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Performance of *Peltophorum dubium* under intraspecific tree competition and cardinal directions as possibility for integrated livestock-forestry systems

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Peltophorum dubium **can be an alternative of forestry species to be included in integrated crop-livestock-forestry systems in tropical region. The aim of this research was to evaluate the performance of *P. dubium* under intraspecific tree competition and cardinal directions to measure the possibility of introduction in integrated livestock-forestry systems. The experiment was performed in a Nelder Wheel competition, which is used in forestry research to test tree competition. The experimental design was factorial (10×2×5) with 12 replicates. The treatments were accomplished by ten tree competitions (159, 201, 255, 322, 408, 516, 653, 827, 1,046 and 1,324 trees ha^{-1}), two cardinal directions (North-South and East-West) and five times after planting (12, 18, 24, 30 and 36 months). The highest tree competition (1,342 trees ha^{-1}) in 36 months after planting, promoted increase in the cylindrical volume of the tree in both North-South and East-West cardinal directions. Nevertheless, the cardinal direction East-West was profitable to increase tree height, diameter at breast height (DBH), cylindrical volume per tree and cylindrical volume per hectare. The DBH measured in 24 months after planting was 5.0 cm, which is considered the minimum DBH to introduce livestock into the integrated system without significant damage on trees. Regarding these preliminary results in the first three years, *P. dubium* was promising as Brazilian native species to be inserted in integrated livestock-forestry system or single forestry as an option for *Eucalyptus* spp.**

Key words: Forestry, dendrometry, Nelder Wheel, integrated systems, agroforestry.

INTRODUCTION

Sustainable agricultural systems have increased through the last decade. The integrated crop-livestock-forestry systems (ICLFS) have pointed out as a quite promisor production system to be used to recover degraded pasture in Brazilian Cerrado (Almeida et al., 2013). ICLFS is defined as integrated production system that enables to have three components (crop, livestock and forestry) at the same area, with at least two components at the same time. Nevertheless, forestry is always in the area and determines the cycle of the system. ICLFS allows increase in the diversity of products at the same production area. In this ICLFS, trees species might be well defined because of its impact on crop, pasture and livestock combined in integrated systems of production.

The benefits of trees in integrated systems for animal grazing is related to better microclimate and animal thermal comfort (Karvatte et al., 2016). However, the trees can result in negative effects on grain crops yields in tree crop zone (Nasielski et al., 2015) and pasture in case of higher tree competition (Burner and Brauer, 2003). As reported by Franchini et al. (2014), decrease in soybean grain yield can be related to the age of the trees, which was not observed significant effects in the first two year of *Eucalyptus* species age; nonetheless, the decrease of soybean grain yield can achieve 27% after four years of *Eucalyptus* spp. establishment.

Nevertheless, the most common ICLF systems use *Eucalyptus* spp. as tree species because of faster growth and enables to introduce livestock sooner than native forest species; besides *Eucalyptus* spp., multiple use and high commercial value (Grossman, 2015). Even with many positive feature of *Eucalyptus* spp., the possibility to have native forestry species, as *Peltophorum dubium,* might be considers. Monocrop of *Eucalyptus* spp. is not profitable for balanced ecosystems; this way is quite relevant to have other forestry species as the alternative to maximize the diversity of the ecologic system.

As possibility of native species, *P. dubium* shows some features that have been pointed as a profitable species to introduce in ICLS with some positive features as narrow crown area (Matos et al., 2015), which increases the incidence of sunlight in crops and pasture cultivated under the trees. Soybean, rice and corn as crop components and *Brachiaria* species as pasture are profitable to be inserted in ICLFS. *P. dubium* (Spreng) is a leguminosae found in tropical seasonal semi-deciduous forest in Brazil (Lisi et al., 2008). Moreover, *P. dubium* can be found in Atlantic forest of Brazil and can reach 20 m of height and 90 cm of trunk diameter at breast height (DBH).

As reported by Lima et al. (2015), *P. dubium* is very adaptable in different regions, which may imply in different response with the environment conditions. To insert the *P. dubium* in an integrated crop-livestock-forestry system is quite important to know the growth rate, because tree height and DBH determine the moment to introduce the livestock into the integrated system of production. Faster growth shown by *Eucalyptus* spp. makes this species widely used in tropical climate in integrated systems (Grossman, 2015). However, the *P. dubium* shows higher wood basic density (0.65 g cm^{-3}) in ten-years-old (Vivian et al., 2010) in comparison to *Eucalyptus grandis* (0.52 g cm^{-3}), at the same age (Githiomi and Kariuki, 2010).

The preferable destination of wood in ICLS is for timber, as veneer wood and sawmills (Almeida et al., 2013), which turn *P. dubium* as a profitable option due to its higher wood basic density. To obtain high quality of wood from integrated system is necessary to conduct the trees with pruning and find the profitable plant density and cardinal directions to improve wood quality and growth.

The tree competition has been pointed as the variable that affects some dendrometric features. Matos et al. (2015) observed decreasing in cylindrical volume of trees in higher *P. dubium* competition (1,324 trees ha^{-1}), on the other hand, lower tree competition results in less volumetric trunk production per hectare (Folkard et al., 2012). The ideal tree competition might be found for *P. dubium* to improve the recommendation as native species to be chosen as forest component in ICLS. The aim of this research was to evaluate the performance of *P. dubium* under intraspecific tree competition and cardinal directions to be possible inference of some dendrometric parameters to assess the viability of inserting the native species in integrated livestock-forestry systems.

MATERIALS AND METHODS

Location of the experiment

The experiment was carried out from November 2010 to November 2013 on the experimental field of Brazilian Agricultural Research Corporation (Embrapa Western Agriculture), followed by geographic coordinates, 22°33'07'' S, 55°38'37'' W, and average altitude 496 m, the experimental area belongs to the municipality of Ponta Porã, state of Mato Grosso do Sul, Brazil. The weather condition is classified as Aw Köppen-Geiger (Fietz, 2008), with rainy summer and dry winter. The average rainfall and temperature in the region of the experimental is shown in Figure 1.

Soil physical and chemical properties

The experimental site topography was under 5.0% of slope. The soil of the study area was classified as dystroferric Red Latosol, according to Santos et al. (2013), the landscape originally covered

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Abbreviations: DBH, Diameter at breast height; **TH,** tree height.

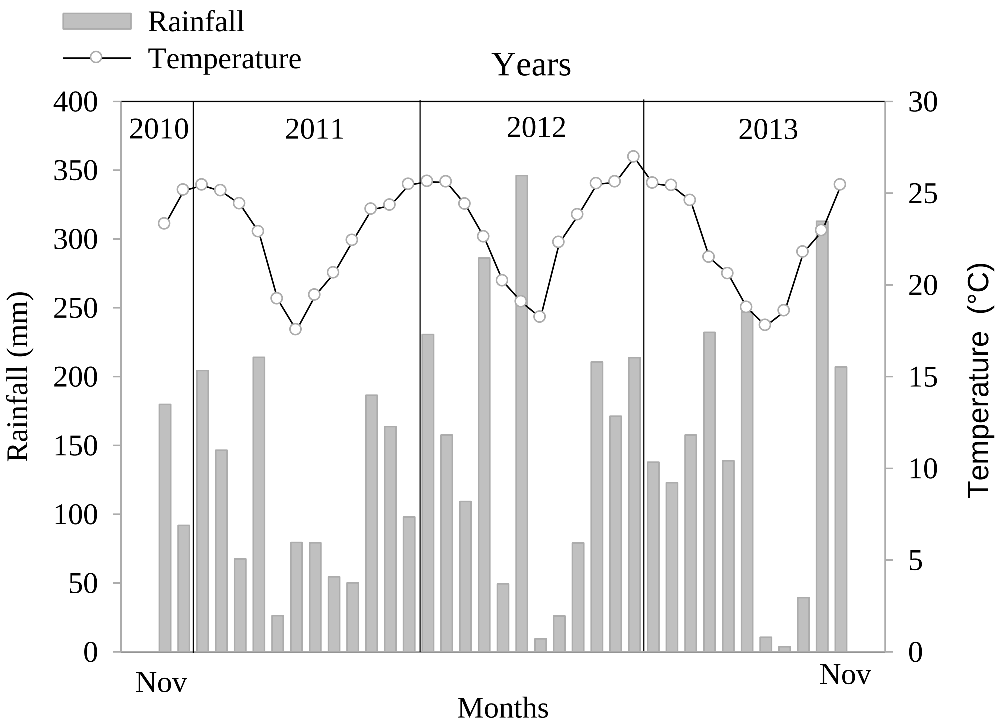

Figure 1. Monthly average rainfall and temperature in the period from November 2010 to November 2013.

Table 1. Some initial soil physical and chemical properties from the experimental area.

Soil properties	Depth (cm)	
	0-10	10-20
pH ($CaCl_2$)	4.42	4.26
SOM (g kg^{-1})	31.78	28.27
CEC ($cmol_c$ dm^{-3})	4.43	3.49
P (mg dm^{-3})	16.86	7.03
K^+ ($cmol_c$ dm^{-3})	0.37	0.21
Ca^{2+} ($cmol_c$ dm^{-3})	2.40	1.46
Mg^{2+} ($cmol_c$ dm^{-3})	0.95	0.53
H+Al ($cmol_c$ dm^{-3})	10.65	11.46
BS (%)	3.72	2.19
Clay (%)	54.9	57.0
Silt (%)	8.68	8.70
Sand (%)	36.43	34.30

SOM: Soil organic matter; CEC: cation exchange capacity; total acidity pH 7.0 (H^+ +Al^{3+}); Exchangeable Ca and Mg (KCl 1 mol L^{-1}); BS: Base Saturation=(∑cations/CEC)x100.

by savanna (Brazilian Cerrado biome). The values of soil physical and chemical properties were obtained at 0 to 10 and 10 to 20 cm depth, as the following results in Table 1. These analyses were accomplished at the Laboratory of Soil Fertility from Embrapa Western Agriculture.

Implementation of the experiment

The whole area of the experiment was 1.33 hectares, defining according to the Nelder Wheel design. The soil tillage was carried out with heavy harrow and leveling harrow, followed by the planting

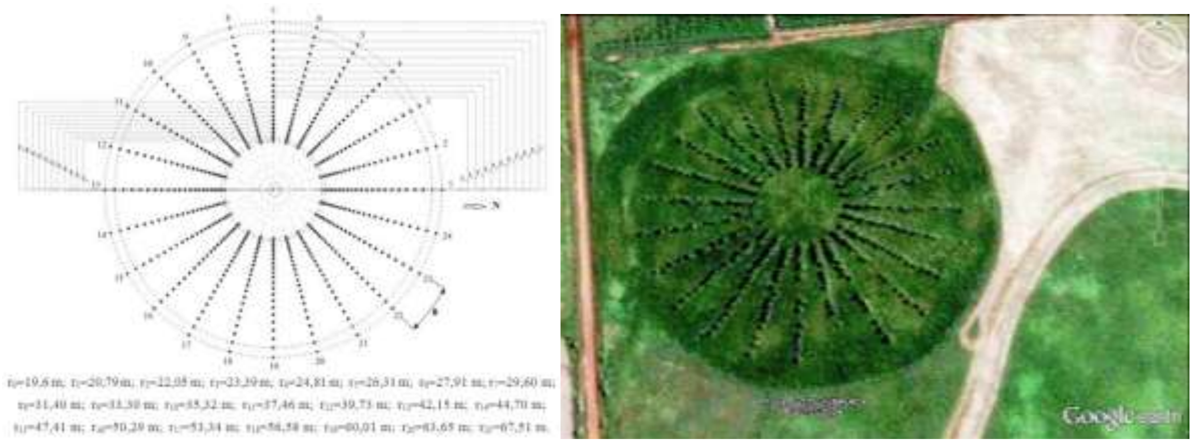

Figure 2. Scheme of Nelder Wheel to define the tree competition of *P. dubium*, and the image of the experiment on the field.

of 528 *P. dubium* seedlings with height of 20 cm in November, 2010. This seedling height is defined as the ideal one for field planting. In order to supply the nutritional requirement of *P. dubium,* each seedling was fertilized with 150 g of N-P-K (6-30-6 + 1% B + 0.5% Zn + 0.5% Cu), at the same day of planting. The application of fertilizer was established in two portions of 75 g; both of them were put in 15 cm apart from the stem of the seedling.

The topdressing fertilization was applied 30 days after the planting. In this occasion, 120 g of the fertilizer formulated as 20-0-20 (N-P-K) was used. The location of the fertilizer was in the area around the tree, being applied at the end of the crown projection. The arrangement of the trees followed the design proposed by Nelder (1962) (Figure 2). The trees distances and angles were determined according to the Equations 1, 2 and 3 (Namkoong, 1965):

$$r_n = r_0 . \propto^n \quad (1)$$

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

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

where r_n is the radial distance to the last trees, r_0 is the radial distance to the first tree in each ray, A_n means the area of tree in each ray, θ is the angles between adjacent rays, and α is the 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) and 67.51 m (r_{21}). The decrease rate was 12.5% in the trees densities from (r_0) to (r_{21}), resulting in the increase of 6.066% in the distance for each new circle, represented by 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 implanted in each ray (Figure 2). The ray number one was located in the direction of the north. This arrangement allowed the evaluation in the experimental circles from r_3 to r_{21} of the trees densities as shown in Table 2.

Treatments and experimental design

The experimental design was factorial (10×2×5) with 12 repetitions (12 trees per Nelder Wheel arc in each cardinal orientation evaluated). The treatments were accomplished by ten tree competitions (159, 201, 255, 322, 408, 516, 653, 827, 1046 and 1324 trees ha^{-1}), two cardinal directions (North-South and East-West) and five times after planting (12, 18, 24, 30 and 36 months).

Measurement of dendrometric variables of *P. dubium*

The dendrometric variables were measured at 12, 18, 24, 30 and 36 months after seedling planting. In all trees, the circumference at 1.3 m of height (C1.3), the tree height (TH) and cylindrical volume per tree (CVT) were measured. In order to obtain these measurements, the tape-measure and graduated scale were used. Based on these measurements earlier, 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 × TH) were defined. The cylindrical volume per hectare (CVH) was defined with the relation of CVT and tree densities evaluated.

Statistical analysis

The variables evaluated in the experiment were submitted to the analysis of variance (ANOVA) by the *F*-test. The response surface was adjusted in case of significant interaction ($p<0.01$) between trees competition and time after planting. The simple Pearson's correlation matrix of dependent variable was performed to obtain the degree of relationship between them. In case of significant correlation ($p<0.05$), the strength was defined as Table 3, according to Hinkle et al. (2003). These statistical analyses were carried out with the software SPSS for Windows, version 11.0.0 (SPSS Inc., Chicago, IL, EUA).

RESULTS AND DISCUSSION

P. dubium tree competition impact on tree height

The dendrometric parameters of *P. dubium* changed with the treatments applied (Table 4). The tree height (TH) and diameter at breast height (DBH) were affected ($p<0.01$) by tree competitions, time after planting and the

Table 2. 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	62.91	159
22	21	67.51	-	-

Table 3. The rule for interpreting the size of Person's correlation coefficients.

Size of correlation	Interpretation
0.90 to 1.0 (-0.90 to -1.0)	Very high positive (negative) correlation
0.70 to 0.90 (-0.70 to -0.90)	High positive (negative) correlation
0.50 to 0.70 (-0.50 to -0.70)	Moderate positive (negative) correlation
0.30 to 0.50 (0.30 to -0.50)	Low positive (negative) correlation
0 to 0.30 (0 to -0.30)	Negligible correlation

Table 4. Summary of analyses of variance (ANOVA) for tree height (TH), diameter at breast height (DBH), cylindrical timber volume per tree (CTV), and cylindrical volume per hectare (CVH) of *Peltophorum dubium.*

Source of variation	*df*	Mean square			
		TH (m)	DBH (cm)	CVT (m^3)	CVH (m^3 ha^{-1})
Tree competition (TC)	9	14.22**	14.32**	0.000456**	2467.049**
Time after planting (TAP)	4	337.65**	365.38**	0.009281**	3370.711**
Cardinal directions (CD)	1	0.08^{ns}	0.28^{ns}	0.000008^{ns}	0.0113*
TC × TAP	36	0.31^{ns}	0.28^{ns}	0.000037**	226.6965**
TC × CD	9	1.14**	0.68*	0.000028*	28.1409**
TAP × CD	4	0.70^{ns}	0.49^{ns}	0.000006^{ns}	1.8094^{ns}
TC × TAP × CD	36	0.13^{ns}	0.13^{ns}	0.000006^{ns}	5.256**
Residual	814	0.41	0.31	0.000014	14.279
CV (%)	-	13.8	11.8	36.5	20.6

^{ns}, **, * no significant effects, significant at level of 1 and 5% by F-value, respectively. Df: Degree of freedom.

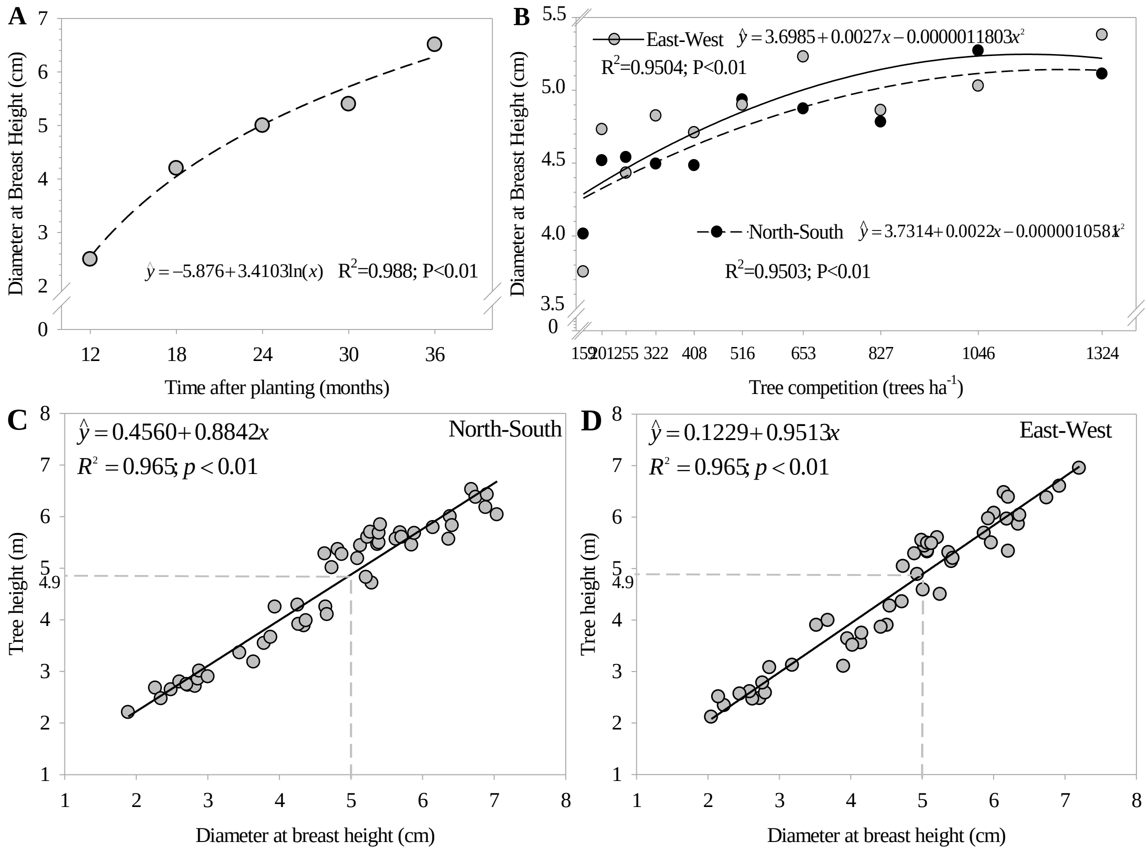

Figure 3. Diameter at breast height (DBH) of *Peltophorum dubium.* (A) Effects of time after planting on DBH; (B) Effects of tree competition on DBH; (C) correlation between tree height *vs* DBH in North-South cardinal direction; (D) correlation between tree height *vs* DBH in East-West cardinal direction.

interaction between tree competitions *vs*. cardinal directions (Table 4). The tree height of 2.62 m (12 months after planting) was compatible for what was obtained by Oliveira et al. (2009), who obtained the range of 1.5 to 3.5 m at 12 months after planting for native species including *P. dubium*. On the other hand, tree height was 29.1% higher than the average found by Matos et al. (2015) for *P. dubium* in the same region of studying in 12 months after planting. As reported by Carvalho (1994), *P. dubium* showed high adaptive plasticity, resulting in different behavior among the same location of plantation.

The height of *P. dubium* showed faster growth between 12 and 24 months after planting and slow between 24 and 36 months. The absence of growth between 24 and 30 months may be related to the freezing occurred in winter season (Figure 1), which may have compromised the growth during this period; anyway, the growth in summer season after fall-winter season was not as fast as the initial growth which comprised between 12 and 24 months.

The cardinal directions affected the tree height (Figure 3B). The cardinal direction East-West showed improvement in tree height in comparison with North-South (Figure 3B). Tree competition of 1047.6 trees ha^{-1} was necessary to achieve the highest tree height in cardinal direction North-South, occasioning in 4.88 m of tree height, and cardinal direction East-West of tree rows required 1143.78 trees ha^{-1} to achieve the highest tree height (5.24 m). The row directions of East-West promoted increase of 6.87% of *P. dubium* height, which is possibly related to improvement of sunlight use efficiency. The East-West cardinal orientation of the tree row is quite important to have higher light incidence, temperature and canopy openness (Camargo et al., 2011).

Diameter at breast height under tree competition and cardinal directions

The diameter at breast height (DBH) of *P. dubium* was affected (p<0.01) by tree competition, time after planting and the interaction between tree competition *vs*. cardinal directions (Table 4). DBH of 5.0 cm was achieved in 24 months after planting (Figure 3A), which may be considered a profitable time for grazed animal introduction in the integrated crop-livestock-forestry systems. In order

Table 5. Pearson´s correlation between dendrometric variables.

Correlation	North-South				East-West			
	TH	DBH	CVT	CVH	TH	DBH	CVT	CVH
TH	1	0.965	0.936	0.696	1	0.965	0.948	0.710
DBH	-	1	0.965	0.710	-	1	0.954	0.684
CVT	-	-	1	0.774	-	-	1	0.788
CVH	-	-	-	1	-	-	-	1

TH: Tree height (m); DBH: diameter at breast height (cm); CVT: cylindrical volume per tree (m^3); CVT: cylindrical volume per hectare (m^3 ha^{-1}).

to introduce cattle, DBH needs to be above 5.0 cm to avoid significant damage caused on tree trunk in DBH lower than 5.0 cm (Sanchez-Velasquez and Pineda-Lopez, 2010). Even with this recommendation, the improvement in researches related to *P. dubium* associated to stocking rate, cattle weight and damage caused on tree through different DBH with the introduction of livestock might be investigated.

The tree competition (1144 trees ha^{-1}) in East-West cardinal direction showed higher DBH (5.24 cm) than North-South cardinal direction, which showed 4.88 cm of DBH in 1,040 trees ha^{-1} (Figure 3B). The results showed by *P. dubium* in relation to DBH were not expected because in lower tree competition, DBH decreased, however, these results can be associated with other factors as wind and lower tree competition that affected negatively the growth in diameter and tree height.

The cardinal directions North-South and East-West of the tree rows did not affect the correlation between DBH and tree height (Figure 3C and D). In both cardinal directions, the *P. dubium* showed ratio of tree height and diameter at breast height close to 1:1 (0.97:1); this way DBH of 5.0 cm is going to reach a height of 5.0 m, which is crucial to determine the livestock initiation into the integrated livestock-forestry system.

The greatest challenge in introducing *P. dubium* or other Brazilian native species in integrated livestock-forestry systems is the slow growth in comparison to *Eucalyptus* spp. Tree height and DBH are traits that most affect the time of livestock introduction in the production systems. But, in comparison to *Eucalyptus* spp., the results showed by *P. dubium* are promisor due to the DBH achieved 5.0 cm at 24 months after planting (Figure 3A). Nevertheless, this recommendation of 5.0 cm of DBH was established by *Eucalyptus* spp. and not for *P. dubium*. This way, it is quite important in further research to evaluate the possibility to introduce livestock with other DBH of *P. dubium* to know if higher wood density of *P. dubium* in comparison to *Eucalyptus* spp. can be a positive point to reduce the introduction time of livestock in the integrated livestock-forestry systems.

Based on the equation adjusted for time after planting and DBH, in a scenario with the possibility to introduce livestock with ≥5.0 cm DBH, the animal grazing might be introduced in 24 months after tree planting, which is not much longer than *Eucalyptus* spp.

Cylindrical volume of *P. dubium* under tree competition

In respect to cylindrical volume per tree (CVT), significant effects ($p<0.01$) were obtained by tree competition, time after planting, cardinal directions of the rows and their interactions (Table 4). The cardinal direction East-West resulted in higher CVT in tree competition above 408 trees ha^{-1}, these results showed very high positive correlation with DBH and TH in both cardinal directions (Table 5). In cardinal direction East-West, the CVT was 0.014 and 0.013 m^3 for North-South, resulting in 6.27% of CVT higher in cardinal direction East-West (Figure 4A). The cardinal direction East-South can have higher use efficiency of sunlight (Camargo et al., 2011), occasioning in higher carbon dioxide assimilation and consequently higher CVT.

Based on significant ($p<0.01$) interactions between time after planting *vs.* tree competition, the response surface was adjusted and showed in higher tree competition increase in CVT (Figure 4B). The highest CVT (0.0248 m^3 tree) was obtained in the extreme values of tree competition (1324 trees ha^{-1}) and time after planting (36 months after planting) (Figure 4B). The highest tree competition did not affect negatively the CVT, which is quite important to use *P. dubium* in ICLS due to the absence of decreasing in higher tree competition and the possibility to increase the cylindrical volume per hectare. Usually, the increase in tree competition decreases CVT, which depletes the capacity of increasing the number of trees per hectare without decreasing CVT. In the case of *Eucalyptus* spp., the increase in tree competition reduced CVT due to higher tree competition (Ferreira et al., 2016), as well as observed for *P. dubium* (Matos et al., 2015).

Interactions of tree competition *vs.* cardinal directions on cylindrical volume per hectare

The interaction of times after planting *vs.* tree competition was observed by cylindrical volume per hectare (CVH) in

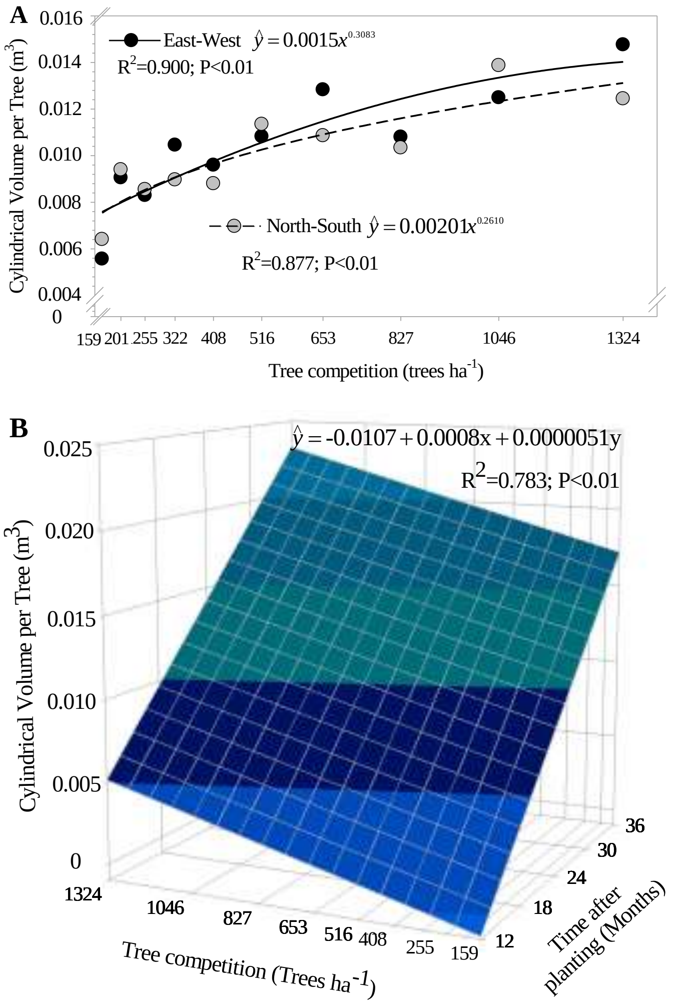

Figure 4. Cylindrical timber volume per tree (CVT) of *Peltophorum dubium.* (A) CVT in function of cardinal directions and tree competition; (B) CVT surface response in function of tree competition and time after planting (months).

both cardinal directions (Table 3). The CVT was higher in 1,324 trees ha^{-1} in both cardinal directions (Figure 5A and B). The initial development of the *P. dubium* until 36 months after planting showed this species quite interesting to be introduced in integrated crop-livestock-forestry systems or single forestry, due to its flexibility to adapt under variable tree competition without negative effect on cylindrical volume produced.

The expected is decreasing CVT and CVH under higher tree competition, due to reduction of light use efficiency (Nelson et al., 2016), soil nutrients competition (Dong et al., 2016), and water limitation (Pezzopane et al., 2015). Nevertheless, this absence of limitation in higher tree density showed by *P. dubium* indicates this native Brazilian species as a quite promising native forestry species for woody production in higher tree density. Furthermore, the highest wood density (0.75 g cm^{-3}) for mature trees of *P. dubium* in comparison to *Eucalyptus*

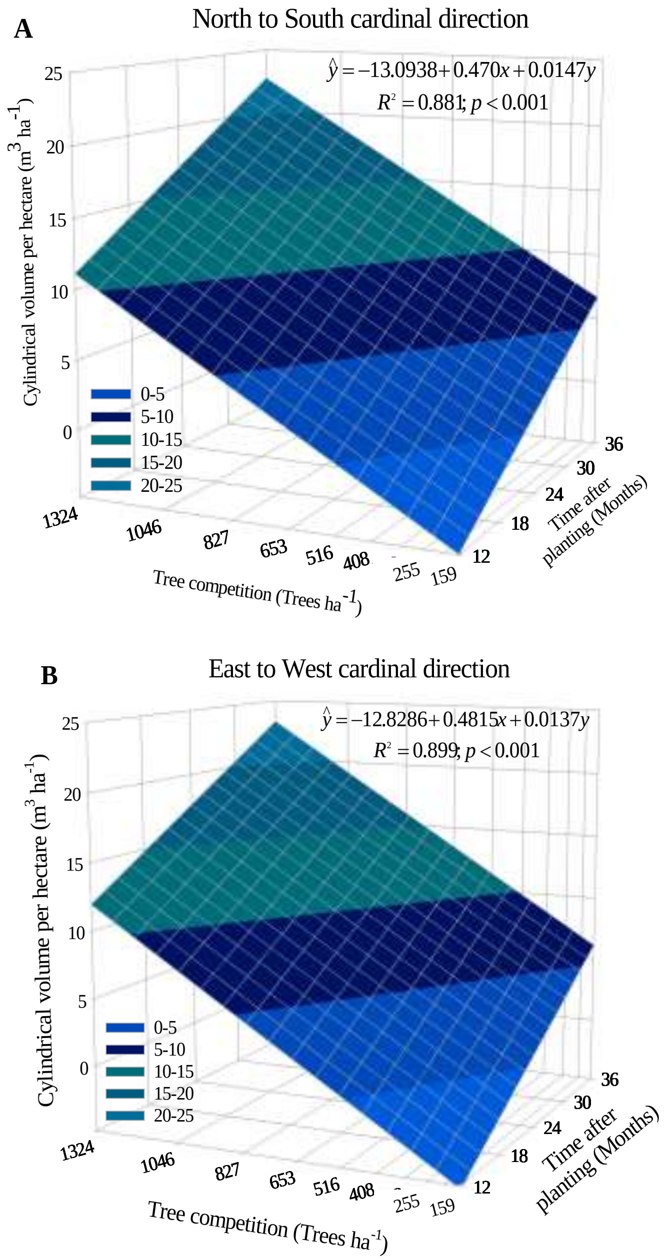

Figure 5. Cylindrical volume per hectare (CVH) of *Peltophorum dubium.* (A) CVH surface response in function of tree competition *vs*. time after planting in North-South cardinal direction; (B) CVH surface response in function of tree competition *vs*. time after planting in East-West cardinal direction.

spp. (0.45 g cm^{-3}) as forestry component in integrated system may be a decision point to be evaluated to choose which species to use. Nevertheless, the woody density depends on the tree maturity and is expected increase through time (Richter, 2015). The possibility to increase the number of trees per hectare without decrease in CVT which is quite preferably due to the opportunity of increasing economic gain with the timber.

Conclusion

The *P. dubium* showed potential to be inserted in integrated livestock-forestry system due to the absence of negative effect in tree competition on dendrometric tree parameters. The diameter at breast height and tree height showed very high positive correlation; the increase in tree height resulted in increase in DBH in a proportion of 1.0 cm (DBH) for 1.0 m of tree height.

The highest tree competition of 1,342 trees ha^{-1}, in 36 months after planting, promoted increase in cylindrical volume per tree in both cardinal directions North-South and East-West. Nevertheless, the cardinal direction East-West was profitable to increase tree height, DBH, and cylindrical volume per tree.

DBH measured in 24 months after planting was 5.0 cm, which is considered the minimum DBH to introduce livestock into the integrated system without significant damage on trees. Concerning these preliminary results in the first three years, *P. dubium* was promising as Brazilian native species to be inserted in an integrated crop-livestock-forestry system or single forestry as an option for *Eucalyptus* spp.

Conflict of Interests

The authors have not declared any conflict of interests.

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