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The crown efficiency of Parana-Pine

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A B S T R A C T

Background: *Araucaria angustifolia* has high-quality wood, variability and ecological adaptation to environmental conditions. In most cases, the crown efficiency expresses the capacity of tree growth and can be described by the ratio between the increment in basal area with its crown projection area. This measure allows determining the growth capacity of each tree to be removed during a thinning. **Objective:** This study evaluated the crown efficiency of *Araucaria angustifolia* trees, according to the sociological position: dominant, codominant, dominated and open grown trees. **Results:** The relationship between crown efficiency and crown projection area for trees of three social positions in the forest and open growth trees shows the reduction of efficiency with the increase of crown projection area. Open grown trees are more efficient, followed by dominant, codominant and dominated. The inclusion of variable of the crown length in model of efficiency provided best values of the adjustment and accuracy, except in model the dominated trees, that did not alter in reason of the higher competition, low vigor and luminosity to which the crown is submitted. In open growth trees, the increase in value R^2 was of 51.6%, confirming the dependence of the variable of crown length on the explanation of the crown efficiency. **Conclusion:** Trees with better sociological position in stand have more efficient crown, as the crown length increases. Narrow and long crowns are more productive, grow in smaller spaces, and permit greater number of trees per area unit. For maximize the production per area unit, the forest management should be based on specific conditions of the trees. This specie needs light for its development and silvicultural activities are necessary to be conserved in nature. This research will improve silvicultural activities and economic planning of araucaria in southern Brazil.

INTRODUCTION

In southern region of Brazil, there is one of the most characteristic forest formations of the Atlantic Forest Biome, the Mixed Ombrophilous Forest (Oliveira-Filho and Fontes, 2000), also known as "Araucaria Forest" (IBGE, 2012). This forest is characterized by the presence of the *Araucaria angustifolia* (Bertol.) Kuntze specie that constitutes the upper stratum with a dominant character in this vegetation (Higuchi *et al*., 2012).

In spite of the great pressure, over the years, for the extraction of araucaria due to its qualities for wood use, the species still has a strong presence in many existing forest remnants (Kanieski *et al*., 2010). Thus, it is important to obtain information that allows the management of forests in a rational manner, executing plans and practices directed to the characteristics of the species.

As a result of this intense exploratory pressure in the past, *araucaria* was included in the official list of Brazilian flora species threatened with extinction in the vulnerable category (Brasil, 2008), and more recently in the International Union for Conservation of Nature - IUCN Red List of Threatened Species (Thomas, 2013) as

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critically endangered. Although the IUNC among other measures, recommends management and harvest of araucaria forests, the use of wood this species suffers restriction because of regional legislation.

In this sense, attributes of crown are important in many physiological processes and influence in the growth rate, in the growth of trunk diameter, in the fruit production and in the seeds, among others (Kozlowski and Pallardy, 1996). The growth depends on the light quantity absorbed in leaves, also on the efficiency of the conversion of light absorbed in biomass and allocation of photoassimilates in tissues (Binkley *et al*., 2013). The capture of light by a plant depends on the amount of radiation and the architectural arrangement of leaves within the crown, on a direct leaf orientation to the light sources and on the degree of shading resulting from the overlap of the leaf in a plane orthogonal to the light source (Pearcy *et al*., 2004).

The crown efficiency expressed by the ratio between the increase in volume of the basal area, with a crown projection area, allows to identify the least efficient trees (Sterba *et al*., 1993; Reid *et al*., 2004; Gspaltl *et al*., 2012), can be used to determine which trees to remove in thinnings (Sterba and Amateis, 1998). Thus, they defined the remaining trees after thinning in order to obtain the maximum efficiency of the growth space and consequently the growth of volume per hectare (O'Hara, 1988), that is infer about the growth in response to various silvicultural treatments (Waring *et al*., 1981). The knowledge of the efficiency of a tree is essential for the establishment of structured stands that increase the efficiency of the use of tree resources and the production at the level of stands (Gspaltl *et al*., 2013).

Additional information are importants for silviculture in mixed forests uneven aged with araucaria in southern Brazil, to favor larger growth trees for a same crown projection area. The analysis of this dimension according to the social position of the tree and the crown length makes it possible to select "future trees". The present study evaluated the crown efficiency of araucaria trees growing in natural forest according to social positions: dominant, codominant, dominated and open growth trees in field areas, to support the management and conservation strategies of the specie.

Methodology:

The sampling site is located in two rural properties, in the municipality of Lages, SC state (27° 48'S and 50° 19'W), where araucaria trees were measured in competition in natural forest and open growing trees in the field area. These areas are located about 5 km distance between them and 30 km from the municipality.

The climate, according to the classification of Köppen, is subtropical humid, without dry season and with temperate summer (Cfb). The altitude of the municipality is approximately 987 meters, with average annual temperature of 15.2ºC and average annual precipitation of 1685.7 m (Alvares *et al*., 2013). The predominant soils in the region are Nitossolos Haplings and Humus Cambisols developed from basaltic rocks (Embrapa, 1999).

A total of 423 araucaria trees were intentionally selected. Of these, 308 trees are in the interior of the natural forest (dominant: n = 122, codominant: n = 84 and dominated: n = 102), distributed according to the diameter classes found in the forest and the remaining group, 115 trees, was of trees that grew free, in an open field area.

In each tree, the diameter at breast height (d) was measured with diametrical tape, the height (h) and the height in the crown base (hbc) were measured with the Vertex IV hypsometer. The crown length (lc) was obtained by the difference between h and hbc. In addition, four crown rays were measured in open grown trees and eight in trees of the forest, from the central axis of the tree at level d, according to the cardinal points: north (N), northeast (NE), east (E), southeast (SE), south (S), southwest (SW), west (W), and northwest (NW). In all trees, the crown rays were measured by an only one person to avoid possible tendencies. The crown radius mean (mcr) of the tree was determined by the expression (1): $mcr = [(\Sigma\ cr^2)/k]^{0.5}$. Where: mcr = crown radius mean, in m; cr = radius of the crown according to the cardinal point, in m; number of radius of crown, k = 4 for open grown trees; and k = 8 for trees in the forest.

The crown projection area (CPA) was calculated considering the circular shape as - $CPA = \pi.mcr^2$, aiming to minimize errors in estimates (Costa *et al*., 2013). Social position of the tree in the forest was based on the silvicultural criterion, assessing the position in the vertical stratum of the forest, the presence of competing neighboring trees and the respective degree of exposure on crown light: dominant tree - occupied the upper stratum with high exposure of the crown to light; codominant tree - occupied the intermediate stratum with average exposure of the crown to light; and dominated tree - positioned in the lower stratum with low crown exposure to sunlight (Costa *et al*., 2014).

Periodic increment was determined on two rolls of increment, radially extracted at the breast height diameter, with the Pressler borer. When necessary, due to the difficulty of quantification of the increments of the trees under high competition, we returned to the field to collect two more rolls of increment of the same tree. Growth rings were measured in millimeters with Image Pro-Plus Software, recording the radial increments of each tree in the text file.

Thus, it was possible to determine, for each tree, the annual periodic increment in the basal area (PAIg) of araucarias with the expression (2): $PAIg = (g-g_{-t})/t$. Where: PAIg = annual periodic increment in basal area, in cm².year^{-1}; g = basal area obtained at the end of the period, in cm²; g_{-t} = basal area obtained at the begin of the period, in cm²; t = period of time considered in this study was five years.

To describe the relation of crown efficiency (CE) in function of CPA, it was used the allometric model in nonlinear form (3): $CE = \beta_0. CPA^{\beta_1}$. Then, in model (3), it was added the variable of crown length (lc) by the expression (4): $CE = \beta_0.CPA^{\beta_1}.lc^{\beta_2}$. Where: CE = (PAIg/CPA), in cm².m^{-2}.year^{-1}; PAIg = annual periodic increment in basal area, in cm².year^{-1}; CPA = crown projection area, in m²; lc = crown length, in m; β_0, β_1, β_2 = estimated regression coefficients.

All statistical models were processed in the Statistical Analysis System - SAS version 8.0 (Sas Institute, 1999). The fitted models were evaluated according to the coefficient of determination (R^2), the root mean square error (RMSE) and graphical distribution of residues in function of the estimated values.

Results:

Trees were sampled with a range of diametric distribution, between 10.0 cm to 85.9 cm in group trees, growing in the forest, and 18.0 cm to 68.1 cm, in open growth trees (Table 1). The crown length of trees in forest presented reduction of 2.9 m, in average, when compared to trees in open field areas. Growth trees in competition show a reduction, in average, of the PAIg value of 37.4 cm².year^{-1} (Table 1).

Table 1: Biometric characteristics of Araucaria trees

Variables	Type	Minimum	Mean	Maximum	VC%
d	Forest	10.0	37.8	85.9	41.4
h		7.2	16.6	25.0	21.8
lc		0.6	4.5	10.7	42.4
CPA		4.1	77.3	404.2	77.8
PAIg		3.1	19.1	79.7	67.8
CE		0.0269	0.3719	1.8211	92.2
d	Open growth	18.0	41.6	68.1	24.9
h		7.3	12.5	18.0	20.9
lc		1.7	7.4	13.7	42.4
CPA		15.2	75.5	180.5	48.3
PAIg		6.6	56.5	133.8	54.7
CE		0.0621	0.8388	2.5809	55.0

Where: d = diameter at breast height, in cm; h = total height, in m; lc = crown length, in m; CPA = crown projection area, in m²; PAIg = annual periodic increment in basal area, in cm².year^{-1}; CE = (PAIg/CPA), in cm².m^{-2}. year^{-1}; VC% = coefficient of variation.

The relationship between crown efficiency and CPA for trees of three social positions in the forest and open growth trees, fitted with the model (3) was significant, (see the statistics in Table 2), and shows the reduction of efficiency with the increase of CPA (Figure 1), where open growth trees were more efficient. The same relationship revealed that trees with a better sociological position were more efficient in sequence: dominant, codominant and dominated. This result may be associated with availability water, light, competition between trees, site conditions, among other factors that limit the growth of trees under competition. Thus, these factors act together, not only in relation to shape, size and dimensions of crown, but mainly to annual growth rates.

Table 2: Statistical models of crown efficiency estimate for Araucaria

Type	Coefficients		Standard error	Value t	Prob.>|t|	R^2	RMSE
Dominant	β_0	6.0121	0.7672	7.8	<0.0001	0.647	56.6
	β_1	-0.6203	0.0370	-16.8	<0.0001		
Codominant	β_0	3.2592	0.5338	6.1	<0.0001	0.570	50.6
	β_1	-0.5572	0.0517	-10.8	<0.0001		
Dominated	β_0	5.6521	0.5953	9.5	<0.0001	0.780	46.1
	β_1	-0.8805	0.0404	-21.8	<0.0001		

Open growth trees	β_0	4.9421	1.6129	3.1	0.0027	0.192	50.4
	β_1	-0.4284	0.0816	-5.3	<0.0001		
Dominant	β_0	1.4754	0.2305	6.4	<0.0001	0.825	40.0
	β_1	-0.7683	0.0341	-22.5	<0.0001		
	β_2	1.1412	0.0982	11.6	<0.0001		
Codominant	β_0	1.9942	0.4182	4.8	<0.0001	0.625	47.5
	β_1	-0.5698	0.0486	-11.7	<0.0001		
	β_2	0.3831	0.1112	3.5	0.0009		
Dominated	β_0	5.8091	0.6500	8.9	<0.0001	0.781	46.3
	β_1	-0.8758	0.0423	-20.7	<0.0001		
	β_2	-0.0425	0.0708	-0.6	0.5497		
Open growth trees	β_0	2.1729	0.4393	5.0	<0.00)1	0.708	30.5
	β_1	-0.7629	0.0581	-13.1	<0.0001		
	β_2	1.1067	0.0965	11.5	<0.0001		

Where: CE = crown efficiency, in $cm^2.m^{-2}$. $year^{-1}$; CPA = crown horizontal projection area, in m²; lc = crown length, in m; n = number of trees; β_0, β_1, β_2 = estimated regression coefficients; Prob.>|t|= Probability of significance for the value t; R^2 = coefficient of determination; RMSE = root mean square error.

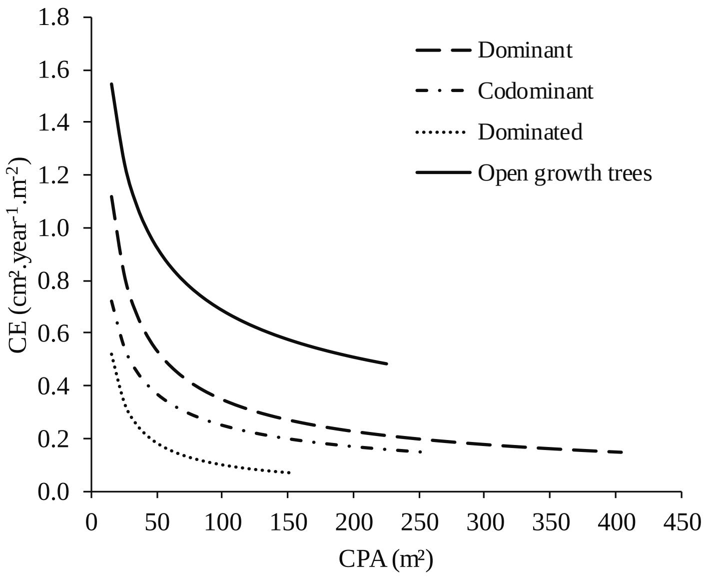

Fig. 1: Crown efficiency of Araucaria trees

The inclusion of variable of the crown length in efficiency models (Table 2), provided best values of the adjustment and accuracy, except in model the dominated trees, that did not alter in reason of the higher competition, of the low vigor and luminosity to which the crown is submitted. In open growth trees, the increase in value R^2 was of 51.6%, confirming the dependence of this variable on the explanation of the crown efficiency.

Curves of crown efficiency developed with fixed values: maximum, mean and minimum for the variable of crown length show increased crown efficiency in trees with higher crown length (Figure 2). This behavior was evident in open growth trees (Figure 2d), in sequence of social position dominant (Figure 2a) and codominant (Figure 2b). In dominated trees under greater competition, the effect had little influence on the crown length increase, with line regressions almost overlapping (Figure 2c), reflecting the low vigor of these trees in assimilation and their conversion in biomass.

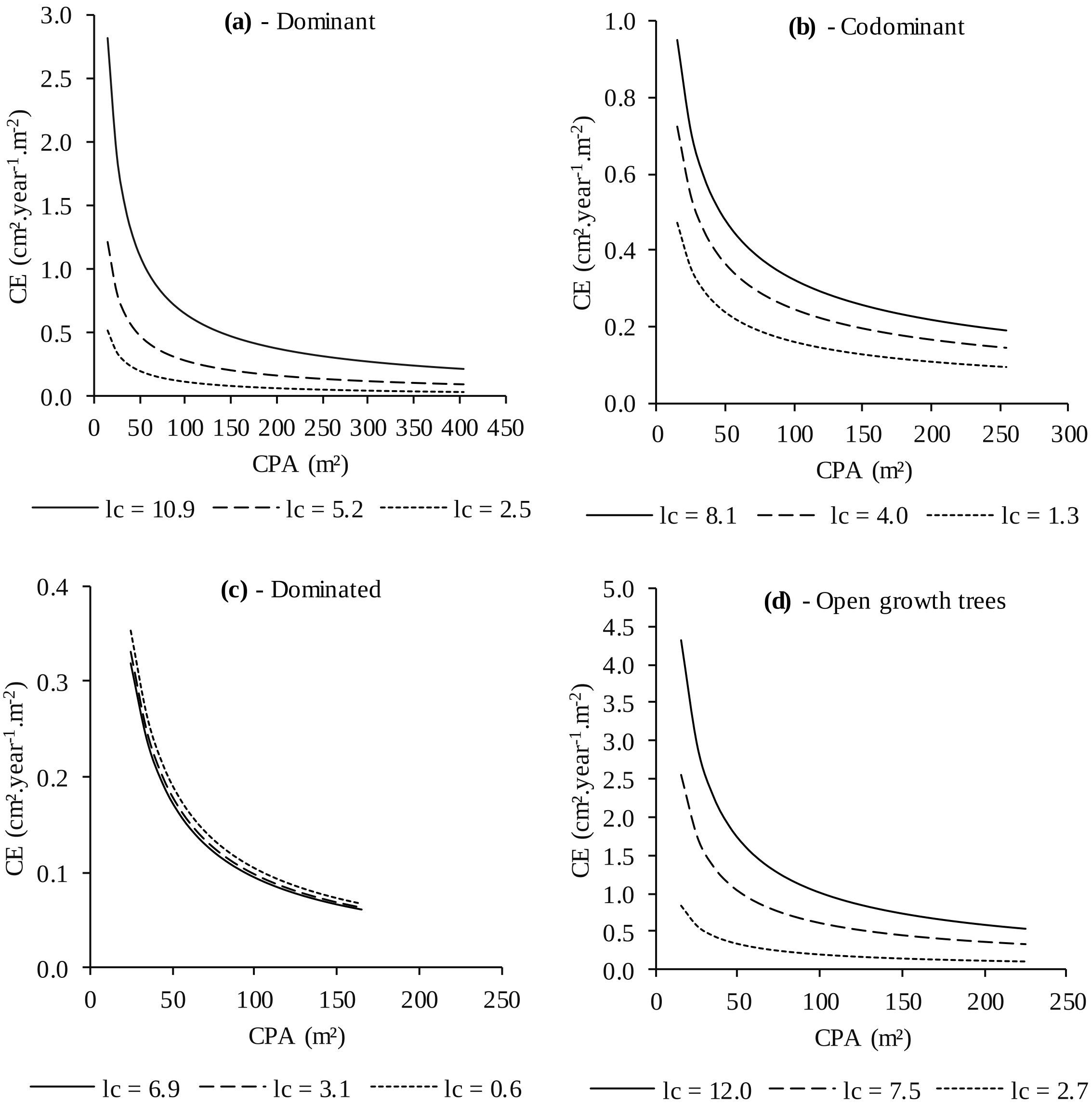

Fig. 2: Crown efficiency of araucaria trees with value: minimum, mean and maximum; with the inclusion of crown length (lc) in model, according to the social position of trees growing in the forest and open growth trees

Discussion:

For a given CPA, it occurs an increase of crown efficiency for trees of better social position, respectively, in sequence: dominant, codominant and dominated (Figure 1). Similar results were also described by Durlo (1996) and Mattos (2007) for *Cedrela fissilis*, *Cordia trichotoma* and *Cabralea canjerana* in the south of Brazil. Effect of the dimensional relationships of Araucaria were investigated by Costa and Finger (2017), evidencing that trees with high competition have reduced crown length and lower growth rates in diameter.

Attributes of crown are important variables used in models of mortality, growth and crown biomass of tree. Machado *et al*. (2015), found improvement in fit and precision of h/d models when separating Araucaria trees in crown length classes. They also found that Araucarias with larger crown lengths tend to be taller and thicker. In another study of h/d models for Araucaria obtained improvements in the fit and accuracy when used separated groups of trees according with the social position occupied in vertical stratum of the forest and the classification in the degree exposure of the crown to light (Costa *et al*., 2014).

Minatti *et al*. (2016), developing models of crown insertion height, crown diameter and crown proportion for araucaria, found statistically significant differences regarding the tendencies of these variables according to the sites. The same authors report that these models allow to identify the need for intervention in the forest as well as changes in the structural dynamics with different patterns in time.

Hess *et al*. (2016) mention that modifications of crown morphology in Araucaria are related to competition and variation in diameter breast height, which indicates that the forest management should be based on these characteristics to propose silvicultural interventions in the forest and increase the growth rates of individual trees.

Conclusion:

Crown efficiency is higher in open grown trees, followed by trees with a better social position in the forest: dominant, codominant and dominated.

The competition between trees causes clear and strong reduction of the crown. Trees with narrow and long crown have higher growth and should be preferred because they allow more trees per unit area. In order to maximize the volume per unit area, forest management must provide the specific conditions of trees.

This specie needs light for its development and silvicultural activities are necessary to be conserved in nature. This research will improve silvicultural activities and economic planning of araucaria in southern Brazil.

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