Australian Journal of Crop Science AJCS
AJCS 9(11):1003-1009 (2015) ISSN:1835-2707

Effects of intra-specific tree competition on dendrometric parameters of *Peltophorum dubium*

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Abstract

The purpose of this research was to assess the performance of dendrometric parameters of *Peltophorum dubium* in several trees competition and stand age. The experiment was carried out in Brazil from 2009 to 2013. The experimental evaluations were done on variables such as cylindrical volume (CV), crown diameter (CD), diameter at beast height ($DBH_{1.3\ m}$), crown area (CA) and total height of tree (THT). The experiment was performed in a Nelder wheel competition, which is used in forestry research to test tree competition in a single plot. The interaction between the treatments (tree competition and stand age) was statistically significant ($p \leq 0.01$) for all variables assessed. The correlation between THT with the other dendrometric variables was strongly negative. These results might be attributed to the tree competition, where the tree competition was higher the THT was higher, as well. This increase in THT caused depletion in $DBH_{1.3\ m}$, CD, CA and CV. The higher THT did not guarantee higher $DBH_{1.3\ m}$ and CV of *P. dubium*, because these dendrometric parameters showed strong and negative correlation during 37 months of stand age. Even with these depletions on dendrometric parameters in higher tree competition, it was possible to affirm that *P. dubium* is a forestry species that show a high adaptation in the variation of the tree competition ranged from 179 to 1,324 tree ha^{-1} until 37 months of stand age.

Keywords: forestry, dendrometry, Nelder wheel.
Abbreviations: RSM_Response Surface Method; $DBH_{1.3\ m}$_Diameter at Breast Height of 1.3 m; THT_Total Height of Tree.

Introduction

The Mato Grosso do Sul state in Brazil, located at the middle center of the country, has a great potential to apply the integrated crops, livestock and forestry as systems, and in particular, the integrated livestock-forestry system. In this region there are many areas of extensive livestock being used for forage grass with some stage of degradation, consequently, there are problems with the offer of forage grass for the livestock in winter season (Euclides et al. 2010). Thus, the integrated livestock-forestry system may be adopted to recover this degraded forage grass (Almeida et al., 2013; Latawiec et al., 2014). The choice of appropriate tree species to establish the integrated livestock-forestry system is one of the most important steps to achieve success in the accomplishment of system implementation. As reported by Almeida et al. (2013), to reach success in the implementation of the integrated livestock-forestry system there are some important features in tree species such as ecologic compatibility with environment, perennial, fast growth, resistance to wind, capability to nitrogen fixation, tall straight trunks and smaller crown diameter.

These features are quite important for livestock-forestry system, because they allow the entrance of the light in forage grass to grow under the shadow of the trees crown. With the adoption of appropriate trees and forage grass species, it is feasible to improve the production and quality of the forage grass (Lin et al., 2001). It may increase the livestock performance in respect to weight gain of the cattle, milk production from cows, animal health and breeding. These benefits are due to the improvement of the environment because of the tree species in this integrated system can decrease the temperature of the environment and recycle the nutrients in the soil by the trees and forage grass (Fontes et al., 2014).

The *Peltophorum dubium* (Spreng) is a leguminosae that can be found in tropical semicaducifolia forest in the states of Goias, Minas Gerais, São Paulo and Mato Grosso do Sul, in Brazil. Furthermore, it is possible to find *P. dubium* in Atlantic forest of Brazil, as well. This tree species can reach 20 meters of height and 90 centimeters of truck diameter at breast height in 1.3 m of height ($DBH_{1.3\ m}$). But, the definition of the appropriate planting density must be well planned. Lower trees competition implies in the decrease of volumetric production per hectare, but it determines a larger single volume per tree (Folkard et al., 2012). As reported by Almeida et al. (2013), the wood from livestock-forestry system is available to timber, such as sawmills and veneer wood. However, in area with higher tree competition the diameter of the trees are smaller, because in this situation there are many trees covered by taller trees, in which the growth of these trees is lower (Coomes et al., 2007), but it is feasible to obtain higher value of the total cylindrical volume in the whole area.

One of the most limitations to study tree species is to use large areas to carry out the experiment to be able to assess the growth parameters in field. In 1964, the scientist Nelder proposed a design which is called nowadays as Nelder wheel competition. In this design, it is possible to assess many tree competitions in a small area (Nelder 1962). In this research, we used this design which makes possible the evaluations of many trees competition in a small area.

The integrated livestock-forestry system is commonly carried out with *Eucalyptus* sp, without any other option of species to insert in this system. The *P. dubium* is a tree species that may be turn in an option to apply in this cropping system of production mainly due to its wood density (0.75 to 0.90 g cm^{-3} in average) which is higher than *Eucalyptus* sp (0.40 to 0.63 g cm^{-3} in average). This is quite favorable for funds returns. However, the information on *P. dubium* is very rare. Therefore, it is necessary to study this forestry species to understand its performance in several tree competitions. Based on the information above, this research was carried out with the purpose to assess the performance of dendrometric parameters of *Peltophorum dubium* in several tree competitions and stand ages.

Results and Discussion

Behaviour of P. dubium tree competition on total height and diameter at breast height

The interaction between tree competition and stand age was statistically significant ($p \leq 0.05$), which was possible to adjust the response surface methodology (RSM). The total height of tree (THT) showed a direct relationship between the tree competition and stand age (13, 25 and 37 months after planting) (Fig. 1A). The THT was considered fine for native trees species as the case of *P. dubium*. The *P. dubium* height in this experiment reached 1.9 m at the stand age of 13 months. In results of Oliveira et al. (2009), they found high mean range (1.3 to 3.5 m) for native trees (*Samanea tubulosa, Cedrela fissilis, Peltophorum dubium, Acacia cebil* and *Swietenia macrophylla*). These results were obtained in 12 months of stand age.

We observed that in any of the evaluated stand age, even the lowest stand age (13 months), there was significant influence of the tree competition on THT (Fig. 1A). As reported by Benvenuti-Ferreira et al. (2009) the tree competition of *P. dubium* affected the THT from the six year after planting. It showed higher THT in higher tree competition.

Based on the results of RSM (Fig. 1A), it is feasible to assure that during the first three years of growth, the highest THT (4.33 m) was obtained with 1,185 trees ha^{-1}. The effect of higher THT in higher tree competition has already observed in *Eucalyptus* spp. (Forrester et al., 2013) and other native tree around the world (Xue et al., 2011). The explanation for this effect is the interception of light for taller trees, in which the trees grow more in height than diameter. This behaviour was observed here, because the correlation between THT and $DBH_{1.3\ m}$ was strongly negative (r=-0.980) (Table 1).

Besides the influence of the trees competition and stand age, the soil quality might be one important factor that changes the trees response in respect to the average height of the *P. dubium*. In this experiment, the soil analysis showed high level of the nutrients content, indicating that the soil fertility was not a limited factor for the growth of the trees. In respect to the $DBH_{1.3\ m}$, at 13 months of stand age, the mean value was 3.9 cm, which was considered a good performance. According to Oliveira et al. (2009), the mean values range of 2.2 to 5.4 cm was measured at 12 months of stand age. These values were reached at the integrated livestock-forestry system with many native trees species. In higher tree competition, it is common to observe that the trees are much thinner. This was also reported by Peltola et al. (2009) and Lida et al. (2012). The results of this experiment followed this tendency, what was feasible to scrutinize that the highest values of $DBH_{1.3\ m}$ (7.25 cm) were found in the smallest tree competition (179 tree ha^{-1}) (Fig. 1B).

The $DBH_{1.3\ m}$ showed interactive reaction for tree competition and stand age ($p \leq 0.05$). In the equation adjusted for the data of $DBH_{1.3\ m}$ (Fig. 1B), variable tree competition with positive signal in this equation was identified. This positive signal means that there is the smallest point in trees competition for any stand age. Other important observation is that the smallest point is located in the highest tree competition. With the increase of the tree competition the decrease of $DBH_{1.3m}$ was observed. In relation to trees $DBH_{1.3\ m}$, even with the decrease in $DBH_{1.3\ m}$ with the increasing of tree competition, it is feasible to infer that at least during the three first years the *Peltophorum dubium* showed a good adaptation in higher tree competition. This feature is quite interesting for planting in thinner management, because in this management system it is preferable to work with species that grow in diameter even in high tree competition for a longer period of time before the first partial thinning.

It is quite important to know that the results indicated that the decrease of $DBH_{1.3\ m}$ is related to the increase of tree competition. However, this decrease is not so high that makes the use of tree competition until 1.324 trees ha^{-1} impossible. Based on the results obtained, the $DBH_{1.3\ m}$ in 37 months of stand age in 179 trees ha^{-1} was 7.25 cm, while in contrast at the same stand age, the trees competition of 1,324 trees ha^{-1} showed 5.88 cm. It means that higher trees competition decrease 19% of $DBH_{1.3\ m}$. Nevertheless, it is important to emphasize that the trees competition of 1,324 trees ha^{-1} represents 7.4 turns higher the number of trees per hectare. This increase in trees per hectare may results in gain on economic financial.

The P. dubium tree competition effects on its crown diameter and area

The effect of trees competition and stand age was observed on crown diameter of *P. dubium* tree (Fig. 2A). The highest values of crown diameter were obtained in smaller tree competition and higher stand age (37 months). These effects were obtained for $DBH_{1.3\ m}$, as well. The analysis of correlation showed strong and positive (r=0.961) correlation between crown diameter and $DBH_{1.3\ m}$ (Table 1). The crown diameter of tree and $DBH_{1.3\ m}$ is strongly correlated (Nutto et al., 2006, Johnson et al., 2009 and Schuler et al., 2013), what may explain this similarity of results between these variables. These similar results for $DBH_{1.3\ m}$ and crown diameter are resulted of the higher correlation between trees competition and stand age, which is considered strong for many Brazilian native trees species (Sanquetta et al., 2011). Based on the RSM, it was calculated the highest and smallest point of crown diameter in each stand age evaluated, being possible to obtain the highest limited tree competition to develop the crown diameter of *Peltophorum dubium*. On one hand, the highest tree competition (1,324 trees per hectare) in 37 months of stand age showed the smallest value of crown diameter (4.21 m) (Fig. 2A). On the other hand, the smallest tree competition (179 trees per hectare) in 37 months of stand

Table 1. Evaluation of correlation matrix between dendrometric variables at 37 months of tree stand age.

	THT	$DBH_{1.3\ m}$	CD	CA	CV
THT	1	-0.980	-0.948	-0.950	-0.918
$DBH_{1.3\ m}$		1	0.961	0.964	0.978
CD			1	0.999	0.942
CA				1	0.947
CV					1

THT= Total height of tree (m); $DBH_{1.3\ m}$= Diameter at breast height (cm); CD= Crown diameter (m); CA=Crown area (m^2); CV=Cylindrical volume (m^3).

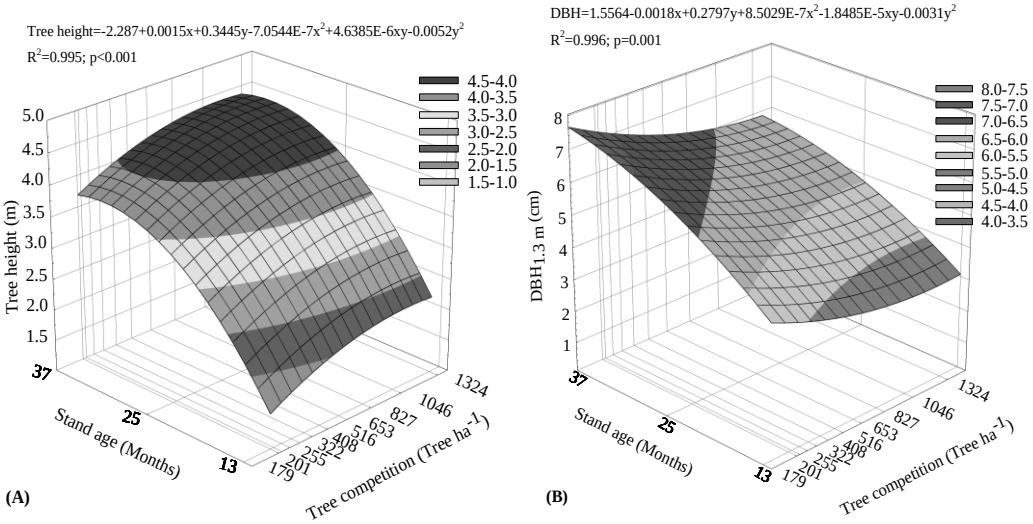

Fig 1. Surface response of total height (A) and $DBH_{1.3\ m}$ (B) of *Peltophorum dubium* in response to the trees competition and stand age (months after the seedling planting).

age showed the highest value of crown diameter (5.1 m) (Fig. 2A). The difference between the two tree competitions was 17.5%. It means that *P. dubium* trees can support higher tree competition in the first three years of stand age, with values of trees competition close to *Eucalyptus* spp in Brazilian forestry, which are 1,667 *Eucalyptus* trees per hectare. In evaluation of *Eucalyptus urophylla* in integrated livestock-forestry system under different spatial design (3x2 m, 6x4 m and 10x4 m) and stand age of trees (12, 18 and 24 months),, Araújo et al. (2011) were observed that the crown diameter was not affected by trees competition until 24 months after planting. In the continued evaluation of crown feature, the area on the ground occupied by crown was calculated. As the area on the ground occupied by crown is derived of crown tree competition, the behavior of both variables were similar, which resulted in smaller values in higher trees competition (Fig. 2B). These results are due to the fact that *P. dubium* trees reach higher height in environment with more competition, in which the crown area is smaller.

The trees crown are strongly influenced by trees competition and their dimension determines the growth of the truck, because the leave mass is one of the most important factor that determines the growth of the truck (Xu and Harrington, 1998). The results showed that with the increase of stand age the tree competition necessary to reach the point of smaller crown area increases, as well (Fig. 2B). The crown diameter and area were strongly and positive correlated with cylindrical volume, r=0.942 and r=0.947, respectively (Table 1).

Effect on cylindrical volume of P. dubium in several tree competitions

In this study, the evaluation of the cylindrical volume per tree (CVT) of *P. dubium* trees was chosen due to lack of study on shape of *P. dubium.* Fig. 3 shows that higher values of CVT are found in low trees competition and only near the stand age of 37 months. The response surface indicates that the development of cylindrical volume is still increasing because of the curve of this variable in any trees competition. A portion of this result has already expected because the truck volume is strongly correlated with the size of the tree crown. The correlation of CVT with the crown diameter was strong and positive (r=0.942) (Table 1).

The cylindrical volume of tree is considered as the most worth properties of the trees for commercial purpose of forestry products. The evidences show that *P. dubium* species is adequate in many kinds of arrangements to compose integrated crop-livestock-forestry system, especially the integrated livestock-forestry system, if it was considered just dendrometric parameters. The variation in tree competition for this species showed a good performance which makes the integrated system possible (livestock-forestry) in tree competition ranged from 179 to 1324. By the way, it is necessary to define the degree of shadow tolerance and water, light and nutrients competition in future research for these arrangements with crops, forestry and forages grass.

Table 2. Some initial soil physical and chemical properties in the soil from the experimental area.

Soil properties	Depth (cm)
	0-20
pH ($CaCl_2$)	5.7
SOM (g kg^{-1})	32
CEC (cmolc dm^{-3})	11.4
P (mg dm^{-3})	8
K^+ ($cmol_c$ dm^{-3})	0.44
Ca^{2+} ($cmol_c$ dm^{-3})	6.1
Mg^{2+} ($cmol_c$ dm^{-3})	2.6
H+Al ($cmol_c$ dm^{-3})	2.3
BS (%)	79.2
Clay (%)	76.2
Silt (%)	4.5
Sand (%)	19.3

SOM: Soil Organic Matter; CEC: Cation Exchange Capacity; total acidity pH 7.0 (H^+ +Al^{3+}); Exchangeable (KCl 1 mol L^{-1}) Ca and Mg; BS: Base Saturation=(∑cations/CEC)x100.

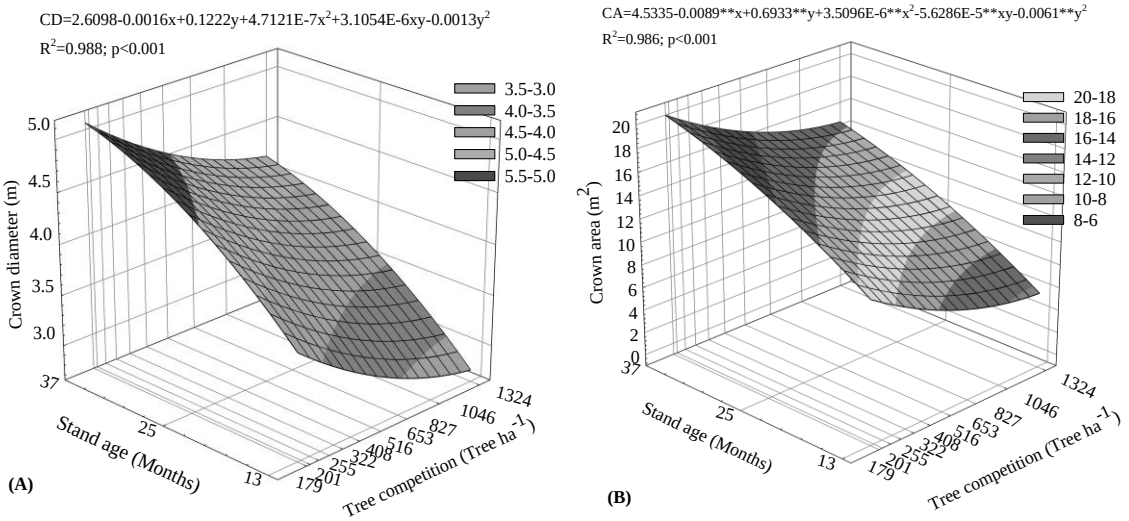

Fig 2. Surface response of crown diameter (A) and area (B) of *Peltophorum dubium* trees in function of trees competition and stand age (months after the seedling planting).

Table 3. Trees competition in each circle of the Nelder wheel competition.

Series	Circle	Radial distance (m)	Area per tree (m^2)	Trees competition (trees ha^{-1})
		r_n		
1	0	19.60	-	-
2	1	20.79	-	-
3	2	22.05	7.55	1324
4	3	23.39	8.50	1177
5	4	24.81	9.56	1046
6	5	26.31	10.75	930
7	6	27.91	12.10	827
8	7	29.60	13.61	735
9	8	31.40	15.31	653
10	9	33.30	17.22	581
11	10	35.32	19.37	516
12	11	37.46	21.79	459
13	12	39.73	24.51	408
14	13	42.15	27.59	362
15	14	44.70	31.03	322
16	15	47.41	34.90	286
17	16	50.29	39.27	255
18	17	53.34	44.18	226
19	18	56.58	49.71	201
20	19	60.01	55.92	179
21	20	63.65	-	-
22	21	67.51	-	-

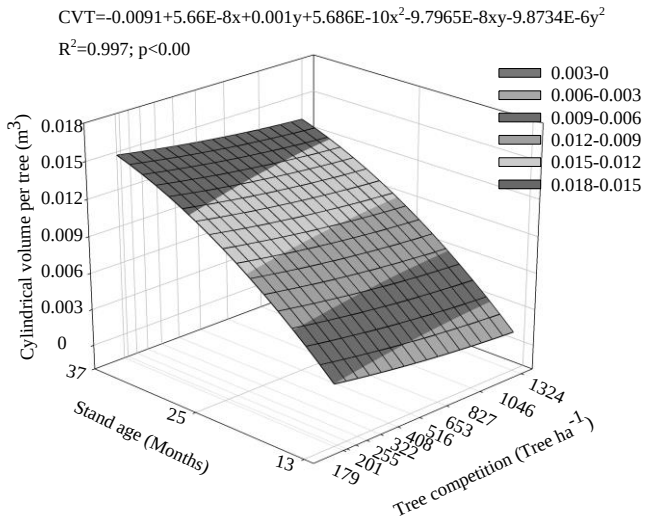

Fig 3. Surface response of cylindrical volume per *Peltophorum dubium* trees in function of trees competition and stand age (months after the seedling planting).

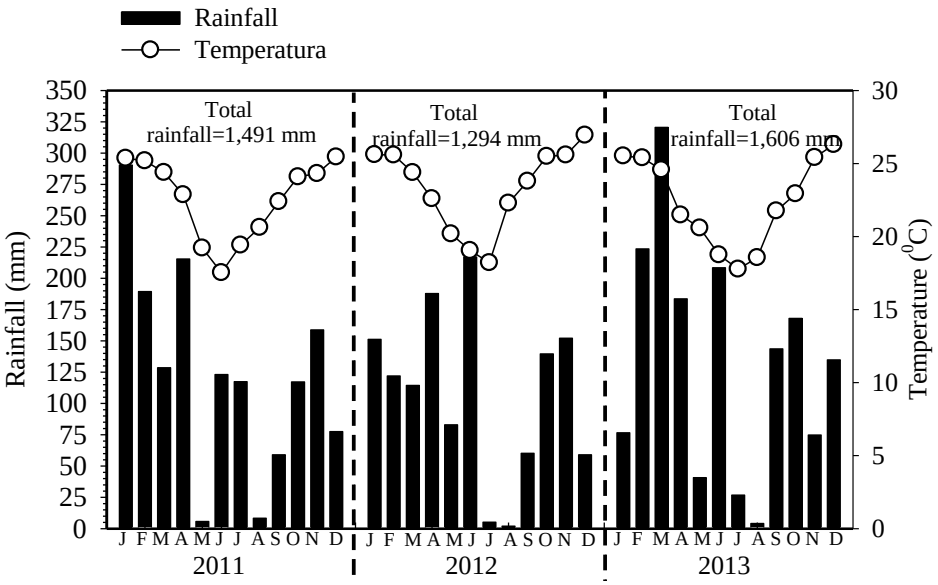

Fig 4. Rainfall and temperature monthly in the period from January 2011 to December 2013. J=January, F=February, M=March, A=April, M=May, J=June, J=July, A=August, S=September, O=October, N=November, D=December.

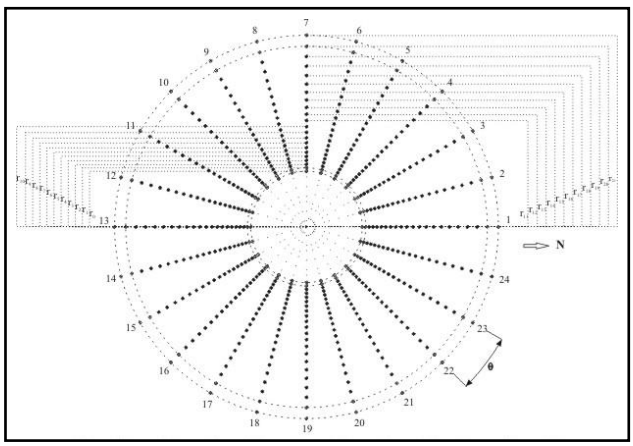

Fig 5. Scheme of Nelder Wheel to define the tree competition of *P. dubium*.

Materials and Methods

Location of the experiment

The experiment was carried out during the years 2009 to 2013 on the experimental farm of Universidade Federal da Grande Dourados (UFGD), followed by geographic coordinates, 22°13'18.54"S, 54°48'23.09" W, and average altitude 412 m. The experimental area belongs to the municipality of Dourados, state of Mato Grosso do Sul, Brazil. The weather condition is classified according to Köppen-Geiger (Fietz, 2008). The rainfall and temperature in the region of the experimental site is showed in Fig. 4.

Soil physical and chemical properties

The experimental site topography was under 5% of slope. The soil of the study area was classified in a dystroferric Red Latosol, according to Santos et al. (2013). The landscape was originally covered by savanna (Brazilian cerrado). The values of soil physical and chemical properties were obtained at the depth of 0 to 20 cm, as the following results in Table 2. These analyses were accomplished at the Laboratory of Soil Fertility from Universidade Federal da Grande Dourados (UFGD).

Implementation of the experiment

The whole area of the experiment was 1.33 hectares. The tillage of the area was carried out with heavy harrow and leveling harrow, followed by the planting of 528 *P. dubium* seedlings in December 2009. At the same day of planting, to supply the nutritional requirement of *P. dubium*, each seedling was fertilized with 150 grams of N-P-K (6-30-6 + 1% B + 0.5 % Zn + 0.5% Cu). The application of fertilizer was established in two portions of 75 g, both of them was put 15 cm far from the stems of the seedlings.

The cover fertilization was applied 30 days after the planting. In this occasion, 120 g of the fertilizer formulated as 20-00-20 (N-P-K) was used. The location of the fertilizer was in the area around the tree, being applied in the end of the crown projection. The arrangement of the trees followed the design proposed by Nelder (1962) (Fig. 5). The trees distances and angles were determined according to the equation 1, 2 and 3 (Namkoong, 1965):

1 $$r_n = r_0 . \propto^n$$

2 $$A_n = \tan\left(\frac{\theta}{2}\right).\left[\frac{r_n^2}{4}\right].f(\alpha)$$

3 $$f(\alpha) = (1+\alpha)^2 - (1+\alpha^{-1})^2$$

Where,
r_n, radial distance to the last trees,
$r_{0,}$ radial distance to the first tree in each ray,
A_n, it means the area of tree in each ray,
θ, angles between adjacent rays
α, Constant that determines the rate of change in space growth.

The Nelder Wheel competition was defined by 22 concentric circles, with distance from the center ranging between 19.60 m (r_0) to 67.51 m (r_{21}). The decrease tax was 12.5% in the trees densities from the (r_0) to (r_{21}), which resulted in the increase of 6.066% in the distance for each new circle, that represented α=1.06066. Both inner and outer circles were considered borders. The angle θ between the Nelder Wheel rays was of 15°, resulting in 24 rays and 24 seedlings were planting in each ray. The ray number 1 was located in the direction of North. This arrangement allowed the evaluation in the experimental circles from r_2 to r_{19} of the trees densities showed in Table 3.

Treatments and experimental design

The experimental design was factorial (3×10) with 24 repetitions. The treatments were accomplished by 10 tree competition (179, 201, 255, 322, 408, 516, 653, 827, 1046 and 1324 trees ha^{-1}) in three stage of stand age (13, 25 and 37 months after tree planting).

Plant material and measurement of dendrometric variables of P. dubium

The dendrometric variables were measured at 13, 25 and 37 months after tree implementation, which was considered the stand age. In all trees, the circumference at 1.3 m of height (C1.3), the total height of trees (THT) and the crown diameter (Cd) were measured. To obtain these measurements the tape-measure and graduated scale were used. Based on these results, the diameter of trunk ($DBH_{1.3\ m}$= $C_{1.3}$/pi), the transversal area of trunk (g= pi/($D_{1.3}^2$/4) and the cylindrical volume (CV= g x THT) was calculated.

To determine the crown diameter (Cd) two measurements perpendiculars of the crown projection were carried out. The average values in each variable were derivative of each circle with the same tree competition space (Redmond et al., 2005).

Statistical analysis

The data were submitted to analysis of variance (ANOVA) and in the case that interactions among the treatments (tree competition and stand age) observed, the surface response methodology (SRM) was applied. The statistical analysis was performed using the program SPSS for Windows, version 11.0.0 (SPSS Inc., Chicago, IL, EUA).

Conclusion

The *P. dubium* trees height showed direct relationship with tree competition. The $DBH_{1.3\ m}$ and crown diameter as well as the crown area and cylindrical volume showed inversely relationship with the trees competition. All dendrometric parameters showed strong correlation at 37 months of stand age. Higher THT did not guarantee higher $DBH_{1.3\ m}$ and cylindrical volume of *P. dubium*, because these dendrometric variables showed strong and negative correlation. In 37 months of stand age, higher THT depleted $DBH_{1.3\ m}$, crown diameter; crown area and cylindrical volume were observed. But this depletion is not so high that makes the use of trees competition until 1.324 trees ha^{-1} impossible. Even with this depletion dendrometric variable in higher tree competition, it was possible to affirm that the *P. dubium* is a forestry species with high adaptation values in the variation of the tree competition ranged from 179 to 1,324 tree ha^{-1} until 37 months of stand age. These results indicate that *P. dubium* may be introduced as tree species to make part of an integrated system (crop-livestock-forestry) in tree competition ranged from 179 to 1,324.

Acknowledgement

The authors are grateful to Universidade Federal da Grande Dourados (UFGD) for the collaboration of researchers and CNPq (National Council for Scientific and Technological Development CNPq) for the financial support to the accomplishment of this work.

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