ESTUDIO PARA LA DETERMINACIÓN DEL ÁREA FOLIAR EN ESPECIES ARBUSTIVAS

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SUMMARY

Given the interest and importance of the leaf area, it is necessary that simple and efficient methods to determine it should be found. With this aim, several measures have been obtained from 210 leaves of each of the following species *Arbutus unedo L.*, *Pistacia lentiscus L.*, *Myrtus communis L.*, *Cistus ladanifer L.*, and *Cistus albidus L.* From these measures the leaf area has been determined by three different procedures: firstly, by the application of the formula S= K x length x width; secondly, by studying the simple correlation with only one independent variable, and, finally, by the study of multiple correlation. The introduction of a specific coefficient (K_e) as an additional independent variable has been observed to improve the correlation coefficient more than any other independent variable. On the other hand, in spite of improving the fitting, multiple regression equations do not seem suitable for the determination of the leaf area.

Key words: leaf area, shrubby, *Arbutus unedo L.*, *Pistacia Lentiscus L.*, *Myrtus communis L.*, *Cistus ladanifer L.*, *Cistus albidus L.*

RESUMEN

Se han medido 210 hojas de cada una de las siguientes especies arbustivas: *Arbutus unedo L.*, *Pistacia Lentiscus L.*, *Myrtus communis L.*, *Cistus ladanifer L.*, *Cistus albidus L.* A partir de estos valores se ha determinado el área foliar por medio de tres procedimientos diferentes. En primer lugar mediante la aplicación de la fórmula S = K x longitud x anchura; en segundo lugar mediante el estudio de una correlación simple con una sola variable independiente y, finalmente, por el estudio de una correlación múltiple. Se ha observado que la introducción de un coeficiente específico (K_e) como una variable independiente adicional mejora el coeficiente de correlación más que cualquier otra variable. Por otra parte, la utilización de ecuaciones de regresión múltiple no paracen adecuadas para la determinación del áea foliar a pesar de la mejora producida en el ajuste de la ecuación.

Palabras clave: Area foliar, arbusto, *Arbutus unedo L.*, *Pistacia Lentiscus L.*, *Myrtus communis L.*, *Cistus ladanifer L.*, *Cistus albidus L.*

INTRODUCTION

The importance of knowing the nutritive and productive potential of some shrubby and tree species requires efficient, simple and fast methods to determine the leaf area.

Besides being a parameter for the biological description of the sample, the leaf area reveals the photosynthetic capacity of the plant (NDAWUCKLA-SENYIMBA, 1972), and it is closely related to the accumulation of dry matter, metabolism, production, as well as to the ripening and quality of the crop. Its usefulness in the quantification both of the effect in phytopathological processes (ORENSANZ GARCÍA and SASOT BAYONA, 1981) and of the surface exposed to herbicides (KRAATZ and ANDERSEN, 1980) is also noteworthy.

In considering the selection of the most suitable method to determine the leaf area, many authors point out the planimeter as the instrument *par excellence* and it is thus used as a point of reference to compare other methods for measuring leaf areas (ORENSANZ GARCÍA and SASOT BAYONA, 1981; PODESTA, 1981). However, as SHIH (1976) notes, its efficiency depends on the operator's ability. The point planimeter (HEINECKE, 1963), with several variants, is also widely used, though it is not a suitable instrument for measuring very irregular surfaces.

A different approach is the use of indirect methods of prediction, such as the estimation of the dry weight in a number of leaves and the posterior application of regression equations (WALLACE and MUNGER, 1965), or the lineal measurements of the leaves —length and width— (MILTHORPE, 1956) and the subsequent application of different equations to measure the leaf area (STICKLER et al., 1961; ASHLEY et al., 1963; MILTHORPE, 1966; PANALISWAMY and GÓMEZ, 1974). From these considerations we can come to the the conclusion that the leaf area can be determined from one or two main dimensions of the leaf.

MATERIAL AND METHODS

The measurements have been carried out in 210 leaves from five shrubby species (*Arbutus unedo L.*, *Pistacia Lentiscus L.*, *Myrtus communis L.*, *Cistus ladanifer L.*, and *Cistus albidus L.*) selected for their nutritional value for both domestic and wild animals (ZAMORA et al., 1972; RODRÍGUEZ, 1975; SÁNCHEZ, 1988; GÓMEZ et al., 1987).

Due to the similarity of size and physiological function, the leaflets of *P. lentiscus* are considered as simple leaves; a criterium which was already used by DOLPH (1977). The leaves, entirely unfolded, were collected ramdomly provided they showed their complete surface and a healthy appearance. The sample collection was carried out at the end of the winter in the mountain area north of Córdoba (Spain).

The leaves were immediately weighed, and their lenght (X_1), width (X_2) —on graph paper—, and thickness (K_4) —up to 0.05 mm.— were measured. The leaf area was also determined following the «photocopy method» proposed by GÓMEZ (1985). The leaves were then dessicated by oven-drying at 70 °C for 48 hours and weighed again to determine the leaf specific weight (X_9) —specific weight/leaf surface—, according to the method of BARNES and RADCLIFFE (1967). Furthermore, the division of the leaf area by the product of width and length allows the obtention of the coefficient initially calculated by WATSON et al. (1958) as a correction factor (K_s) for transforming the product of dimensions (width x length) into leaf area.

A statistical description of the results, a study of the simple and multiple correlations, and a fitting of the linear regression, potential, exponential and logarithmic equations were carried out both globally and for each species. Finally, variance analysis was used in the comparative study of the species.

RESULTS AND DISCUSSION

The calculation of the lef area is undertaken in this work by following three different procedures: firstly, by the application of the formula S= K x length x width; secondly, by studying the simple correlation with only one independent variable, and, finally, by the study of the multiple correlation.

1. Application of the global and specific coefficient

By the application of the formula,

S= K x length x width

where,

K= S/ length x width

The analysis of this formula, both in its aplication to the whole of the species (K_g), and to each specific one (K_s) has been the objec of many researchers, since in its constancy lies the possibility of determining the leaf area from two measures very easy to be obtained. However, all those efforts, supported by the results of this work (Table 1), emphasize the high variability of these coefficients, and, thus, question its generalized application.

From the correlation established between the coefficient K and the rest of the variables for species (Table 2), we can conclude that only in *A.unedo* there exists a general dependence of this coefficient on the various size or morphological indicators of the leaves. On the contrary, in *C. ladanifer* and *P. lentiscus* the coefficient varies significantly when any of the variables considered —except for the coefficient length/width— varies. In *C.albidus* and *M.*

TABLE 1

Correlation coefficient of the best regression fitting between the coefficient k and the remaing variables of the leaves of the species studied

Variables	Global sample		Arbutus unedo		Pistacia lentiscus		Myrtus communis		Cistus ladanifer		Cistus albidus	
Length	-0.053 NS	L	-0.063 NS	L	0.190 **	E	-0.652 ***	E	-0.408 ***	E	-0.169 *	L
Width	-0.164 *	E	-0.039 NS	L	0.165 *	E	-0.623 ***	E	-0.478 ***	E	-0.240***	L
Length/width	0.205 **	E	-0.094 NS	L	0.041 NS	L	0.166 *	L	0.036 NS	L	0.188**	L_0
Thickness	0.035 NS	L_0	0.091 NS	P	0.211**	E	-0.122 NS	L	-0.376 ***	L	0.012 NS	P
Leaf area	-0.050 NS	L	0.113 NS	P	0.379 ***	E	-0.538 ***	E	-0.342 ***	E	-0.163*	L
Fresh weigth	-0.087 NS	L	0.077 NS	P	0.276 ***	E	-0.482 ***	E	-0.412 ***	E	-0.206**	L
Dry weigth	-0.199 **	E	0.093 NS	P	0.275 ***	E	-0.486 ***	E	-0.417 ***	E	-0.211**	L
Specific weigth	-0.354 ***	E	-0.069 NS	P	-0.134 NS	E	-0.087 NS	E	-0.513 ***	L	-0.105 NS	L

Note: L= Lineal fitting; L_0 = Logaritmic fitting; E=Exponential fitting; P = Potential fitting.

Level of significance: (*)=p<0.05; (**)=p<0.01; (***)=p<0.001; NS = non significant.

TABLE 2

Values of the real surface (S), determined of the specific (K_s) and the general (K_g) correlation coefficients, and the percentage desviation from the real surface for each of the species studied

Species	S	K_s	S (K_s)	dS (K_s) p.100	S (Kg)	dS (Ke) p.100
Arbutus unedo	11.271	0.705	11.312	+0.36	11.985	+6.34
Pistacia lentiscus	2.041	0.705	2.034	-0.34	2.155	+5.59
Myrtus communis	2.222	0.758	2.270	+2.16	2.237	+0.68
Cistus ladanifer	4.280	0.769	4.395	+2.69	4.269	-0.26
Cistus albidus	8.254	0.799	8.334	+0.97	7.792	-5.60

communis the only independent variables are the specific weight and the thickness.

The surface correction coefficient does not vary significantly with the leaf size in *A. unedo*, but it increases the bigger the leaflets of *P. lentiscus* are, and diminishes the smaller the leaves of the remaining species are, specially in the cases of *M. communis* and *C. ladanifer*.

Table 2 shows the mean, real and estimated values (specific and general coefficients) for the leaf area of the five species. The specific correction coefficient or the global coefficient have been used for transforming the length and width parameters. There is an acceptable approximation among the three values, and the differences are not statistically significant.

In using the general coefficient, the highest deviations are found in *A. unedo*, *P. lentiscus*, and *C. albidus*. In the remaining species the general coefficient behaves better than the specific coefficient, possibly due to a greater dependence of K^s on the leaf size.

These results show, according to DOLPH (1977), the advisability of determining the leaf area by the product of the greatest diameters of the leaf and the appropriate correction coefficient for each species, specially in those studies having a great number of samples.

2. Study of the simple correlation with only one independent variable

The variables considered in the prediction of the leaf area are: length (X_1), width (X_2), thickness (X_4), fresh weight (X_6), and dry weight (X_7).

From the analysis of Table 3 it follows that thickness does show a significant correlation in each one of the species —although not at the level of the whole sample—. In these cases thickness may account for from 25% to 32% of the variation in the leaf area; unimportant values that reduce its interest as a leaf area estimator, not to mention the difficulty in obtaining regular measures. The rest of the variables show high correlation coefficients, both at global and specific levels. Variations in lenght and width account for at least 88% of the variation registered in the leaf area when the whole of the species is considered. These values increase up to 94% when specific regression equations are applied (*A. unedo* and *C. albidus*).

Leaf weight (fresh or dessicated) also shows a high correlation with the leaf area when the whole of the species is considered, though these values of r are inferior to the ones obtained by the variables lenght and width. In some instances

TABLE 3

Correlation coefficient of the best regression fitting between the leaf area and the remaing variables of the leaves of the species studied

Variables	Global sample	Arbutus unedo	Pistacia lentiscus	Myrtus communis	Cistus ladanifer	Cistus albidus
Length	0.941*** P	0.957 *** P	0.920 *** P	0.948 *** P	0.956 *** P	0.970 ***P
Width	0.945*** L	0.970 *** P	0.917 *** P	0.966 *** P	0.929 *** P	0.967*** P
Length/width	-0.221 ** E	-0.343*** L_0	-0.040^{NS} L	-0.363 *** L_0	0.230*** P	-0.130^{NS} L_0
Thickness	-0.119^{NS} L	0.349*** P	0.504*** P	0.181 ** P	0.447 *** P	0.410*** P
Leaf area	0.912 *** P	0.925 *** P	0.854 *** P	0.940 *** P	0.983 *** P	0.957 ***P
Fresh weigth	0.853 *** P	0.908 *** P	0.827 *** P	0.933 *** P	0.976 *** P	0.922*** P
Dry weigth	0.050^{NS} L	0.113^{NS} P	0.379 *** L_0	0.504 *** E	-0.342*** L_0	-0.163* L
Specific weigth	0.331 *** P	0.488 *** L	0.199 ** E	0.205 ** P	0.602 *** L	0.120^{NS} P

Note: L= Lineal fitting; L_0 = Logaritmic fitting; E=Exponential fitting; P = Potential fitting.
Level of significance: (*)=p<0.05; (**)=p<0.01; (***)=p<0.001; NS = non significant.

TABLE 4

Values of the real surface (S), determined of the global regression equation, at legth S (Lg), width S (Wg), fresh weigth S (FW_g), dry weigth S (DW_g) for each of the species studied

Species	S	S (Lg),	S(Wg),	S(FW_g),	S(DW_g)
Arbutus unedo	11.271 ^{NS}	8.900 ***	12.264 ^{NS}	8.641***	9.480 **
Pistacia lentiscus	2.041 ^{NS}	2.078 ^{NS}	2.455 ***	2.768 ***	3.158 ***
Myrtus communis	2.222 ^{NS}	2.118 ^{NS}	2.560 **	1.891 ***	2.240^{NS}
Cistus ladanifer	4.280 ^{NS}	6.708 ***	2.699 ***	6.345 ***	5.913 ***
Cistus albidus	8.254 ^{NS}	6.865 *	8.070 ^{NS}	6.179 ***	4.452 ***

Note: Level of significance: (*)=p<0.05; (**)=p<0.01; (***)=p<0.001; NS = non significant.

the fitting improves at the specific level, even surpassing the values of length and width, though, in general, the prediction established from the weight seems to be poorer. In any case, the correlation coefficients obtained, both at global and specific levels, permit a satisfactory prediction of the leaf area.

To observe their relative efficiency as predictors, the values of the leaf area obtained by using the best fitting regression equations are compared —by means of the test T— to the values of the real leaf area.

As Table 4 shows, in most cases the values obtained are significantly different from the real ones; a satisfactory determination of the leaf area by applying a global equation being only obtained in some species, an afact that, obviously, casts discredit on the method. *C. ladanifer* and *A. unedo* show the poorest response to the application of global formulas.

From the study of Table 5 it follows that the measures of length and width used in the regression equation are the most appropriate for determining the leaf area. However, the fresh

TABLE 5
Lineal multiple correlation coefficient obtained from different combinations of variables and leaf area for each of the species studied

Variables	Arbutus unedo	Pistacia lentiscus	Myrtus communis	Cistus ladanifer	Cistus albidus
X_1, X_2	0.97626	0.97172	0.98264	0.93337	0.97424
X_1, X_2, X_4	0.97724	0.97172	0.98271	0.97418	0.97425
X_1, X_2, X_8	0.97976	0.98994	0.99491	0.98624	0.97514
X_1, X_2, X_9	0.97679	0.97237	0.98270	0.97393	0.97473
X_1, X_2, X_4, X_6	0.97892	0.97268	0.98807	0.98696	0.98074
X_1, X_2, X_4, X_7	0.97857	0.97260	0.98565	0.98841	0.97676
X_1, X_2, X_4, X_8	0.98113	0.99033	0.99494	0.98624	0.97517
X_1, X_2, X_4, X_9	0.97737	0.97240	0.98274	0.97433	0.97477
X_1, X_2, X_4, X_6, X_7	0.97893	0.97268	0.98840	0.98847	0.98273
X_1, X_2, X_4, X_6, X_8	0.98191	0.99043	0.99558	0.99311	0.98207
X_1, X_2, X_4, X_6, X_9	0.98130	0.98064	0.99242	0.99167	0.98771

Note: X_1,= length; X_2 = width; X_4 = thickness; X_6,= fresh weigth; X_7 = dry weigth; $X_8 = K_S$; X_9 = specific weigth.

weight must be considered as an independent variable in predicting leaf area, since even having slightly higher deviations it shows the particularity (extendable to dry weight) that it can be measured together and simultaneously in all the leaves that constitute the sample. In agreement with WATSON et al. (1958), and with EASTIN and GRITTON (1969), this fact opens an important field of research in the determination of the leaf area index, not only for woody plants (MARTÍNEZ et al., 1987), but also for herbaceous formations.

3. Study of the multiple correlation

This study is carried out by applying the lineal multiple correlation (R) to groups of two, three, four and five variables, including lenght (X_1), width (X_2), thickness (X_4), fresh weight (X_6), dry weight (X_7), K_s specific coefficient (X_8), and leaf specific weight (X_9). This procedure leads to a high statistically significant determination of the leaf area ($p<.001$) (Table 5). The minimun value found for the prediction of the leaf area from the variables length and width in *P. lentiscus* is 0.971, and the maximun value amounts to 0.996 when a combination of five variables (namely, X_1, X_2, X_4, X_6, X_8) is carried out in *M. communis*.

In comparing these data with the ones obtained from the simple correlation coefficients (Table 3) it can be concluded that the inclusion of an additional variable in the width, length or fresh weight (which are the simple variables with the higher correlation with the leaf area) leads to a slight increase in the values of the correlation coefficient of the species considered, except for *C. ladanifer*, where the correlation of the leaf area with the fresh weight is higher than that obtained for the combination of the variables length and width.

On the other hand, when a new independent variable is added to any of the equations, a better fitting is always obtained in the five species, though the increase obtained by increasing the number of variables is quite small, since, at best, the value of r for a variable increases 0.07 when five independent variables are used, a fact which, apparently, would never justify its use.

From the study of Table 5 the higher suitability of some of the independent variables in determining the leaf area can be inferred. Among the simple variables, length and width are remarkable, in fact, their combined consideration does always permit to increase the value of r found for the best simple fitting. For combinations of a higher number of variables, the introduction of K_s permits a better fitting of the leaf area in *A. unedo*, *P. lentiscus* and *M. communis*. For the two species of the genus Cistus, the fresh (X_6) and dry (X_7) weights improve the fitting when the number of variables increases. In *C. albidus* and *C. ladanifer*, the global coefficient, although significant, shares with other variables (specially, the fresh and dry weights) the improvements achieved with the fitting when the number of variables is increased.

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