Australian Journal of
Crop Science

AJCS

AJCS 11(03):271-276 (2017)
doi: 10.21475/ajcs.17.11.03.pne360

ISSN:1835-2707

Growth and volume of *Myracroduon urundeuva* Allemão after ten years of silvicultural interventions

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Abstract

The application of low impact silvicultural management techniques encourage the growth of tree species of high commercial value without interfering negatively in natural regeneration. The *Myracroduon urundeuva* has high mechanical strength, high density and considerable durability, therefore being highly used in construction, woodworking and carpentry, but had an intense and predatory exploration process devastating its natural populations due to its multiple uses The objectives of this study were to evaluate the diametrical increase of *Myracroduon urundeuva* Allemão adults and assess the influence of competition elimination treatments on the population structure and dynamics. A total of twelve plots of 750 m² were established side by side. The experimental plots were randomly submitted to different treatments after the vegetation survey: (T1) – witness; T_2 – removal of woody species within a one-meter radius (1 m) for each individual of *Myracrodruon urundeuva* with DBH > 9 cm; treatment 3 (T3) – same as T2 plus the removal of vines throughout the plot. A total of 22 individuals were submitted to tree log scaling using the non-destructive method of Huber in October 2014. The relative gains in diameter were higher in treatment 3. Diameter increase was observed in the ten-year period, where the total for the witness treatment is 2.25 cm/year. The treatment T_2 had a diameter growth of 0.90 cm/year and T3 of 2.94 cm/year. The hypsometric equation has precision measurements similar to those found in the adjustments of hypsometric equations for natural forests and for isolated species. The volumetric models were of good performance highlighting the Näslund model.

Keywords: seasonal forests, increase, volume.
Abbreviation: Forest management; timber resources; Lianas competition

Introduction

Seasonal forests (SFs) are so called because their dynamics is related to climatic seasonality (Oliveira-Filho and Rattter, 2002). The SFs occur in the Cerrado by a set of disjunctions or natural fragments, which are still distributed throughout the biome and coincide with well-drained and high fertility soil areas (Eiten, 1994; Oliveira-Filho and Ratter, 2002).

The removal species without using low-impact methods in disturbed forests and forest fragments, usually leads to increased abundance of lianas, reaching levels where the self-regulation or homeostasis mechanisms of the ecosystem are not enough to prevent irreversible structural and functional degradation processes (Engel et al, 1998). In such cases, the lianas itself may not be the primary degradation causes, but may be contributing to the degradation process, and, therefore, its control has been recommended as a conservationist management tool (Engel et al., 1998; Venturoli et al., 2015).

The greatest current challenges are to reduce destructive effects of human interventions in remaining areas, to reconstruct the vegetation of deforested areas reestablishing connectivity between fragments and disjunctions and to develop sustainable methods of forest exploitation (Pereira et al., 2011). This challenge is being faced by investigations that seek to evaluate the behavior of the SFs given the application of low impact silvicultural management techniques, which are designed to encourage the growth of tree species of high commercial value without interfering negatively in natural regeneration (Venturoli et al., 2015; Silva-Neto et al., 2015).

Myracrodruon urundeuva Allemão (also known as aroeira) belongs to the Anarcadiaceae family, is usually deciduous, heliophytic and selective xerophytic (Santin and Leitão-Filho, 1991). The *M. urundeuva* has great geographical distribution in South America, and in Brazil it occurs in the Northeast, Southeast and Midwest regions (Dorneles et al., 2005). *M. urundeuva* is a species exclusive to SFs (Módena, 2010) and its wood has high mechanical strength, high density and considerable durability, therefore being highly used in construction, woodworking and carpentry (Lorenzi, 1992).

The *M. urundeuva* had an intense and predatory exploration process devastating its natural populations due to its multiple uses (e.g., timber use in the construction of posts and pens).

In addition, the selective exploitation of the mastic tree to be used in the timber industry virtually wiped out the large individuals (Brandão, 2000). Therefore, this tree species was considered endangered and categorized as vulnerable until December 2014 (Mendonça and Lins, 2000).

In view of the above, this study aimed to evaluate the growth of *M. urundeuva* submitted to three silvicultural treatments which consisted of competition release and liana cutting operations to increase the diameter of individuals of the species.

Results and discussion

Ten-year growth

Treatment 3 (T3 - removal of woody species in a distance of one meter from each *Myracrodruon urundeuva* Allemão individual with DBH > 9 cm plus the removal of lianas) differed from treatment 2 (T2 - removal of woody species in a distance of one meter from each mastic tree individual with DBH > 9 cm), and was higher than T2 and T1. Diameter increases were greater for treatment 3. Treatment 1 provided lesser growth than treatment 3 in 23.61 %. Treatment 2 was lower than the other treatments. Only treatment 3 (T3 - removal of woody species in a distance of one meter from each *Myracrodruon urundeuva* individual with DBH > 9 cm plus the removal of lianas) differed from the other treatments. *M. urundeuva* individuals present in the treatment where woody species were removed in a distance of one meter from each *M. urundeuva* individual with DBH > 9 cm plus the removal of large lianas in all of the plot had a more prominent growth.

The lianas are frequently considered a nuisance and its removal prior to wood exploitation is recommended as a component of a reduced impact management (Barreto et al., 1998). Liana cutting has been evaluated as a silvicultural treatment to increase tree growth, by reducing population density and, consequently, local competition (Gerwing and Vidal, 2003; Gerwing, 2006). Such inference is based on the strong influence that light has on tree growth, natural regeneration (Silva et al., 1995; Gerhardt, 1996; Pariona et al., 2003), and on the colonization by native species (D'antonio and Vitousek, 1992). A certain amount of canopy openness is necessary in secondary forests for the growth and regeneration of the desired trees hindering the establishment of undesired and/or invasive species that may interfere negatively on natural regeneration (Freitas, 2004). The effects of lianas on individual trees may be perceived by their growth and mortality rates. The lianas compete with tree for light and space, and for water and nutrients and for space for leaf development (Stevens, 1987; Clark and Clark, 1990). In addition, lianas cause physical injuries due to its weight and on the canopies and the effects in torque caused by winds (Putz, 1991). Therefore, the expected effects of lianas are usually negative and must truly be considered in timber production forests.

The proportion of trees infested by lianas in a forest may indicate the potential of lianas killing their hosts. About 43 to 47% of the trees with more than 20 cm DBH at Barro Colorado, Panamá are infested by lianas (Putz, 1984), as are 50% of the trees of a forest at Sarawak, Malásia (Putz and Chai, 1987). On average 69.3% of the trees with DBH>10 cm are colonized by lianas on the canopy or trunk in a 60 ha fragment of a late secondary forest in Botucatu, SP. The load of lianas is positively related with the diameter of the tree host (Clark and Clark, 1990). It is common to find trees infested by more than one liana showing that some trees are more susceptible to infestation, or that colonization by a liana facilitates the appearance of others (Engler et al. 1998; Silva-Neto et al., 2015; Venturoli et al., 2015).

Diameter increase

The total diameter increase for the ten year period for the witness treatment amounted to 2.250 cm/year, for T2 to 0.906 cm/year and T3 to 2.945 cm/year. The medial growth in ten years was 0.120 cm/year (T1), 0.088 cm/year (T2) and 0.1371 cm/year (T3), as shown in figure Figure 2.

Differences in the increases in the diameter of the individuals between the witness (treatment 1) and the other treatments (2 and 3) (p<005) were observed in 2003. The results found for the *M. urundeuva* Allemão population in the Semideciduous seasonal secondary forest studied showed that the individuals of this species responded positively to the silvicultural interventions, once the largest increases in diameter were observed in the plots where the only intervention was the removal of lianas. These results supported the classical theory of diametrical growth related directly with spacing between trees in the forest (Oedekoven, 1968; Smith, 1986). A study carried out with the community of the same area found that the annual medial increases in diameter of the species, in the plots submitted to silvicultural treatments, followed the intensity of interventions, being higher in the treatments with more intense intervention (treatments 2 and 3) (Venturoli et al., 2015).

The treatment consisting of freeing the desirable individuals (treatment 2) had a median (0.27 cm/year) 6% higher than the witness (treatment 1), which had the lowest medial diameter increase among treatments (0.26 cm/year). The treatment consisting of freeing the desirable individuals (treatment 3) plus liana removal had a median 15% higher than the witness, reaching 0.30 cm/year. The growth in medial diameter in the community was 0.28 cm/year (for a four-year period – 2003 to 2007) and the medial diameter increase for *M. urundeuva* Allemão (for a ten-year period – 2003 to 2013) recorded in this study was 0.13 cm.year^{-1}.

M. urundeuva Allemão interacted with the other species of the seasonal forest, so the removal of woody species on a 1.0m radius surrounding each individual significantly affected the diametrical growth. The concentration of individuals in the lower diameter classes suggested that the trees are small, as is typically found in secondary forests (see Figure 3).

Uneven-aged forest stands (with individuals in different developmental stages) tend to have a higher number of individual in the lower diameter classes due to the natural forest succession under the competition dynamics, as many individuals die and recruitment is faster when few reach adulthood, maintaining forest balance. In higher diameter classes, few individuals represented the diameter increase, and may have not represented the behavior of the population due to the small number of replicas (only two individuals), thus explaining the removal of individuals considered outliers in the hypsometric model and later allometric equations.

Hypsometric relation

The adjusted hypsometric relation adjusted for the values of 2003 ($Y= 0.01688 (DBH)^3-0.2483(DBH)^2+1.824 (DBH) +0.9683$), with the parameters $\beta_0= 0.968251$, $\beta_1= 1.82383$, $\beta_2=-0.248284$, $\beta_3= 0.0168817$ and a coefficient of determination of 0.78594. This equation was used to estimate

Table 1. Parameter estimations and measures of the accuracy of the equations in estimating the stock in volume of trees *Myracrodruon urundeuva* Allemão with DBH > 9 cm, in a Semideciduous seasonal secondary forest, in Pirenópolis GO, in 2013 (β_0, β_1, β_2 and β_3 - parameters of models; R² - Regression coefficient ; S_{yx} - Standard error).

	β_0	β_1	β_2	β_3	R²	Syx
Näslund: $Y= \beta_0 DBH^2+ \beta_1 DBH^2 H+ \beta_2 DBH^* H^2+\beta_3 H^2$	-0.0096	0.0202	-0.0002	0.0000006	0.9844	0.0166
Ogaya: $Y=DBH^2 (\beta_0+\beta_1 H)$	-0.0041	0.0181	----	----	0.9841	0.0172
Schumacher and Hall: $Y= \beta_0 DBH^{\beta 1} H^{\beta 2}$	-0.0095	0.0202	-0.0002	----	0.9843	0.0189
Logarithmic Spurr : $Y= \beta_0 (DBH^2 H)^{\beta 1}$	-0.0667	0.0989	----	----	0.9627	0.0201
Honner: $Y=DBH^2/(\beta_0+\beta_1 H)$	0.0314	0.1894	----	----	0.9323	0.0187
Takata: $Y= (DBH^2 H) / (\beta_0+\beta_1 DBH)$	0.0155	1.0641	----	----	0.9578	0.0181
Husch: $Y= \beta_0 DBH^{\beta 1}$	0.0155	1.0641	----	----	0.9678	0.0191

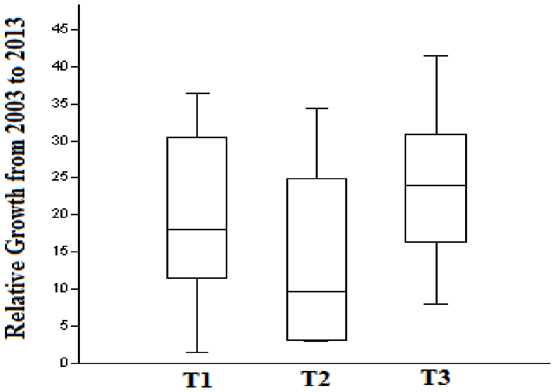

Fig 1. Box plot comparing medians between treatments and the relative 10-year growth patterns (%), among years of evaluation (mean value 2003 – 2013 - T1 – witness; T_2 – removal of woody species within a one-meter radius (1 m) for each individual of *M. urundeuva* with DBH > 9 cm; T3 – same as T2 plus the removal of vines throughout the plot).

the height of the individuals in 2013. The adjusted hypsometric equation in this study shows similar accuracy measurements to those found in hypsometric equations adjusted for natural forests and exotic species. Andrade et al. (2006) adjusted hypsometric equations for a fragment of Seasonal Semidecidous forest in the northern region of the state of Rio de Janeiro and found a coefficient of determination between 0.61 and 0.85, similar to the values recorded in this study. Tonini and Schwenberg (2006), tested eight hypsometric models for *Acacia mangium* crops in Roraima, and obtained R^2 between 0.41 and 0.98. Tonini et al. (2008) evaluated six hypsometric models for native Brazil nut tree populations (*Berthollettia excelsa* Bonpl.) and found R^2betweeen 0.54 and 0.70, lower than the recorded in this study.

The best hypsometric model for estimating total height (Ht) of *M. urundeuva* in an area classified as Seasonal semideciduous Montana forest in the Atlantic Forest Domain, was an exponential model with a coefficient of determination of 68.64% (lower than the recorded in this study), standard deviation of 2.17, β_0 = 3.613484 and β_1 = 0.542622 (Soares et al. 2011). Comparisons with other studies show that the hypsometric equation obtained for *M. urundeuva* in a Semideciduous seasonal secondary forest in Pirenópolis, Goiás has an intermediate to good classification.

Volumetric models

All the equations were highly significant, with high F values, $p<0.05$, high coefficients of determination (R²) and low error estimations (Syx) (see figure 9 for the residue distribution). Some models had different behaviours as regards residue distribution despite the models being highly significant. The dada are not ideally distributed in some models with sinous distributions, which may be due to the small number of repetitions.

The values found for the mastic tree were 0.442405. Negative signals of the coefficients associated with the total height (Ht) indicate an error in estimating these coefficients, once Ht is alwas positivelly correlated with bark volume. Therefore, the Schumacher and Hall models were not chosen for exhibiting inconsistency in the coefficient associated with Ht, despite

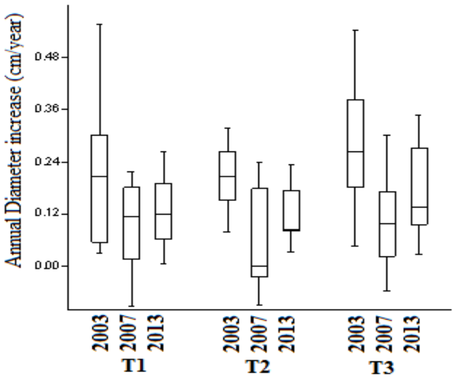

Fig 2. Box-plot comparing medians of the treatments in the ten years assessing the annual diameter increases in cm/year (T1 – witness; T_2 – removal of woody species within a one-meter radius (1 m) for each individual of *M. urundeuva* with DBH > 9 cm; T3 – same as T2 plus the removal of vines throughout the plot)

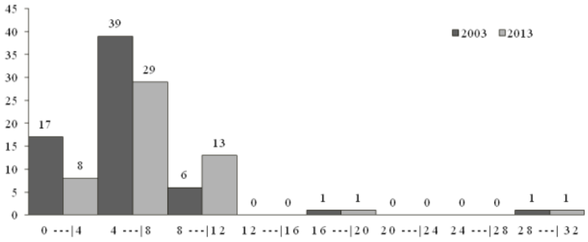

Fig 3. Distribution of absolute frequencies among diameter classes (show in centimeters) for *Myracrodruon urundeuva* Allemão populations.

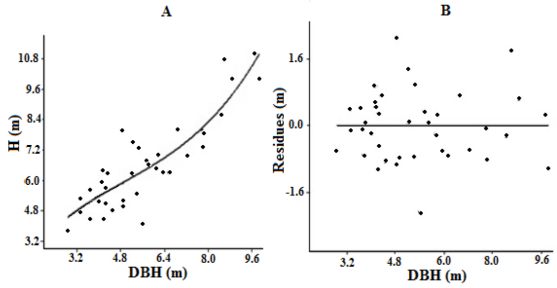

Fig 4. Representation of the 3rd order polynomial adjustment curve of the hypsometric relation $(Y= 0.01688 (DBH)^3-0.2483(DBH)^2+1.824 (DBH) +0.9683)$, with the parameters β_0= 0.968251, β_1= 1.82383, β_2=-0.248284, β_3= 0.0168817, R^2=0.78594. Graph B shows the distribution of residues of the hypsometric equation for *M. urudeuva* Allemão in a Semideciduous seasonal secondary forest, Pirenópolis – Goiás.

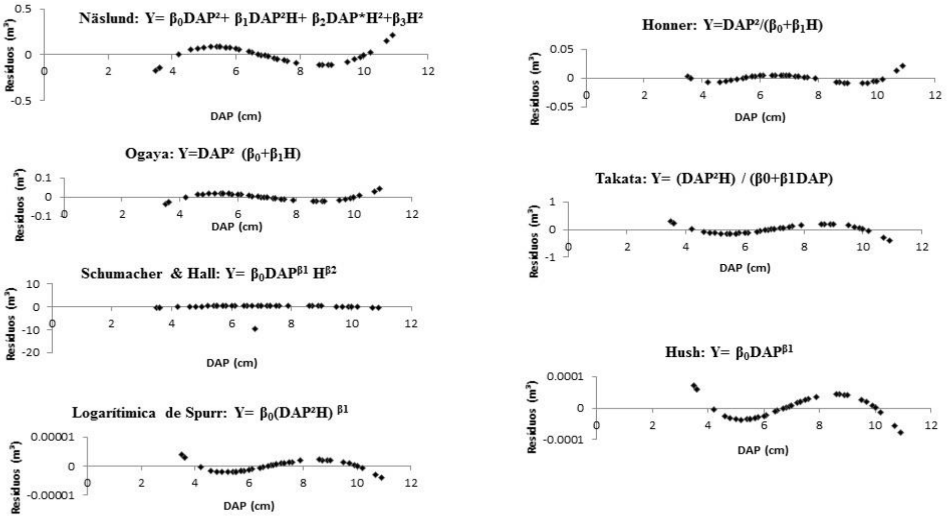

Fig 5. Residues of the volume equations for the population of *M. urundeuva* at the RPPN Vagafogo in a Semideciduous seasonal secondary forest.

having the best accuracy mesures in estimating the volume of the mastic tree. The Näslund model had the best accuray measure in Cerrado *sensu stricto* areas when comparred to the other equations. However, the model has tendencies of overestimating the volume of smaller trees. Non-linear equations of Schumacher and Hall and Logarithmic Spurr have such a tendency (Rezende et al., 2006). Baima et al. (2001) expalined the better adjustment of the dual input equations by the fact that diameter and heigth are highly correlated with volume. The dual input equations developed for a dry land forest in Moju, PA, estimated a better volume than others. Silva et al. (1984) assigned the better adjustment for the Tapajós National Forest to the Schumacher and Hall equation.

In addition, Soares et al. (2011) reported negative coefficients associated with total height (Ht) for the mastic trees in the respective equations. Using models that use the DBH (cm) and H (total or commercial) to estimate volume are more recommended by this study for presenting a better adjustment. Using these models is also recommended for native species given that some may be managed on a sustainable approach.

Materials and Methods

Study area

The study was carried out in a fragment of Semideciduous seasonal secondary forest (Ibge, 2004), under Litholic Neosol (Ibge, 2001), located in the Wildlife Sanctuary Vagafogo in Pirenópolis, Goiás (-15º51'09" and -48º57'33"), at an average altitude of 770 meters above sea level.

Experimental design

The experiment was conducted in a randomized block design with two treatments and control. The treatments consisted on the release of competition in a distance of one meter for each *Myracrodruon urundeuva* Allemão individual with DBH ≥ 9cm (T2). This treatment (T2) was associated with the removal of lianas in the entire plot (T3). In addition, one of the treatments was a witness treatment, referred to treatment 1 (T1).

The blocks were defined by an environmental gradient of humidity:

- Block I – closest to the forest under the influence of Grota da Mina Stream (± 60 meters), environment most influenced by the riparian environment.
- Block II – far from the Grota da Mina stream (± 90 meters), environment under less influence of the riparian environment than block I.
- Block III – lesser influence of the riparin environment, largest distance from the stream and closest to the Cerrado *sensu stricto*.

Log scaling

M. urundeuva Allemão individuals located in the forest were scalled using the Hubber method (Soares et al., 2006), with the tree standing. The commercial height was measured using an electronic inclinometer and the diameter at breast height (DBH) using the measuring tape. Diameter measures made for the log scaling were taken at the base of the tree trunk, at 0.30m, 0.70m, 1.30m (DBH), 1.60m and at 1.80m relative to ground level.

Volumetric models

Seven volumetric models were adjusted with the DBH (measured at 1.30 m) (X_1), in centimeters, and tree height (X_2), in meters as independent variables and the total volume and the volume of the trunk with the bark as the dependent variables as models Lemos-Junior et al. (2016). The volumetric variables used are described below:

- Näslund: $Y= \beta_0X_1^2+ \beta_1X_1^2X_2+ \beta_2X_1X_2^2+\beta_3X_2^2$;
- Ogaya: $Y=X_1^2 (\beta_0+\beta_1X_2)$;
- Schumacher and Hall: $Y= \beta_0X_1\beta_1 X_2\beta_2$;
- Logarithmic Spurr : $Y= \beta_0(X_1^2X_2) \beta_1$;
- Honner: $Y=X_1^2/(\beta_0+\beta_1X_2)$;
- Takata: $Y= (X_1^2X_2) / (\beta_0+\beta_1X_1)$;
- Husch: $Y= \beta_0X_1\beta_1$.

Where:
X_1= Diameter at breast height (cm);
X_2= Height (m);
β_0 = Predicted value for the height when the diameter is zero ;
β_1 = slope of the line corresponding to the value of the first derivative;
β_2 = Rate of change in volume (m³) as it occurs variation in height (m), with constant DBH (cm);
β_3 = coefficient of the multivariate model;

The model selection criteria are based on the adjusted determination coefficient, the corrected residual standard and percentage error and graphical analysis of residuals.

Statistical analysis

The Kruskal-Wallis test (95% statistical significance) was carried out to compare the diametric growth of *M. urundeuva* Allemão among treatments. The Kruskal-Wallis test the non-parametric test used to compare three or more independent samples. It tells us if there is a difference between at least two of the treatments and does not require normal distribution. Therefore, there was no need for normality test.

Conclusion

A better development was recorded in regards to diameter increase and relative growth for individuals of this population, submitted to more intense silvicultural interventions (treatment 3). The hypsometric equation ($Y= 0.01688 (DBH)^3-0.2483(DBH)^2+1.824 (DBH) +0.9683$) was considered satisfactory for native species of seasonal semidecidous forests. All equations were highly significant, with high values of F, $p<0.05$, high coefficients of determination (R^2) and low error estimations (Syx). Despite the models being highly significant, some models exhibited different behaviors in regards to residue distribution. Some models had sinuous distributions which may occur due to a low number of repetitions.

Acknowledgements

The authors are grateful to the members of the Forest Inventory Laboratory (in Portuguese Laif) of the Federal University of Goiás, to Evandro and Catarina for the provision of the work in the Vagafogo Private Natural Heritage Reserve (RPPN).

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