right main veins and then the leaf area was measured by a leaf area meter (LI-3100C, LI-COR Biosciences).

The second dataset was collected in a ‘Vermentino’ conventional spur hand pruning vineyard located in Gallura wine region, Berchidda, Italy (40º 49’ N; 9º 17’ E). The Vermentino vines, grafted on 1103P rootstock, were spaced 2.5 m between rows and 1.3 m within the rows, spur hand pruned and trained to vertical trellis and single curtain. The same sampling and measuring procedures described before were followed to calculate individual leaf area of the 20 Vermentino shoots collected, starting in 4 July (pea size) and ending in 28 August (ripening).

These procedures were repeated 4 times for both vineyards in main phenological stages: pea size, bunch closure, veraison and ripening, according to Lopes *et al*. (2004).

2.2 Data analysis and models description

Data were treated separately per variety and separated per category – primary and lateral. For each primary shoot we computed the variables needed for the model (Lopes and Pinto, 2005): sum of primary leaf area (LA_1), number of primary leaves (NL_1), area of the largest primary leaf (L_1), area of the smallest primary leaf (S_1). From these variables two new variables were calculated:

- the mean primary leaf area: $M_1 = (L_1 + S_1)/2$ (1)

- the mean primary leaf area per shoot: $MLA_1 = M_1 * NL_1$ (2)

For lateral leaf area all lateral leaves were grouped into one set of data from which the same type of variables reported for primary leaves were computed per shoot: sum of lateral leaf area (LA_2), number of lateral leaves (NL_2), area of the largest lateral leaf (L_2) and area of the smallest lateral leaf (S_2). A similar approach was used for calculated variables:

- the mean lateral leaf area: $M_2 = (L_2 + S_2)/2$ (3)

- the mean lateral leaf area per shoot: $MLA_2 = M_2 * NL_2$ (4)

The mathematical models used for leaf area estimation were developed by Lopes and Pinto (2005) for Tempranillo grapevines and are represented by the following equations (5 and 6):

$LA_1 = EXP[(0.0835 + 0.992 * \ln(MLA_1)]$ (5)

$LA_2 = EXP[(0.346 + 1.029 * \ln(MLA_2) – 0.125 * \ln(L_2)]$ (6)

For the evaluation of the goodness of fit to the observed data, the following deviance measures were used (Schaeffer, 1980):

- mean absolute error: $MAE = (\Sigma \mid y_i - \hat{y}_i \mid)/n$ (7)

- mean absolute percent error: $MA\%E = 100 [\Sigma (\mid y_i - \hat{y}_i \mid / \mid y_i \mid)]/n$ (8)

where y_i represents the observed values, $\hat{y}_i$ the simulated values and n the number of pairs.

A linear regression analysis of observed *vs*. predicted was performed with the observations taken as independent Y-variable (Mayer and Butler, 1993) and F-tests were conducted for slope=1 and for intercept=0 using SAS®. The modeling efficiency (EF), a dimensionless statistical parameter that relates model predictions to observed data was determined (Loague and Green, 1991).

3 – RESULTS

3.1 – Estimation of primary leaf area per shoot

Figure 1 presents the relationship between observed and estimated values of primary shoot leaf area using equation 5. Visual observation showed a very good agreement between observed and estimate values for the two datasets. The visual appraisal is corroborated by the statistic measures of validation (Table 1).

The mean absolute percent error (MA%E) presented similar values between the two varieties. The linear regression between observed (dependent variable) and estimated (independent variable) shows a very high and significant R^2 for the two datasets, although the fitted lines presented some differences. While the Vermentino fitted line presents an intercept not significantly different from zero and a slope not significantly different from 1, Cannonau fitted line shows either an intercept significantly >0 and a slope significantly <1. Both modeling efficiency values are higher than 0.86, the highest value being obtained on Vermentino dataset.

3.2 – Estimation of lateral leaf area per shoot

Figure 2 presents the relationship between observed and estimated values of lateral shoot leaf area using equation 5. In general the validation of the lateral leaf area model presented lower goodness of fit as that reported for primary leaf area (Fig. 2 and Table 1). The MA%E present higher values than those obtained on the validation of primary leaf area model. Both linear regressions had a very high and significant R^2 but while the intercept of the Vermentino fitted line is not significantly different from zero the intercept of Cannonau fitted line is significantly > 0. Both slopes of the two fitted lines are significantly different from one. Both modeling efficiencies are ≥0.85, the highest value being obtained with the Vermentino dataset.

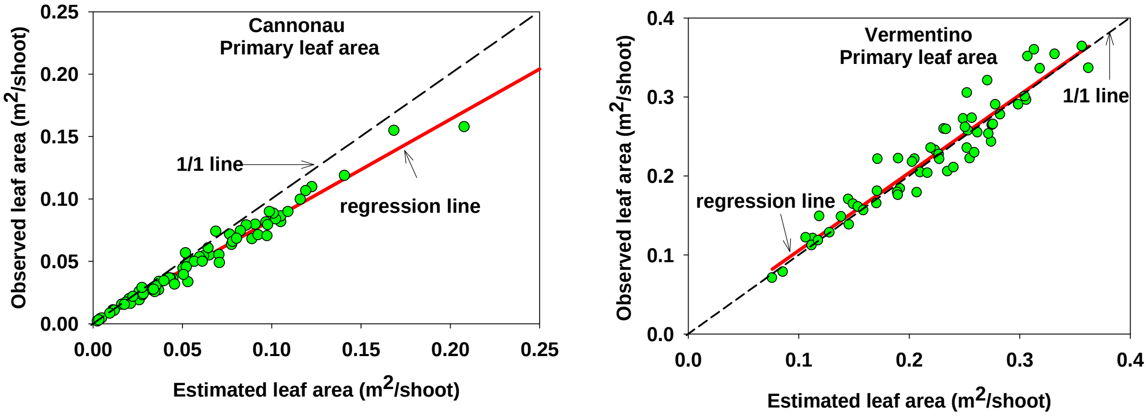

Figure 1. Relationship between observed and estimated values of Cannonau and Vermentino primary shoot leaf area.

Table 1 – Statistical data from the validation of the mathematical models proposed by Lopes and Pinto (2005) (equation 5 and 6) for the estimation of grapevine primary and lateral leaf area per shoot.

Data set	nº shoots	Deviance measures		Linear regression				Modeling efficiency
		MAE	MA%E	R^2	Intercept(1)	Slope(2)	RMSE	
Cannonau primary	79	95.5	7.2	0.89	169.7***	0.91*	117.3	0.86
Cannonau lateral	75	102.5	17.9	0.98	24.9*	0.81***	150.8	0.85
Vermentino primary	60	138.9	7.5	0.91	70.5 ns	0.99 ns	214.2	0.91
Vermentino lateral	57	268.5	17.0	0.96	8.6 ns	0.88***	450.5	0.92

(1) t-test for intercept = 0; (2) t-test for slope = 1; ns - not significant; * and *** $P < 0.05$ and $P < 0.001$ respectively.

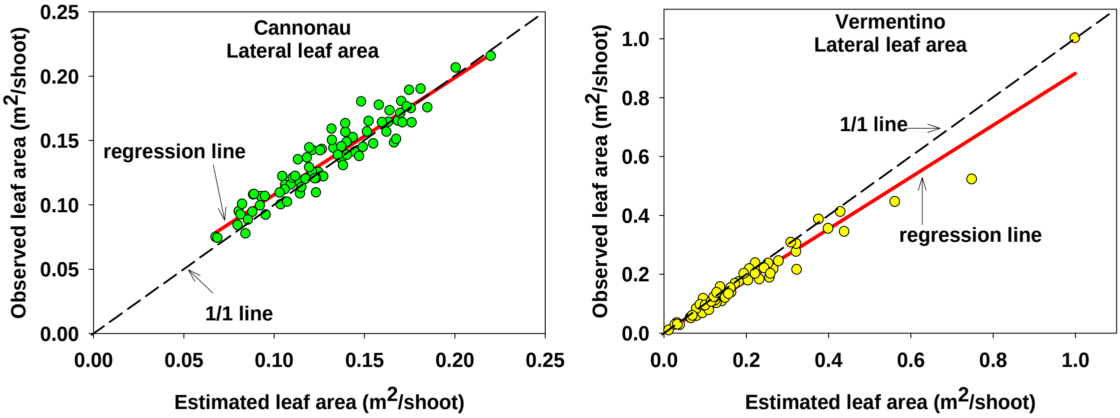

Figure 2. Relationship between observed and estimated values of Cannonau and Vermentino lateral shoot leaf area.

4 – DISCUSSION

Validation of the models showed a very good fit both for primary and lateral leaf area. In both models, the modeling efficiency, an overall measure of goodness of fit for both varieties, was close to 0.90 for principal and lateral models, indicating a very good fit (Mayer and Butler, 1993). However some differences remain in model performance.

In general validation of the primary leaf area model showed a good fit for both the Cannonau and the Vermentino datasets. The mean absolute percent error values were within the limits of acceptability (≤ 10%) (Kleijnen, 1987) and the high modeling efficiency indicate a good level of accuracy (Mayer and Butler, 1993). The higher modeling efficiency of the Vermentino dataset indicates a better fit than for Cannonau. This is corroborated by the fact that the slope of the Cannonau fitted line between observed *vs* estimated was significantly < 1 indicating that the model overestimates the primary leaf area per shoot.

While for the area of primary leaves both datasets presented a MA%E within the limit of acceptability suggested by Kleijnen (1987), for lateral leaf area the MA%E was higher than 10% indicating a lower goodness of fit. The regression analysis between observed and estimate lateral shoot leaf area values also indicate a good fit although both fitting lines have slopes significantly <1 indicating that the model overestimate lateral leaf area by a multiplicative factor.

This positive validation with data from Italian varieties is an important feature for the model. These good validation results, combined with the results of other validations made by Lopes and Pinto (2005) and by Lopes *et al*. (2005) showed that this model can be used to accurately predict primary leaf area per shoot independently of the terroir, variety, year, growth stage and training system. The lower goodness of fit presented by the lateral leaf area model may be avoided if the model would be built on each variety data. The possibility of a generalized use of this type of model represents a powerful tool for grapevine research, and even for consultants and advanced growers allowing them to evaluate vine leaf area more frequently and with low cost.

5 – REFERENCES

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