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Analysis of leaf area in black wattle throughout its plantation cycle

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Leaf area is one of the most important biophysical characteristics of a plant, as it determines how much photosynthetic radiation is intercepted so that the photosynthesis can occur. The presented research aim was to generate numerical indicators of leaf area and to study the behavior of black wattle *(Acacia mearnsii* De Wild.) throughout a plantation cycle (7 years), relating them with environmental variables. The study was conducted in commercial stands located in agroecological regions with high densities of black wattle plantations in the state of Rio Grande do Sul, Brazil. The leaf area was obtained by measuring leaf biomass and leaf area with an integrator (3000 Canopy Analyser, *Li-Cor).* Leaf area was found to be strongly related to leaf biomass, and is not influenced by planting site, but rather by stand age. Values of individual leaf area vary depending on stand age and plantation area. The leaf area is related to soil properties and particularly with the phosphorus content. It is also related to meteorological conditions, most notably accumulated solar radiation. The obtained model, which involves global accumulated solar radiation, phosphorus and clay content, adequately explain variations in leaf area.

Key words: Global solar radiation, phosphorus, leaf biomass, black wattle, plantation cycle.

INTRODUCTION

Black wattle (*Acacia mearnsii* De Wild.) is a commonly occurring tree species today in the state of Rio Grande do Sul, and stands of the species rank among the most widely planted in the region behind the genera *Eucalyptus* and *Pinus*. According to Simon (2005) black wattle is the primary source of bark for the global plant-based tannin industry, used mostly in leather tanning. The high-quality wood from the species is ideal for pulp

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and paper production, and most of the wood is consumed in these industries. Cultivation of the species currently benefits nearly 40 thousand families and thus plays an important socioeconomic role (Stein and Tonietto, 1997).

Leaf area is a variable indicator of productivity because plant growth (when soil nutrition, water availability and temperature are not limiting factors) depends on the amount of photosynthetically active radiation intercepted and the utilization efficiency of this energy during photosynthesis for biomass production (Monteith, 1977). Thus, leaf area is one of the most important biophysical characteristics of the plant since it determines how much light energy is intercepted so that the photosynthesis can occur. It is therefore related to growth and yield (Linhares et al., 2000; Xavier and Vettorazzi, 2003).

Although the recognized importance of leaf area as indicator of stands productivity, few studies have been developed regarding the environmental factors influencing this variable and even its behavior throughout the plantation cycle. Generating numerical indicators of leaf area with the purpose to address these points will allow further studies to be conducted relating leaf area to yield (either in timber, volume or biomass) of certain species. Thus, the present study sought to analyze leaf area in stands of black wattle *(Acacia mearnsii* De Wild.) for the duration of the plantation cycle; and with the following hypothesis to be tested: Leaf area in plantations of black wattle can be evaluated as a function of the climatic and soil variables.

MATERIALS AND METHODS

This study was conducted using data from temporary plots in commercial plantations of black wattle in the municipalities of Cristal and Piratini, Rio Grande do Sul, Brazil, where the species is planted at high concentrations. In each municipality stands were studied in an age sequence: one, three, five and seven years. In the municipality of Cristal, central coordinates of stands are located at 30° 55' S and 52° 10' W. In Piratini central coordinates of stands are located at 31° 24' S and 52° 57' W. Plantings were spaced in a 3 × 1.75 m configuration (1,904 plants per hectare) for year one and 3 × 1.5 m for all other ages (2,222 plants per hectare).

In each stand a North-facing slope was selected where one plot was demarcated in the each of the upper, middle and bottom thirds of the slope. The size of the plots was 9 × 16 m for the forest stands one-year old and 9 × 14 m for all other ages, making four rows of 10 plants in each row. In each of the plots the circumferences at breast height (1.3 m) of all trees were measured using a graduated metric tape, and two average trees with respect to this variable in each plot were selected for evaluation of leaf biomass and leaf area.

Leaf biomass was analyzed by separating it from the other compartments (stem, branches and flowers + fruits) and then determining its wet weight on a digital scale (Portable Electronic Scale) with accuracy to 0.5 g. To determine the dry weight, 200 g samples were removed and immediately weighed to determine the wet weight. These samples were then dried in a mechanical convection oven at 75°C to constant weight and the material was weighed again to obtain the moisture content and, consequently, the dry weight of the leaves by the expression:

$$\mathrm{DWL} = \frac{\mathrm{WWL} * \mathrm{DW_S}}{\mathrm{WW_S}} \quad (1)$$

Where: DWL = dry weight of leaves, in kg; WWL = wet weight of leaves, in kg; DW_s = dry weight of the sample in kg. WW_S = wet weight of sample, in kg.

In this study, leaf area was preferred instead of leaf area index for its simplicity and easy applicability in the analysis performed. To determine leaf area three samples of 50 g each were taken from the tree canopy. The leaflets were separated from the petiole and rachis and spread flat using an ironing board heated to 65°C. Leaf area was then determined using an integrator (3000 *Canopy Analyser Li-Cor).* At the end of the process, all material (petiole, rachis and leaflets) was dried in a mechanical convection oven at 65°C to constant mass and weighed on an analytical balance. Thus, the plant leaf area was calculated by the expression:

$$\mathrm{LA} = \frac{\mathrm{LDW} * \mathrm{LA_S}}{\mathrm{DW_S}} \quad (2)$$

Where: LA = leaf area in m²; LDW = total dry weight of the leaves, in kg; LA_s = leaf area of the sample, in m²; DW_s = dry weight of the sample, in kg;

Additionally, an evaluation of the chemical characteristics of the soil surface horizon (0-20 cm) was conducted in the plots. To this end, three samples were collected in each plot using an auger which was then combined to yield a single mixed sample for the stand. Samples were sent to the Soil and Plant Tissues Analysis Laboratory of the Universidade Regional Integrada do Alto-Uruguai e das Missões in the municipality of Frederico Westphalen, Rio Grande do Sul, to determine the following variables: pH (potential Hydrogen), SMP Index (SMPI) (Shoemaker, Mac lean and Pratt Index), clay (Arg), organic matter (OM), phosphorus (P), potassium (K), aluminum (Al), calcium (Ca), magnesium (Mg), calcium + aluminum, CEC at pH 7, CEC base saturation and CEC aluminum saturation.

The meteorological data used were: Maximum, minimum and mean air temperature, relative air humidity, rainfall and hours of sunshine were obtained at the INMET (National Institute of Meteorology) of the Climatological Station of Pelotas. This was the station closest to the study site when the research was being conducted, about 85 km from the municipality of Cristal and 70 km from Piratini. The global incident radiation was estimated using the Angstrom equation, modified by Prescot and Penman using the mathematical development of Vianello and Alves (2000). Coefficients were fitted for the municipality of Pelotas by Steinmetz et al. (1999).

Initially, the relationship between the dry weight of leaves (DLW) and leaf area (LA) of samples was studied. The linear model LA = $\mathrm{B_0} + \mathrm{B_1}\,\mathrm{PSF} + \varepsilon i$ was evaluated and fit statistics were derived: coefficient of determination, standard error of the estimate, F significance, significance of coefficients, confidence interval for the coefficients, and distribution of residuals. To verify if the relationship between dry leaf weight and leaf area was constant over time and among planting sites, a covariance analysis (ANACOVA) was performed. The analysis evaluated the necessity of using independent functions over time and in different planting sites. In other words, the hypothesis of equality of the line slopes was tested. The ANACOVA was calculated using the Snedecor method, with the lines slope verified by the F value for 1% error for the mean square of the differences.

The second step was to study the variation in the average leaf area of individuals by analysis of variance. The study factors were the local combination of planting site versus stand age. Initially, we tested the basic assumptions of the analysis of variance (homogeneity) using the Bartlett's test, to then determine F by analysis of variance. The effects of any significant factor ($p < 0.05$) in the study were dismembered and the comparison of means was made by the Tukey's test. When the age factor was significant, we performed regression analysis and F test, which indicated what, should be the degree of the polynomial to be used.

The third step was to verify the relationship between the chemical properties of the soil surface horizon and meteorological conditions and the mean leaf area. To this end, a Pearson correlation analysis was conducted, which was qualitatively assessed for intensity using the criteria proposed by Callegari-Jacques (2003). Such relationships were also analyzed by the stepwise variable selection technique, one of the most recommended methods to select appropriate explanatory variables.

The models generated by this method were tested with respect to the regression conditions using the White test (homoscedasticity), Shapiro-Wilk test (normality) and Durbin-Watson test (independence). For the multiples, the level of tolerance and hence the variance inflation factor (VIF) was determined. Finally, a regression was also performed on the standardized variables, which permitted identification of the relative impact of independent variables on the dependent variances with respect to changes in standard deviation.

Dummy variables were added to the model chosen to describe leaf area over time. This permitted one to determine whether the relationships between the dependent variables (estimators of the probabilistic function) and the independent variables (variables selected by the *stepwise* method) were the same between the two planting sites.

RESULTS AND DISCUSSION

Relationship between dry leaf weight and leaf area

The correlation between leaf area (LA) and dry leaf weight (DLW) was 0.99, that is, very strongly related. The model equation intercepts (LA = $B_0 + B_1\,\mathrm{MSF} + \varepsilon i$) were not significant for either planting site (municipalities of Cristal and Piratini) nor at any age of the sampled stands (1, 3, 5 and 7 years). New model adjustments were conducted without an intercept, that is, LA = $B_1\,\mathrm{MSF} + \varepsilon i$ and fit statistics were excellent, resulting in coefficients of determination greater than 93%, standard error in the estimates smaller than 7%, F highly significant ($p < 0.01$) and adequate distribution of residuals. Thus the relationship between leaf area and leaf weight can be used to obtain leaf area. Analysis of covariance revealed that ratios do not need to be used independently (that is, for each combination of age and site). Several groups were identified, though mean square differences were not significant ($p > 0.01$). Two groups were defined; the first representing stands aged 0-3 years and the second representing stands older than 3 years. Therefore, Group 1 was composed of stands sampled in the municipality of Cristal + Piratini aged 3 years or less. Group 2 was composed of stands sampled in both municipalities and greater than 3 years old.

The relationship between mass and dry leaf weight for group 1 was 65.57 (that is, one kilogram of leaves represented 6.56 m² leaf area). In group 2, the relationship was 61.63 (that is, one kilogram of leaves represented a leaf area of 6.16 m²). This significant difference expresses the vitality of the leaves at young ages in the stand regardless of the planting site. The relationship between leaf specific density (given by the mass of the leaflet) and the petiole + rachis tends to decrease over the course of the plantation cycle, since some of the pinnae will fall from the leaflet. Thus, mass increases while leaf area is diminished. Factors related to competition between trees in the stand are among the causes, as well as canopy formation that shades leaves of the lower canopy, morphological and physiological changes, and leaf age.

Both groups were tested for fit quality statistics as well as regression constraints (Table 1). Both adjustments resulted in excellent coefficients of determination, standard error in the estimate, standard error in the coefficients, appropriate distribution of residuals and met the requirements of the regression; thus, revealing that the relationships obtained can be used to predict leaf area. No previous studies in the literature were found that describe the aforementioned relationship in black wattle.

Variation in black wattle leaf area throughout the plantation cycle and by planting site

Analysis of variance revealed that the interaction between planting site and stand age was statistically significant ($p < 0.01$), indicating that the effects are not independent. The main factors, planting site and stand age, were also significant (Table 2).

Mean of the leaf areas are presented in Table 3. In the municipality of Cristal the highest mean of leaf areas tended to occur in the year 3, decreasing to the initial levels in the year 5, when averages between stands of 1 and 5 years old were similar. From that point, again the values of leaf area tended to be larger, reaching maximum levels by the seventh year, in which the mean was identical to the observed in the 3 year old stand, and both of these values were greater than the rest. In the municipality of Piratini, leaf area tended to increase until year 3 and remain constant to year 5, with similar means between 3 and 5 years. The 7 year old forest stand has presented the highest leaf area average. This divergent behavior over the duration of the planting cycle and between planting sites resulted in a (planting location *versus* age) highly significant interaction.

Within the same age group, statistical differences

Table 1. Model fit statistics describing leaf area as a function of dry leaf weight in black wattle in Rio Grande do Sul, Brazil.

Statistics	Group 1: ≤ 3 years	Group 2: > 3 years
Correlation coefficient (%)	99.94	99.86
Coefficient of determination (%)	99.87	99.72
Standard error ($cm^2\ g^{-1}$)	10.14	13.71
Standard error	4.01%	5.79%
F	55218.32**	25452.73**
White	7.62^{ns}	6.24^{ns}
Shapiro-Wilk	0.96^{ns}	0.98^{ns}
Durbin-Watson	1.80^{ns}	1.87^{ns}

Group	Coefficients		Standard error	*t*	Confidence interval		
1: ≤ 3 years	b_1	65.5715	0.28	234.99**	65.0151	≤ Y ≤	66.1279
2: > 3 years	b_1	61.6306	0.39	159.54**	60.8603	≤ Y ≤	62.4009

** = Significant at 1% probability. ns = not significant at 1% probability.

Table 2. Analysis of variance of area of individuals in average sample diameter at breast height in black wattle stands in Rio Grande do Sul, Brazil.

Source of variation		Degrees of freedom	Mean square
	Main effect		
Plantation site		1	0.0364**
Stand age		3	0.1293**
Site*age		3	0.0278**
Coefficient of determination		81.01%	
Coefficient of variation		4.31%	
	Simple effects		
Age	1	1	0.00002^{ns}
	3	1	0.0054^{ns}
	5	1	0.0214*
	7	1	0.0927**
Site	Cristal	3	0.0396**
	Piratini	3	0.1175**

** = Significant at 99 of probability. Ns = not significant at 1% probability. * = Significant at 95% probability.

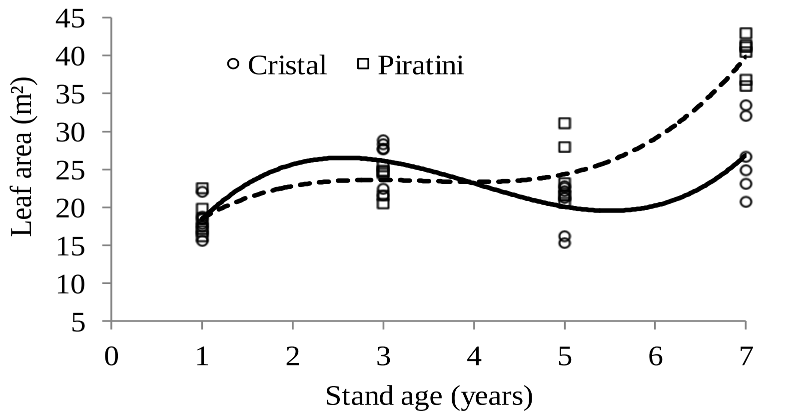
among planting sites in 5 and 7 year old stands were observed (Table 2 - simple effects), and those stands established in Piratini had the highest mean leaf area values. These results suggest that when mean values of leaf area are used, one must consider planting location and stand age. These may be derived from the trend curves fitted to represent the relationship between leaf area and stand age and are presented in Figure 1. The relationship between variables was represented by third degree equations, explaining 55.91 and 89.69% of the variation in leaf area as a function of age for the municipalities of Crystal and Piratini, respectively.

It was observed that in Piratini's stands the leaf area follows a gradual increase as the stand age increases. On the other hand, leaf area in Cristal follows a different trend, increasing up to the third year, decreasing up to the fifth year and then, it tends to increase up to the end of the cycle. The variation in leaf area observed here was also observed for black wattle leaf biomass in the same study sites and throughout the plantation cycle by Mochiutti (2007) who noted that leaf biomass increased until year 3, decreased until year 4 and stabilized after 5

Table 3. Tukey's test comparing mean leaf areas of mean diameter at breast height sampled in individuals from black wattle populations in Rio Grande do Sul, Brazil.

Plantation site	Stand age (years)			
	1	3	5	7
Cristal	18.44^{aB}	26.13^{aA}	20.09^{bB}	26.90^{bA}
Piratini	18.55^{aC}	23.62^{aB}	24.38^{aB}	39.82^{aA}

Means followed by the same lowercase letter vertically and uppercase letter horizontally, did not differ by the Tukey test at 95% probability.



$$\text{Piratini LA} = 0.3953x^3 - 4.0947x^2 + 13.769x + 8.4875 \quad R^2 = 89.69\%$$
$$\text{Cristal LA} = 0.5535x^3 - 6.6974x^2 + 23.437x + 1.1478 \quad R^2 = 55.91\%$$

Figure 1. Trends in leaf area in individuals of average sampled diameter at breast height in black wattle stands in Rio Grande do Sul, Brazil.

years of growth. Kozlowski et al. (1991) report that leaf biomass or leaf area index (leaf area) increases with age of the forest stand until a maximum is reached. The value subsequently stabilizes or declines slightly. These authors also point out that the age of maximum leaf biomass and the slope of the decline depends on the species, spacing and the forest site. Thus, it is evident that environmental conditions in which plants are grown contribute to leaf area dynamics. The observations generated interest in relating the variable to the chemical features of the soil and meteorological conditions (that is, factors determining site quality.)

Relationship between chemical attributes of the soil surface horizon and leaf area

Through simple linear correlation analysis, the element phosphorus (P) was the variable found to be most strongly correlated with leaf area (r = 0.71). Three other variables were frequently correlated, namely: potassium (r = 0.55), calcium (r = 0.39) and base CEC (r = 0.30). Other variables were found to be weakly correlated with leaf area (pH = 0.23, Mg = 0.27, SMPI = 0.27, H + AL = -0.28, Clay = -0.25, MO = -0.20, CEC Al = -0.18 and CEC pH 7= -0.05).

No studies were found in the literature that addresses the relationship between soil and leaf area in black wattle stands or other forest species. Studies have been conducted in black wattle to determine the correlation between soil attributes and dendrometric variables (Rachwal et al., 1997): dominant height (Mochiutti, 2007), diameter at breast height and wood volume (Rachwal et al., 1997; Mochiutti, 2007), and the patterns observed in the present study are consistent with the correlations cited by the above authors. Such evidence highlights the interrelationship between soil and leaf area and consequently growth and yield of the species.

The effect of P on dendrometric variables in black wattle stands is already known. Mochiutti (2007) evaluated the influence of physical and chemical features of the soil on the growth of this species (in the same location) and observed that the only soil variables that were significantly correlated with dominant height were P, Al and A horizon CEC, although the strength of the relationship is low (r = 0.237, -0.232 and -0.219, respectively).

Moreover, the aforementioned author observed that assessing the effects of Ca and Mg and fertilization with P and K on growth and yield of black wattle wood by year 3 revealed that P was the most important nutrient for growth and yield. According to Stein and Tonietto (1997), these nutrients are part of basic fertilization programs used in cultivating the species and, according to Mochiutti (2007), growth could be improved by adequate fertilization in areas where P and K are less available. In the Southeast Range, also in the state of Rio Grande do Sul, on Litholic Neossols, Cambissols, and Gleisols, Rachwal et al. (1997) observed correlations between the DBH in black wattle with other attributes: Aluminum saturation (r = -0.65), Ca + Mg (r = 0.55) and base saturation (r = 0.60) of the surface horizon, thus demonstrating that soil composition affects stand growth.

The stepwise method resulted only in a single step, in which only the most correlated variable was retained in the model, producing the equation: LA = 18.4050 + 1.9571 P. The fit resulted in a coefficient of determination of 50.05% and a standard error in the estimate of 21.34%, and all coefficients of the model were significant. Also, it was observed that the algebraic signs of the regression coefficients were positive, indicating an increase in leaf area for every unit increase in P and consistent with expectations (that is, a direct relationship between these variables). The positive value of B1 found in the model can be interpreted as an increase in leaf area on the order of 1.9571 m² with the addition of 1 mg L^{-1} of P in the soil.

Vieira et al. (2011) emphasize that P is considered an essential element, participating directly in compounds and vital reactions in the plants, and indirectly since the absence of that element would interrupt the plant's life cycle. Because of its role in the protein synthesis, lack of the element is reflected in retarded plant growth (Malavolta, 1980), and this effect was also observed in the leaf area of black wattle. Phosphorus deficiency may negatively affect the Calvin cycle, according to Walker (1983).

Relationship between meteorological conditions and leaf area

Meteorological conditions related to leaf area were: Accumulated precipitation, average maximum air temperature, average minimum and average relative humidity, and accumulated solar radiation. A simple linear correlation analysis revealed that the cumulative global solar radiation (Rgac) was most strongly correlated with leaf area (r = 0.71), followed by accumulated rainfall (r = 0.69), and strong in both cases. Mean temperature was frequently seen to be correlated with leaf area (r = 0.41) while other variables such as maximum temperature (r = 0.17), minimum temperature (r = 0.23) and relative humidity (0.28) were weakly related. Caron et al., (2003) also observed high correlations between lettuce biomass and solar radiation and low correlations with mean air temperature.

The stepwise method resulted only in a single step, in which only the most correlated variable was retained in the model, producing the following equation: LA = 16.1080 + 0.0004 Rgac. The fit resulted in a coefficient of determination of 50.41% and standard error in the estimate of 21.27 %, and all model coefficients were significant. Furthermore, it was found that the algebraic signs of regression coefficients were positive; thereby, indicating an increase in leaf area for each Rgac unit increases. This was consistent with expectations (that is, a direct relationship between these variables). The positive value of B1 found in the model can be interpreted as an increase in leaf area of 0.0004 m² above 1 MJ m^{-2} Rgac.

No studies in the literature were found that simulate or relate growth in leaf area with accumulated solar radiation. Solar radiation is a recognized factor linked to crop production because it directly influences the formation of biomass. Caron et al. (2003) proposed equations for estimating plant biomass that include solar radiation as an input variable, resulting in a model that performed better at predicting lettuce growth. Such a model may also prove useful in explaining the variations in leaf area in black wattle.

Relationship between chemical attributes of soil surface horizon and meteorological conditions with leaf area

The stepwise method resulted in three steps. The first input variable in the model was the accumulated solar radiation (Rgac), the second was phosphorus (P) content, and the third was clay (Arg) content. In the first step we obtained the equation LA = 16.1080 + 0.0004 Rgac, and the fit revealed a coefficient of determination of 50.41%, standard error in the estimate of 21.27 % and all model coefficients were significant. In the second step the equation LA = 12.3566 + 0.0003 Rgac was obtained and the coefficient of determination of the fit was 83.10%, the standard error in the estimate was 13.60%, and all

Table 4. Statistical fit for models obtained by the *stepwise* method for estimating leaf area in black wattle stands.

Model	R²	R²aj	Syx	F	α (F)	W	SW	DW
$LA = b_0+b_1Rg$	50.41%	42.14%	21.27%	6.099	0.048	4.37^{ns}	0.97^{ns}	1.54*
$LA = b_0+b_1 Rg+b_2 P$	83.10%	76.34%	13.60%	12.295	0.012	6.41^{ns}	0.91^{ns}	3.08*
$LA=b_0+b_1Rg+b_2P+b_3 Arg$	93.84%	89.22%	9.18%	20.317	0.007	8.00^{ns}	0.25^{ns}	2.19^{ns}

Model	Coefficients		Syx	t	α (t)	Confidence interval		
$LA = b_0+b_1Rgac$	b_0	16.1078	3.96	4.07	0.007	6.4178	≤ Y ≤	25.7978
	b_1	0.0004	0.00	2.47	0.048	0.000003	≤ Y ≤	0.0008
$LA = b_0+b_1 Rgac+b_2 P$	b_0	12.3566	2.80	4.41	0.007	5.1467	≤ Y ≤	19.5665
	b_1	0.0003	0.00	3.13	0.026	0.0001	≤ Y ≤	0.0006
	b_2	1.6174	0.52	3.11	0.027	0.2807	≤ Y ≤	2.9542
$LA=b_0+b_1Rgac+b_2P+_{b3} Arg$	b_0	20.0836	3.48	5.76	0.004	10.4083	≤ Y ≤	29.7589
	b_1	0.0004	0.00	5.13	0.007	0.0002	≤ Y ≤	0.0006
	b_2	1.4799	0.35	4.17	0.014	0.4947	≤ Y ≤	2.4650
	b_3	-0.3561	0.13	-2.64	0.058	-0.7305	≤ Y ≤	0.0183

R = coefficient of determination, R²adj = adjusted coefficient of determination; Syx = standard error, F = F value, bi = coefficient of the model, LA = leaf area; Rgac = solar radiation accumulated in MJ m^{-2}; P = phosphorus content in MG/L; Arg = clay content in %, W = White, SW = Shapiro-Wilk, DW = Durbin-Watson.

model coefficients were significant ($p < 0.05$). These two variables were expected, since they were the most related with leaf area as was shown earlier (Table 4).

In the third step, clay content was the variable with the highest significant partial correlation coefficient (α_F<0.15, value set for the input variable) since Rgac and P were already in the equation, resulting in the equation: LA = 20.0836 + 0.0004 + 1.4799 Rgac P - 0.3561 Arg, which showed a correlation coefficient of 93.84% and standard error of estimate of 9.18% (Table 4). Clay was the only variable with significance value greater than 5% (α_t = 0.058) a fact related to the weak correlation between it and leaf area.

The clay content in the soil is strongly correlated with Al (r = 0.80), and is also very strongly related to the combination of H + Al (r = 0.92), which are considered elements harmful to plant growth. Negative correlations between soil Al and DBH (r = -0.65) were observed in black wattle stands by Rachwal et al. (1997), as observed between Al and Al + H and leaf area (r = -0.26 and r = -0.28, respectively). Thus, the inclusion of clay in the model is valid, though it is weakly correlated with leaf area (-0.25). Caron et al. (2003) and Machado et al. (2008) also obtained the best equations with regard to the fit indicators and precision when all variables were involved in the models, including those with low simple linear correlation.

It was noted that all the algebraic signs of the coefficients are consistent with expectations (that is, direct relationship between leaf area and the variables Rgac and P variables and inverse relationship with Arg). Furthermore, it was observed that models that include Rgac and Rgac + P did not meet all the regression conditions tested, because the residuals distribution independence test was significant. Therefore, the only model that met all the regression requirements (homoscedasticity, homogeneity and independence) was the model obtained in the third step, which included Rgac, phosphorus and clay. It was also verified that this model does suffer multicollinearity problems, given that the tolerance values range from 0.90 and 0.84 and the variance inflation factor is less than 10 (ranging from 1.06 to 1.10), that is, the independent variables that compose it are not correlated.

To eliminate the effects of different measurement units of the independent variables and to verify the relative impact on the dependent variables, they were standardized before making estimates of model coefficients LA = bo + b1 Rgac + b2 P - b3 Arg. This transformation created a common unit with which was possible to determine the variable of greatest impact. The obtained equation was: LA = 0.6699 Rgac + 0.5350 P - 0.3390 Arg. The expression allows one to identify that Rgac is the most influential variable in explaining the variation in leaf area, followed by P and Arg, which in turn, is less important in the estimation process.

When soil and climatic factors are studied simultaneously, as in the model: LA = b0 + b1 Rgac + b2 P + b3 Arg, the multiple correlation coefficient of the expression was 96.87%, residuals were adequately distributed, making the equation an appropriate tool to explain variations in leaf area. Though, based on a small data set, the resultant model appears to be adequate for simulating the effects of climatic variations and soil fertility on leaf area, and hence growth and yield in black wattle stands.

In the equation obtained leaf area (as a function of Rgac and P and Arg) was related to planting site and subjected to regression analysis using a dummy variable. This suggests that a single equation can be fit, and planting site need not be considered since the dummy variable used to evaluate the effect of planting site was not significant ($p > 0.05$).

Conclusions

Leaf area was strongly related to dry leaf weight. The relationship between leaf area and dry leaf weight was not influenced by planting site, but rather by the age of the stand. The coefficients of leaf area/dry leaf weight could be used to estimate leaf area. Values of leaf area varied depending on stand age and plantation site. Leaf area was related to soil properties and particularly with phosphorus content. Similarly, it was also related to meteorological conditions, most notably accumulated solar radiation. The obtained model, which involves global accumulated solar radiation and phosphorus and clay contents, adequately explained variations in leaf area.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Callegari-Jacques SM (2003). Bioestatística – Princípios e Aplicações. ArtMed: Porto Alegre.

Caron BO, Medeiros SPL, Manfron PA, Schmidt D, Pommer SF, Biachi C (2003). Eficiência de conversão da radiação solar fotossinteticamente ativa interceptada em fitomassa de alface. RBA. 11(2):261-268.

Kozlowski TT, Kramer PJ, Pallardy SG (1991). The physiological ecology of woody plants. Academic Press, New York.

Linhares CA, Ponzoni FJ, Shimabukuro YE (2000). Relação entre volume de madeira e índice de área foliar em um povoamento de *Pinus* spp.: estudo de caso. Árv. 24:47-54.

Machado SA, Aguiar LP, Figueiredo Filho A, Koehler HS (2008). Modelagem do volume do povoamento para *Mimosa scabrella* Benth. na região metropolitana de Curitiba. Árv. 32(3):465-478.

Malavolta E (1980). Elementos de nutrição mineral de plantas. Agronômica Ceres Ltda., São Paulo.

Mochiutti S (2007). Produtividade e sustentabilidade de plantações de acácia-negra (*Acaica mearnsii* De Wild.) no Rio Grande do Sul. PhD Dissertation, Federal University of Paraná.

Monteith JL (1977). Climate and the efficiency of crop production en Britain. Proc. R. Soc. Lond. 281(980):277-294.

Rachwal MFG, Curcio GR, Dedecek RA (1997). Caracterização do desenvolvimento e produção de madeira da *Acacia mearnsii* aos 3 e 5 anos de idade em solos derivados de micaxistos no município de Piratini, RS. Embrapa Florestas, Colombo.

Simon AA (2005). A cadeia produtiva da acácia-negra, aspectos econômicos, sociais e ambientais. In: Strohschoen, A.G., Rempel, C. (Eds.), Reflorestamento e recuperação ambiental, ambiente e tecnologia: o desenvolvimento sustentável em foco. Univates, Lajeado, pp. 149-166.

Stein PP, Tonietto L (1997). Black Wattle silviculture in Brazil. In: Brown AG, Ko HC. (Eds.), Black Wattle and its Utilization. RIRDC, Barton, pp. 78-82.

Steinmetz S, Assis FN, Soares WR (1999). Estimativa da radiação solar global a partir da insolação na região de Pelotas, Rio Grande do Sul. Agropecu. Clim. Temp. 2(1):77-85.

Vianello RL, Alves AR (2000). Meteorologia Básica e Aplicações. UFV, Viçosa.

Walker D (1983). C3, C4: mechanisms, and cellular and environmental regulation, of photosynthesis. Bookplan, Worcester.