REVISTA BRASILEIRA DE FRUTICULTURA
Published by the Brazilian Society of Fruit Crops
ISSN 0100-2945

Economy - Scientific Communication- Edited by: Alessandro Dal´Col Lúcio

Mathematical models to estimate leaf area of grapevine varieties Chardonnay, Marselan and Pinot Noir

Sabrina Sautchuk[1]*, Alberto Fontanella Brighenti[1], Tiago Camponogara Tomazetti[1], Thainá Carolina Graciano Votre[1], Jackson Felipe Cardoso[1], Aparecido Lima da Silva[1]

[1] Universidade Federal de Santa Catarina, UFSC - CCA , Florianópolis, SC, Brasil.
*Corresponding author: *sabrinasautchuk@gmail.com*

Abstract: This study aimed to develop mathematical models for estimating leaf area in three grapevine cultivars (‘Chardonnay’, ‘Marselan’, and ‘Pinot Noir’) grown with plastic overhead cover in Santa Catarina, Brazil. Linear measurements of midvein length, left and right secondary veins, and the sum of secondary veins were taken from 200 leaves per variety during the 2020/21 and 2021/22 cycles. Linear regression models were developed using leaf area and midvein length, midvein length squared, sum of secondary veins, and sum of secondary veins squared as predictors. Model performance was evaluated based on Pearson correlation coefficient, root mean square error, bias, and efficiency. The developed models accurately estimate leaf area for the tested grapevine cultivars under plastic cover conditions, with the best-performing model using the sum of secondary veins squared as a predictor variable. These models can be useful for researchers and grapevine growers for estimating leaf area and improving plant growth management.

Index Terms: *Vitis vinifera* L., plastic cover, linear equations, length of veins.

Modelos matemáticos para determinação de área foliar nas variedades Chardonnay, Marselan e Pinot Noir

Resumo: Este trabalho teve como objetivo desenvolver modelos matemáticos para estimar a área foliar de três cultivares de videira (‘Chardonnay’, ‘Marselan’ e ‘Pinot Noir’) cultivadas sob cobertura plástica, em Santa Catarina, Brasil. Medições lineares do comprimento da nervura central, das nervuras secundárias direita e esquerda, e da soma das nervuras secundárias foram feitas em 200 folhas por variedade, durante os ciclos 2020/21 e 2021/22. Modelos de regressão linear foram desenvolvidos usando área foliar e comprimento da nervura central, comprimento da nervura central ao quadrado, soma das nervuras secundárias e soma das nervuras secundárias ao quadrado como preditores. O desempenho do modelo foi avaliado com base no

Rev. Bras. Frutic., v.46, e-957 DOI: *https://dx.doi.org/10.1590/0100-29452024957*
Received 11 May, 2023 ● Accepted 02 Feb, 2024 ● Published May/Jun, 2024. Jaboticabal - SP - Brazil.

coeficiente de correlação de Pearson, erro quadrático médio, viés e eficiência. Os modelos desenvolvidos estimam com precisão a área foliar das cultivares de videira testadas sob condições de cobertura plástica, com o modelo de melhor desempenho, usando a soma das nervuras secundárias ao quadrado como variável preditora. Esses modelos podem ser úteis para pesquisadores e viticultores para estimar a área foliar e melhorar o manejo do crescimento das plantas.

Termos para Indexação: *Vitis vinifera* L., cobertura plástica, equações lineares, comprimento das nervuras.

Leaf area (LA) is a crucial measure for assessing plant growth, photosynthesis, and ecological competition, and determining crop ecosystem productivity, especially in viticulture (BUTTARO et al. 2015, SILVESTRONI et al., 2018). Non-destructive methods for measuring LA are preferred as they reduce variability and do not compromise other LA-dependent parameters (SILVA et al. 2004). Direct methods involve portable LA integrators, but they can be costly and require standard measurement protocols (JUNGES and ANZANELLO, 2021).

Indirect methods use mathematical equations based on leaf blade measurements such as length, width, and vein lengths (DEMIRSOY, 2009; BORGHEZAN et al., 2010; BUTTARO et al., 2015; JUNGES and ANZANELLO, 2021). However, the relationship between veins and LA can vary depending on the species, cultivar, edaphoclimatic conditions, and vine management (JUNGES and ANZANELLO, 2021). Thus, improving the accuracy and efficiency of LA estimation is a critical process for advancing agronomic and ecophysiological research in viticulture (TOMAZETTI, 2020).

To validate leaf area estimation models, statistical errors beyond the correlation between estimated and observed leaf area, such as root mean square error (RMSE), bias, and model efficiency, should be considered (BUTTARO et al., 2015). In vine cultivation under plastic cover, leaves tend to have a larger area due to anatomical transformations compensating for solar restriction, resulting in increased photosynthetic capacity (TAIZ and ZEIGER, 2004; CHAVARRIA et al., 2008; CHAVARRIA et al., 2012). This study aims to develop linear models for the leaf area of Chardonnay, Marselan, and Pinot Noir varieties grown with plastic overhead cover in Santa Catarina.

This study was conducted in an experimental vineyard located in Nova Trento – SC (27°15’34”S, 48°56’54”W, at an altitude of 78 meters). The vineyard is situated in a region with a humid subtropical climate (Köppen-Geiger classification: Cfa), characterized by warm summers and mild winters with no dry season. The soil in this area is predominantly Alic Cambisol Tb A moderate, clayey texture (POTTER et al., 2004). The vineyard was implanted in 2018 using a Y-trellis training system, and plastic cover made of low-density polyethylene (LDPE) plastic film was used to cover the vines. The plastic cover was arranged along the planting line, following a north-south orientation, placed on metallic wires which were over steel arches (tunnels with a height of 1.50m from the vine to the plastic cover and 3m wide).

Leaves were collected from adult plants in the pea-sized berries phenological stage, and 200 leaves longer than 30 mm were randomly selected for each variety and cycle. Leaf area was measured using a portable leaf area meter (ADC BioScientific Ltd – AM300, England) after obtaining measurements of midvein (MV), left and right secondary veins (SV), and sum of secondary veins (SSV) using a millimeter ruler.

Linear models were fitted using ordinary least squares method to adjust the measured leaf area to the variables of midvein (MV), MV^2, sum of secondary veins (SSV), and SSV^2. Models were adjusted with 70% of randomly sampled leaves and the remaining 30% were used for testing them. The models were evaluated based on deviations measures, including angular coefficient, intercept of linear regression between measured (LAo) and estimated (LAe) leaf area, Pearson correlation coefficient (r), root mean square error (RMSE), bias, and model efficiency. Statistical analysis was performed in Python using Scikit-Learn package for linear regression. Specific mathematical models for each variety were proposed based on the data obtained (Table 1), considering genetic variation to reduce deviations (TOMAZETTI, 2020).

Table 1. Parameters of generated models based on linear regression between leaf area (LA) and midvein (MV), midvein squared (MV^2), sum of secondary veins (SSV) and sum of secondary veins squared (SNL^2).

	Model	Angular Coefficient (b)	Intercept (a)	Coefficient of Determination (R^2)
Chardonnay	LA = b MV + a	20.37	-84.50	0.90
	LA = b MV^2 + a	0.97	15.41	0.92
	LA = b SSV + a	13.04	-111.34	0.92
	LA = b SSV^2 + a	0.35	4.02	0.92
Marselan	LA = b MV + a	22.77	-95.28	0.92
	LA = b MV^2 + a	1.02	23.20	0.92
	LA = b SSV + a	14.96	-118.46	0.94
	LA = b SSV^2 + a	0.41	10.45	0.94
Pinot Noir	LA = b MV + a	21.78	-86.67	0.89
	LA = b MV^2 + a	1.06	19.58	0.91
	LA = b SSV + a	13.19	-96.83	0.90
	LA = b SSV^2 + a	0.37	14.36	0.92

The table 1 shows the models constructed with squared variable values presenting angular coefficients (b) closer to one. For ‘Chardonnay’, SSV^2 and MV^2 values were 0.35 and 0.97, respectively, for ‘Marselan’, the values were 0.41 and 1.02, and for ‘Pinot Noir’, the values were 0.37 and 1.06. The intercept (a) values closest to zero were observed in the models obtained from the SSV^2 measure for all varieties, with values of 4.02 for ‘Chardonnay’, 10.45 for ‘Marselan’, and 14.36 for ‘Pinot Noir’. The coefficient of determination (R^2) was highest for ‘Chardonnay’ (0.92) with MV^2, SSV, and SSV^2 measures, for ‘Marselan’ with SSV and SSV^2 measures (0.94), and for ‘Pinot Noir’ with SSV^2 measure (0.92). A higher R^2 value indicates greater data proximity to the model estimate.

The table 2 summarizes the statistical analysis of the models. The Pearson correlation coefficient showed a positive association between leaf area and leaf measures, with SSV2 showing the highest correlation for ‘Chardonnay’, SSV and SSV^2 for ‘Marselan’, and MV, MV^2, and SSV^2 for ‘Pinot Noir’. The RMSE values were lowest for SSV^2 for all varieties, with values ranging from 15.47 to 16.80 for ‘Chardonnay’, 16.67 for ‘Marselan’, and 16.06 to 16.08 for ‘Pinot Noir’. Pearson correlation coefficient measures the linear association between two variables, while RMSE expresses the deviation between the model and actual results (CASTILLO et al., 2005).

Models for ‘Chardonnay’ showed the lowest bias with SSV (-0.45%) and SSV^2

(-0.58%), while for 'Marselan', models from MV^2 and MV resulted in the lowest bias. For 'Pinot Noir', the models from MV^2 and SSV^2 showed the smallest biases. The highest accuracy was observed in the models obtained through SSV and SSV^2 for 'Chardonnay', MV and MV^2 for 'Marselan', and MV^2 and SSV^2 for 'Pinot Noir'. The highest efficiency was observed in the models generated with SSV^2 for 'Chardonnay', SSV and SSV^2 for 'Marselan', and MV, SSV, and SSV^2 for 'Pinot Noir'.

Table 2. Models for estimating leaf area of Chardonnay, Marselan and Pinot Noir obtained by simple linear regression using the measure of midvein length (MV) and sum of secondary veins (SSV). Precision was determined by correlation coefficient (r) and root mean square error (RMSE), accuracy was determined by bias (BIAS), robustness was determined by angular coefficient and model efficiency. Statistics were obtained from model validation, comparing estimated and observed leaf area.

	Model	Pearson Correlation Coefficient (r)	RMSE (cm^2)	BIAS (%)	Model Efficiency
Chardonnay	LA = 20.37 MV – 84.50	0.96	18.42	2.56	0.91
	LA = 0.97 MV^2 + 15.41	0.96	16.47	1.42	0.93
	LA = 13.04 SSV – 111.34	0.96	16.80	-0.45	0.92
	LA = 0.35 SSV^2 + 4.02	0.97	15.47	-0.58	0.94
Marselan	LA = 22.77 MV – 95.28	0.96	18.34	0.24	0.92
	LA = 1.02 MV^2 + 23.20	0.96	18.01	-0.15	0.92
	LA = 14.96 SSV – 118.46	0.97	17.53	0.40	0.93
	LA = 0.41 SSV^2 + 10.45	0.97	16.67	1.99	0.93
Pinot Noir	LA = 21.78 MV – 86.67	0.95	16.92	-2.31	0.95
	LA = 1.06 MV^2 + 19.58	0.95	16.08	0.46	0.95
	LA = 13.19 SSV – 96.83	0.94	17.54	-1.41	0.94
	LA = 0.37 SSV^2 + 14.36	0.95	16.06	-0.93	0.95

The best mathematical models for estimating leaf area in the studied varieties were obtained from the SSV^2 measurement, as demonstrated in Figure 1. This non-destructive method using secondary veins shows promise, although some authors prefer models requiring only the measurement of a single vein, such as the midvein, due to their practicality and ease of measurement in the field (BORGHEZAN et al. 2010; BUTTARO et al. 2015; JUNGES and ANZANELLO, 2021).

Furthermore, the selection of a model requires balancing the predictive qualities of the model while including a minimum number of variables needed to estimate leaf area (BUTTARO et al. 2015). In this work, we chose to adopt secondary veins because the generated models had greater accuracy and precision.

Furthermore, to maintain high levels of precision and accuracy, it was decided to create a model for each variety. It is known that the different varieties of the species *Vitis vinifera* have very diverse leaf morphology, which allows, for example, the recognition of varietal groups in ampelography studies (CARBONNEAU, 1976). Thus, in some cases the equations defined to establish the leaf area for a given variety can be used to estimate the leaf area of others, however not all models may be appropriate when a greater degree of precision is desired (TSIALTAS et al, 2008). In this way, the establishment of equations for each varietal group is a necessary step to promote precision and accuracy (BORGHEZAN et al., 2010).

The evaluation of leaf area in plants in the field can be performed easily and quickly by measuring the length of leaf veins. The leaf area obtained through the proposed mathematical models presents a high correlation between the estimated leaf area and the observed leaf area, with high accuracy and precision.

It is recommended to use the SSV to estimate the leaf area through the equation LA = 0.35 SSV^2 + 4.02 for Chardonnay; LA = 0.41 SSV^2 + 10.45 for Marselan; LA = 0.37 SSV^2 + 14.36 for Pinot Noir.

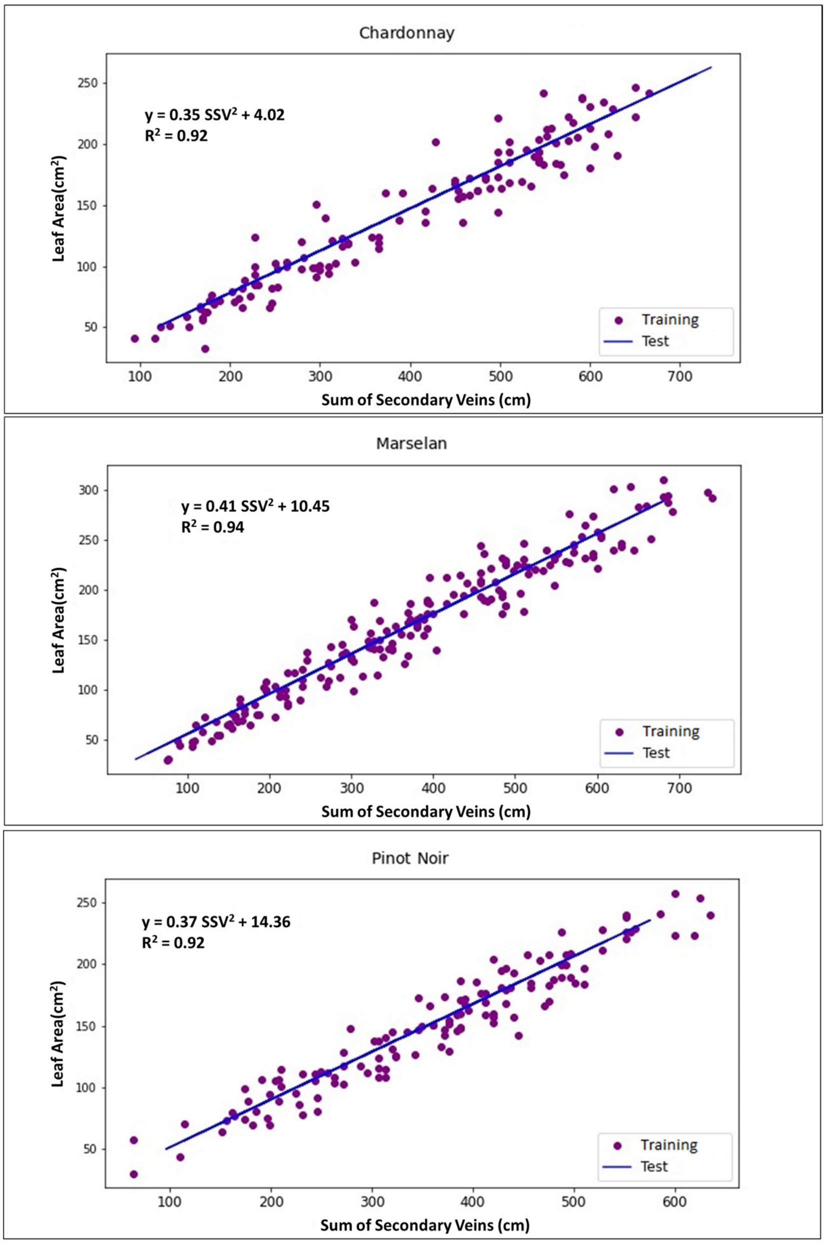

Figure 1 - Linear models selected to estimate the leaf area of Chardonnay, Marselan and Pinot Noir. Training data highlighted in purple, trend line constructed with test data.

References

BORGHEZAN, M.; GAVIOLI, O.; PIT, F.A.; SILVA, A.L. Modelos matemáticos para a estimativa da área foliar de variedades de videira a campo (*Vitis vinifera* L.). **Ciência e Técnica Vitivinícola**, Dois Portos, v.25, n.1, p.1-7, 2010.

BUTTARO, D.; ROUPHAEL, Y.; RIVERA, C.M.; COLLA, G.; GONNELLA, M. Simple and accurate allometric model for leaf area estimation in *Vitis vinifera* L. genotypes. **Photosynthetica**, Dordrecht, v.53, n.3, p.342-8, 2015.

CASTILLO, E.; IGLESIAS, A.; RUÍZ-COBO, R. **Functional equations in applied sciences**. Amsterdam: Elsevier Science, 2005. 729 p.

CARBONNEAU, A. Principles et methodes de mesure de la surface foliari. Essai de caracterizacion des types de feviles dans le genre Vitis. **Annales de Amelioration des Plantes**, Paris, v.28, n.2, p. 327-43, 1976.

CHAVARRIA, G.; SANTOS, H. P.; FELIPPETO, J.; MARODIN, G. A. B.; BERGAMASCHI, H.; CARDOSO, L. S.; FIALHO, F. B. Relações hídricas e trocas gasosas em vinhedo sob cobertura plástica. **Revista Brasileira de Fruticultura**, Jaboticabal, v.30, n.4, p.1022-9, 2008.

CHAVARRIA, G.; SANTOS, H.P.; CASTRO, L.A.S.; MARODIN, G.A.B.; BERGAMASCHI, H. Anatomy, chlorophyll content and photosynthetic potential in grapevine leaves under plastic cover. **Revista Brasileira de Fruticultura**, Jaboticabal, v.34, n.3, p.661-8, 2012.

DEMIRSOY, H. Leaf area estimation in some species of fruit tree by using models as a non-destructive method. **Fruits**, Paris, v.64, n.1, p.45-51, 2009.

JUNGES, A.H.; ANZANELLO, R. Non-destructive simple model to estimate the leaf area through midvein in cultivars of *Vitis vinifera.* **Revista Brasileira de Fruticultura,** Jaboticabal, v.43, n.5, 2021.

POTTER, R. O.; CARVALHO, A. P. de; FLORES, C. A.; BOGNOLA, I. **Solos do estado de Santa Catarina**. Rio de Janeiro: Embrapa Solos, 2004. 721 p. (Boletim de Pesquisa e Desenvolvimento, 46).

SILVA, P.S.L; BARBIN, D.; GONÇALVES, R.J.S.; FIRMINO, J.D.C.; FONSECA, I.C. Leaf area estimates of custard apple tree progenies. **Revista Brasileira de Fruticultura**, Jaboticabal, v.26, n.3, p.558-60, 2004.

SILVESTRONI, O.; LANARI, V.; LATTANZI, T.; PALLIOTTI, A. Delaying winter pruning, after pre-pruning, alters budburst, leaf area, photosynthesis, yield and berry composition in Sangiovese (*Vitis vinifera* L.). **Australian Journal of Grape and Wine Research**, Adelaide, v.24, n.4, p. 478-86, 2018.

TAIZ, L.; ZEIGER, E. **Fisiologia vegetal.** 3.ed. Porto Alegre: Artmed, 2004.

TOMAZETTI, T.C. **Piramidação de genes da Videira (*Vitis vinifera*) para resistência ao Mildio (*Plasmopara viticola*) e caracterização das interações genótipos e ambiente**. 2020. Tese (Doutorado) - Universidade Federal de Santa Catarina, Florianópolis, 2020.

TSIALTAS, J.T.; KOUNDOURAS, S.; ZIOZIOU, E. Leaf area estimation by simple measurements and evaluation of leaf area prediction models in Cabernet-Sauvignon grapevine leaves. **Photosynthetica**, Dordrecht, v.46, n.3, p. 452-6, 2008.