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Morphometry of *Caryocar brasiliense* Camb. in homogeneous plantation in Cerrado region

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Abstract
The objectives of this study was: to describe the morphometric aspects of Pequi tree (*Caryocar brasiliense* Camb.) in homogeneous plantation; to provide part of the necessary subsidies to the appropriate silvicultural management, in commercial cultivation. Also, to select the most accurate model to estimate crown diameter (CD) as a function of diameter at breast height (DBH). The data were collected together with the "Demonstrative unit of fruit species behavior in Cerrado", located in the city of Cuiabá, implemented by EMPAER / MT in 2004. To compile the database, in 2016, a forest census of 80 Pequi trees was carried out, with the measurement or estimation of biometric and morphometric parameters. The DBH data were applied to the selection of the most accurate model to estimate the CD. The statistics adjustment analyzed in the selection of the equations were: adjusted coefficient of determination (R^2_{adj}) and mean standard error (Syx%), besides the significance of regression coefficients (β) and graphical analysis of residues were observed. More than 50% of individuals presents bifurcation, with two to four trunks. Most of the trees have slender crowns, and reflect deep growth, but also large crowns, which express horizontal expansion. The adjusted generic model: $CD = -0{,}0717 + 0{,}3971 * DBH - 0{,}0042DBH^2$, can be used to estimate CD and to regulate spatial occupation during the production cycle.
Key words: **C**rown parameters, Individual tree, Crown modeling, Silvicultural management

Introduction

The knowledge of the morphometric relationships and the tree shape parameters in arboreal species are essential for the improvement of silvicultural interventions. This is highlighted in reforestation with commercial objectives, when using autochthonous or unconventional species, such as the Pequi tree, *Caryocar brasiliense* Camb.

The main forest product is wood, so most of the forest inventory studies are conducted to quantify the woody biomass that can be used for sawmills, paper and pulp and firewood (Orellana and Koehler 2008). Some species provide other products. In the case of the Pequi tree, its fruit is very appreciated in the regions of the Brazilian Cerrado (Rodrigues 2005), besides the use of timber, medicinal, melliferous, ornamental and oleaginous.

Due to its vulnerability, since 1995, the cutting and commercialization of species of the genus *Caryocar* in Brazil has been banned and, since 2008, in the state of Mato Grosso, there is restrictive legislation for *Caryocar brasiliense* Camb. Thus, studies that make feasible the implantation of commercial stands of Pequi and other native species, corroborate for its preservation and conservation in situ, besides ensuring the provision of its products.

Knowing the parameters of tree crown enables the understanding of ecological relations of growth and production (Nutto et al. 2001), since the energy source of a tree comes from sunlight, which is transformed by the photosynthetic process into chemical energy in the crown. The dimensional characteristics and the morphometric relationships of tree crown allow the prediction of the vital space required during its development. Also, the identification of the competition phenomenon as well as inferences about the stability, vitality and productivity of each individual, serving as a practical tool in silvicultural interventions (Durlo 2001; Durlo and Denardi 1998), especially when the age of plants is unknown.

The proportion of crown is an indicative relation of vitality according to the purpose of use and, for non-timber products such as seeds, fruits and leaves, the high value of this relation may be desirable (Condé et al. 2013). When the management of a stand is predicted by the diameter reached by its individuals, the maximum number of trees per unit area can be calculated by the salience index, if there is a significant correlation between this and the DBH (Durlo and Denardi 1998). If management is by objective-height, the coverage index can be used as an indicator of the need for silvicultural interventions. The authors also report that, when squaring the salience index, the corresponding index of living space (ILS) is found.

On the other hand, for Fleig et al. (2003), the ILS is found by the ratio between the crown projection area and the cross-sectional area. There is no difference between the two methods of calculation, since the variables involved are directly related and express the minimum area used by the plants to grow free of competition between the canopies.

The level of slenderness, according to Durlo and Denardi (1998), is an indicative of the tree stability degree and, for Durlo (2001), this index decreases with the increase of tree age, since the growth in height is relatively smaller than growth in diameter, making them more robust and stable. The shape and size of the crown of trees grown free of competition are decisive for silvicultural interventions when they grow in forest stands. Some species have a narrow, elongated crown, characterized as slender, because they occupy small areas of horizontal projection, while others, short canopies, but cover larger areas (Durlo et al. 2004)

However, obtaining crown size by conventional methodologies is considered costly. One of the alternatives is the use of regression models to estimate this variable. In Brazil, the crown modeling of native species has been the object of scarce studies. Some studies have attempted to model the diameter of tree canopies from easily available variables such as DBH (Orellana and Koehler 2008; Sanquetta et al. 2014; Tonini and Arco-Verde 2005).

The objective of this study was to describe the morphometric relationships of the Pequi tree in homogeneous plantation, besides to test and select the most accurate model to estimate the crown diameter as a function of the diameter at breast height.

Materials and methods

In 2004, the Mato Grosso Company of Agricultural Research and Rural Extension (EMPAER / MT) established the "Demonstrative unit of fruit species behavior in Cerrado", in the municipality of Cuiabá in an area circumscribed to the geographical coordinate 15°32'57,93° S and 55°59'54" W. The region climate is classified as Tropical Savannah, type Aw (Köppen), whose annual precipitation is between 1,600 mm and 1,700 mm and the average annual temperature is 26,84°C (Souza et al. 2013).

The seedlings, or seminal origin, were produced from fruits collected in the region of Cuiabá lowland that, according to Libos and Rotunno Filho (2003), has impoverished soils, such as lateritic concretes, latosols and hydromorphic laterites. The collected fruits were stored in raffia bags and fixed at the edge of water body until their pulp is extracted by the action of the natural water flow. Then they were dried in full sun and sown. Only 20% of the seedlings germinated and the rest was affected by the incidence of fungi, which contributed to the deterioration of these seeds.

The data for this study are from 80 Pequi trees, six to twelve years old, whose seedlings were planted in pits at a spacing of 8 m x 8 m, without the application of fertilizers and without irrigation. The application of formicide was carried out only when necessary, regardless of the stage of plants development.

From each tree were measured the circumference at the breast height (CBH), the total height (TH); crown length (CL), from the point of insertion of the first branch in the trunk, the projection rays of the crown, calculated the diameter at breast height (DBH) and estimated the crown diameter (CD) and the crown area projection (CA). From these data, the morphometric indices were calculated (Figure 1).

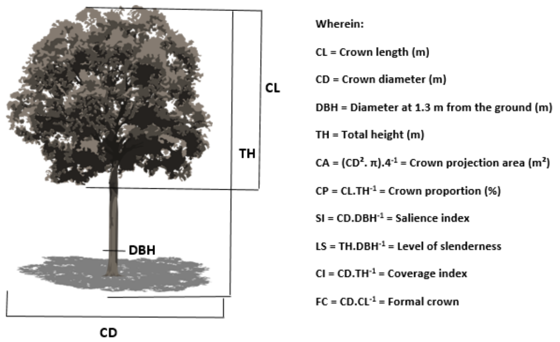

Figure 1. Tree model with dendrometric variables and morphometric relationships

The heights were measured with Haglöf hypsometer and circumferences with tape-measure. For the measurement of the crown projection rays, a measure tape and a compass was used, taking as its origin the center of the trunk and distancing to the crown limit, considering the direction orientated by the cardinal points. Thus, the CD was established by twice the average of four measured rays.

Because it is a tree species with a derived crown, with a complex structure, and that do not result in branches that have been measured as independent trees, a methodology was adopted by Batista et al. (2014). Thus, for the DBH calculation of forked trees, a transversal area of their trunk was added for later transformation in diameter and calculation of the equivalent DBH (equation 1).

$$dg = \sqrt{\sum_{i=1}^{n} di^2} \quad (1)$$

Wherein: dg = equivalent DBH; di = DBH of forked tree trunks; n = Number of observed data

In order to simulate the crown projection area, each tree was georeferenced and its heights were considered equal at all points recorded. The CD was obtained by the multiplication of HT by the CI and the CA was estimated by the calculation of area for circular session.

As the diameter of the tree canopies is difficult to obtain, four regression models were tested in the literature (Tonini and Arco-Verde 2005; Weber 2007; Orellana and Koehler 2008; Sanquetta et al. 2014) for the crown diameter (Table 1). The generic models were formulated with the variables of interest.

Table 1. Models for the estimation of crown diameter as a function of diameter at breast height for *Caryocar brasiliense* Camb. in homogeneous plantation in Cerrado region

Nº	Model	Used by
1	$CD = \beta_0 DBH^{\beta_1} + \varepsilon$	(Sanquetta et al. 2014)
2	$CD = \beta_0 + \beta_1 DBH + \varepsilon$	(Nutto et al. 2001)
3	$1/CD = \beta_0 + \beta_1 (1/DBH) + \varepsilon$	(Sanquetta et al. 2014)
4	$CD = \beta_0 + \beta_1 DBH + \beta_2 DBH^2 + \varepsilon$	(Weber 2007)

CD = crown diameter (m); DBH = diameter at 1.3 m from de ground (cm); β0, β1, β2 = model coefficient; Ɛ= random error

For the statistical adjustments and analyzes, the software R (R Core Team 2015) was used, with the package “lm” for the linear ones, and "nls" for the nonlinear adjustments, with the respective initial values of the parameters (β_0 = 0,05) and (β_1 = 0,7). The standard error of the percentage estimation (Syx%) and the adjusted determination coefficient (R^2_{adj}) were calculated. In addition, for each model, a graphic analysis of the residues (E%) was performed to verify possible trends in the adjustments.

The adjusted coefficient of determination (R^2_{adj}) expresses the amount of the total variation explained by the regression, while the standard error of the estimate in percentage (Syx%) informs the average error caused by the use of the model. As the coefficient of determination increases as a new variable is added to the statistical model, the adjusted coefficient of determination (R^2_{adj}) for the number of coefficients of each equation was used as a criterion (Soares et al. 2011; Thomas et al. 2006).

Results and discussion

In 2016, at twelve years of age, the density was equivalent to 157 trees.ha^{-1}, and the visual variability observed between the individuals was corroborated by the dendrometric and morphometric variables, highlighting the values of coefficients of variation (CV) superior than 40% and even higher than 100% for the formal crown, except for the crown proportion, 21.89% (Table 2).

Table 2. Dendrometric and morphometric parameters of *Caryocar brasiliense* Camb. in homogeneous plantation in Cerrado region

	DBH (cm)	TH (m)	CD (m)	CA (m²)	CP (%)	SI	LS	AI	FC
Average	20.33	8.18	5.87	32.34	71.60	0.32	0.52	0.91	1.60
Maximum	47.8	20.60	12.87	130.09	92.22	0.97	2.10	3.14	10.73
Minimum	5.4	3.50	1.95	2.97	29.27	0.07	0.09	0.19	0.22
CV (%)	46.0	45.11	44.66	85.00	21.89	45.04	73.54	71.23	107.52

DBH = diameter at 1.3 m from ground; TH = total height; CD = crown diameter; CA = crown projection area; CP = crown proportion; SI = salience index; LS = level of slenderness; CI = coverage index; FC = formal crown.

The observed phenotypic variability is, according to Oliveira et al. (2008), a complicating factor for the formation of commercial plantations. On the other hand, it is interesting for significant selection gains and vegetative propagation studies.

The conduction of the species in homogeneous planting and in a wide regular spacing, 64 m² tree^{-1}, contributed to the individual’s primary growth. This confirms the assertion by Zanine and Santos (2004) that the equidistant and ample arrangement between plants delays auto shading and the onset of intraspecific competition by nutrients and water, leading to maximum efficiency in the capture and use of these resources by free cultivation of invasives. This conduction provided a high amplitude in DBH, HT and CD (Table 2).

The results obtained for the average height of the stands were higher than the values found for free-growing Pequi trees in the state of Goiás, Brazil (Santana and Naves 2003; Siqueira 2006). Also, superior in relation to maximum height of *C. brasiliense* Camb. of free-growing in the Brazilian Cerrado (Oliveira and Scariot 2010; Oliveira et al. 2008).

The observed height gain, although sought at forest stands intended for the production of wood volume, may not be adequate for fruit production. It is appropriate to keep the plant with a convenient size when handling the fruits during harvest, considering the limit that does not compromise the production per plant that, according to Santana and Naves (2003), is proportional to the height of the plant. Silvicultural treatments, such as pruning of branches, can be applied to control the growth in height, number and vigor of buddings that will compose the crown of Pequi tree, characterized by sympodial growth.

It was observed in the field that the bifurcation is a striking feature for the species, which presented more than 50% of individual with this occurrence, ranging from two to four trunks per tree (Figure 2).

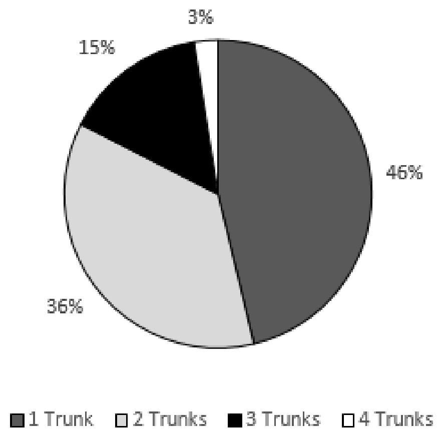

Figure 2. Frequency of trunks without and with bifurcation of Caryocar brasiliense Camb. in homogeneous plantation in Cerrado region

The occurrence of the bifurcation at 1.30 m or at lower heights has a strong influence on the indices that deal with the stability of the individual tree, as in the level of slenderness, since the different trunks of the tree were computed for the calculation of its equivalent DBH. Otherwise, considering each trunk as an independent tree, there would be greater influence on planting density, by overestimating this variable. In this way, forked trees, with smaller height, larger number of branches, and with larger crown diameter would be desirable for fruit production and would express less slenderness.

For the salience index (SI), the trees have crown diameter equivalent to 32 times the DBH and the average CP calculated in 72% allows to infer that the species has abundant crown. However, the PC values ranged from 29% to 92%, and this range can be attributed to the different degrees of competition to which the plants are subjected.

The species presented slender crowns, investing in depth, but also broad crowns, investing in horizontal expansion. As there are no littoral and climatic differences in the experimental area, and the silvicultural management was similar for the trees, it is possible to attribute these differences to the genetic characteristics of the seeds collected in several matrices for the production of seedlings.

If on the one hand the average ILS calculated at 1,194.36 represents loss in productivity due to lower basal area and volume of wood, in other side, indicates a gain in crown expansion, desirable to the settlement objective.

It is noted that, despite the adoption of initial planting spacing of 8m x 8m, where maximum occupancy of 64 m² per tree would be expected. The calculated average CA indicates actual occupancy of around 32.34 m² per tree, which would result in adequate spacing of 6m x 6m and the approximate density of 278 trees per hectare so that the plants grow free of crown competition. There is potential to reach up to four times the calculated average value, represented by the maximum CA of 130.09 m², with a density of up to 77 trees per hectare.

The observed variability for this characteristic allows the selection of matrices, with greater horizontal expansion of canopy. The selection of these matrices is the first step for homogeneity of production and increase of productivity.

As for FC of 1.60, it turns out that the crowns of the Pequi trees are slightly wider than deep. A positive aspect, since the production of fruits by Pequi trees is also proportional to the average crown diameter (Santana and Naves 2003).

The average CI obtained was 0.91. Assuming that this value is constant with the height variation, it is possible to simulate the CD, the CI and, consequently, the ideal density of the stand so that the plants grow free of competition (Figure 3). In this case, for the average height of 10 meters, its multiplication by CI would result in a crown diameter of 9.10 m and in the average density of 154 trees.ha^{-1}.

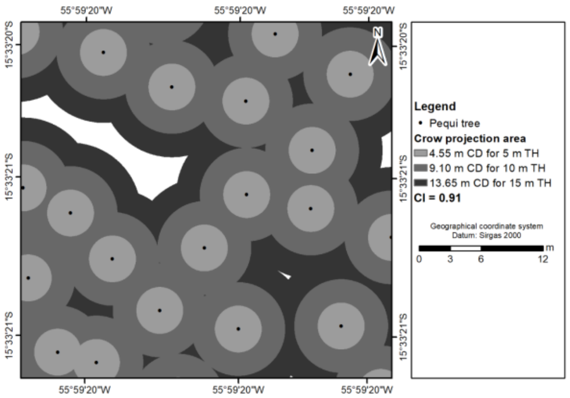

Figure 3. Simulation in classes of crown projection area, according to the height and the coverage index, of *Caryocar brasiliense* Camb. in homogeneous plantation in Cerrado region

Through the simulation of CD, in planting density of 156 trees.ha^{-1}, it can be inferred that the competition between the crowns of Pequi tree is significant when the trees reach 8 m, the average height of the population, intensifying to beyond this height.

The association of the simulation to the average LS of 0.52 indicates that for the population mean the growth in DBH did not stagnate in relation to height (Tonini and Arco-Verde 2005). Thus, it is possible to infer that there are different degrees of competition between plants, given a variation above 70% for this index and above 40% for TH.

More important than the average value of CI is the observation of the variation amplitude of the data and the high CV value of 71.23%. This will allow to verify the existence of several morphometric relationships, through the regression analysis (Durlo and Denardi 1998).

The values of the adjusted coefficients of determination (R^2_{adj}) varied from 0.78 to 0.80 and the standard error of the relative estimation (Syx%) between 24.21% and 33.02% (Table 3).

Table 3 - Coefficients and statistical parameters of the adjusted models to estimate the CD of pequi trees in homogeneous plantation in Cerrado region

Model	Coefficients			Statistical parameters	
	β_0	β_1	β_2	$R^2_{adj.}$	Syx%
1	0.7711*	0.6824*		0.797	24.71
2	1.8153*	0.2000*		0.790	25.07
3	0.1103*	1.6450*		0.789	33.02
4	-0.0717^{ns}	0.3971*	-0.0042*	0.808	24.21

R^2adj. = adjusted coefficient of determination; Syx% = standard error of the estimate in percentage; ns= not significant, *= significant

These results are similar to those found by Orellana and Koehler (2008) in studies about the relationship between CD and DBH for *Ocotea odoriferous* (Vell.). They are also similar to those found by Sanquetta et al. (2014) for *Acacia mearnsii* De Wild., who understood that the adjustment statistics were reasonably satisfactory, due to the variability of the CD as a function of the DBH.

The influence of external factors, such as the competition between neighboring trees, the site and the environmental conditions, as highlighted by Nutto et al. (2001), in studies with *Araucaria angustifolia* (Bert.) when considering the site quality as a limiting factor for maximum crown expansion.

To estimate the CD as a function of DBH, the best fit was obtained with equation (4) in linear form. For all equations, the coefficients presented significant results by the test (t) at the 5% probability level. Only the intercept of equation (4) presented non-significant result, since this parameter is not associated to any independent variable, it was used in this study.

Complementarily, for the quality of the adjustments, the graphical analysis of residues was carried out (Figure 4), and to avoid not detected errors by the primary statistics. In general, the graphs of residues as a function of DBH are approximately zero, but have non-constant variance along the regression line.

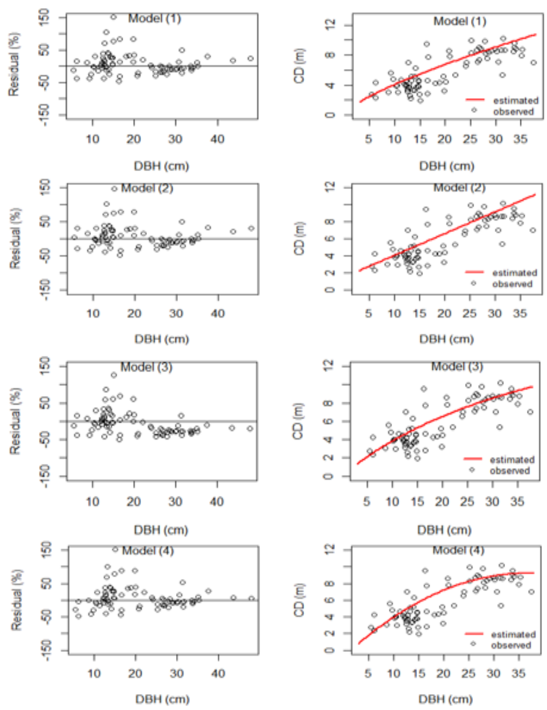

Figure 1. Graphic distribution of percentage residuals and estimated CD curve in function of DBH for models 1 to 4 of Pequi trees in homogeneous planting in Cerrado region

It was observed that the residues tend to increase the dispersion scale in the smaller diameter classes, meaning that trees with higher DBH have a higher correlation with the CD. Even so, the less biased dispersions were obtained with model (4), indicating that the estimates of CD of Pequi trees with the generated equation are superior to the others.

The adjustment performance of the models can also be observed by the estimated curve in relation to the observed data (Figure 4). The estimated curve for the model (4) presented an expected behavior for this relation, with tendency to stabilize the growth in crown diameter as the diameter increases.

Conclusion

The morphometric behavior of Pequi trees under homogeneous plantation, mainly for the mean height and total height, is different from the behavior in the natural condition.

The morphometric indices allow to capture the variation of the phenotypic expression in homogeneous plantations with Pequi trees, originating from different matrices of the same region.

The selection of matrices expressing lower heights, combined with greater horizontal expansion of the canopy, are the most desirable for the commercial cultivation of pequi trees. It also contributes to the homogeneity of production and increased productivity.

The models are adequate to estimate the CD of trees of *Caryocar brasilense* Camb. as a function of DBH, with high variability for the salience index, and the most accurate was the model $CD = -0{,}0717 + 0{,}3971 * DBH - 0{,}0042DBH^2$.

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