ISSN 0100-2945 DOI: http://dx.doi.org /10.1590/0100-29452018061

Revista Brasileira de Fruticultura

Crop Production

Spondias mombin and *Theobroma grandiflorum* in agroforestry system: productivity implications

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Abstract- In agroforestry systems, little is known about the influence of the dominant species on that located in the lower layer of the canopy. The aim of this study was to evaluate if *S. mombin* plants, when in consortium with *T. grandiflorum*, caused some type of depression in the performance of *T. grandiflorum* and also to identify the most favorable *S. mombin* clones for this interaction. The experiment started on February 2005. During 11 years, four levels of influence of *S. mombin* on *T. grandiflorum* caused by the proximity between species were evaluated. As response variables, the vegetative development of *S. mombin* and *T. grandiflorum* was measured; the production of eight vintages *T. grandiflorum* trees was computed, and the mortality rate of plants was recorded. The results showed that the competition exerted by *S. mombin* moderately affected the initial development of plants, as well as the production of fruits in the last harvests, and the survival rate. The most favorable *S. mombin* clones to be used in agroforestry systems with *T. grandiflorum* trees were identified. According to results presented here, it was possible to conclude that *S. mombin* can be indicated as a species to compose AFS with *T. grandiflorum*.
Index terms: consortium, native fruit tree, *Spondias mombin*, *Theobroma grandiflorum*.

Taperebazeiro e cupuaçuzeiro em sistema agroflorestal: implicações na produtividade do Cupuaçuzeiro

Resumo- Nos sistemas agroflorestais, pouco se conhece a respeito da influência da espécie dominante sobre aquela que fica no estrato inferior do dossel. Este trabalho teve por objetivo avaliar se plantas de taperebazeiro, quando em consórcio com cupuaçuzeiro, causavam algum tipo de depressão no desempenho do cupuaçuzeiro. Visou também a identificar clones de taperebazeiro mais favoráveis para essa interação. O experimento iniciou em fevereiro de 2005. Durante 11 anos, foram avaliados quatro níveis de influência do taperebazeiro sobre o cupuaçuzeiro, causados pela proximidade entre as duas espécies. Como variáveis de resposta, foram mensurados o desenvolvimento vegetativo do taperebazeiro e do cupuaçuzeiro; computadas a produção de oito safras de cupuaçuzeiro, e anotada a taxa de mortalidade das plantas. Os resultados demonstraram que a concorrência exercida pelo taperebazeiro afetou, moderadamente, o desenvolvimento inicial das plantas, assim como a produção de frutos nas últimas safras, e a taxa de sobrevivência. Foram identificados os clones de taperebazeiro mais favoráveis para serem utilizados em sistemas agroflorestais com o cupuaçuzeiro. Em função dos resultados gerais aqui apresentados, foi possível concluir que o taperebazeiro poderá ser indicado como uma das espécies para compor SAFs com o cupuaçuzeiro.
Termos de indexação: consórcio, fruteira nativa, *Spondias mombin, Theobroma grandiflorum.*

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Received: June 05, 2018
Accepted: August 27, 2018

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Introduction

Agroforestry systems have several purposes, from food production and wood use to vegetation enrichment, forage production, waste, oil, shading and medicinal use. These systems have already been extensively tested in the Amazon region, and among them, those involving *T. grandiflorum* as predominant agricultural culture (BRIENZA JUNIOR et al., 2009). In addition, they are considered to be important agents in carbon sequestration, being an alternative to the slash-and-burning system, contributing to the mitigation of the climate change effects (TORRES et al., 2014; FERREIRA et al., 2015).

The introduction of AFS into the family production system can be a viable alternative to increase production and income, guarantee food security, recover degraded areas and reduce deforestation and forest fires, reducing economic risks, improving temporal distribution and comfort at work (ABDO et al., 2008).

In the state of Pará, agroforestry systems have gained relevance mainly in the municipality of Tomé-Açu since the late 1970s, when local producers were forced to seek alternatives to the decline of black pepper market caused by fusariosis. One of the alternatives found was the fruit growing activity, with the cultivation of species such as papaya, acerola, melon, orange, palm oil, açai, cacao, cupuaçu, passion fruit, among others, which caused the diversification of activities, associated with consortium in agroforestry systems, allowed local production to be inserted into new markets (ARCO-VERDE, 2008; BOLFE; BATISTELLA, 2011).

Varela and Santana (2009) evaluated the viability of agroforestry systems in the municipality of Tomé-Açu and verified that there is preference of producers for AFS in relation to the traditional system, mainly because the agroforestry system presents less risk, since the diversification of cultures provides greater market reach to producers.

Spondias mombin, also known as taperebá, is a perennial fruit in process of domestication. It is usually planted in agroforestry systems with cacao (*Theobroma cacao* L.), especially in the states of Bahia and Pará (MULLER; GAMA-RODRIGUES, 2012).

As cacao tree, *T. grandiflorum* presents good productivity when intercropped with species that, in adequate spacing, allow the partial shading of the area. When adult, the species tolerates approximately 25% of shading, a level that does not significantly affect the productive performance of plants. In this context, *Spondias mombin* could be an alternative in the composition of agroforestry systems (ALVES; FERREIRA, 2012).

The aim of this study was to evaluate the possible influence of *Spondias mombin* plants on the development and production of *Theobroma grandiflorum* when established in AFS and to identify more favorable *Spondias mombin* clones for this interaction.

Material and methods

The experiment was carried out in February 2005, in an area in the municipality of Tomé-Açu, located in the northeastern mesoregion of the state of Pará. The region presents warm and humid climate, according to the Köppen's climatic classification, Ami type and B 2 rAa', according to Thornthwaite's classification (PACHÊCO, BASTOS, 2001). The soil is a Yellow Latosol of intermediate texture, deep, well drained; however, with low organic matter content, high acidity and low fertility.

The average rainfall distribution and relative humidity during the ten years of the experiment are shown in Figure 1.

The Agroforestry System (AFS) was implanted with four species, adopting the following spacing: black pepper - 4 x (2 x 2 m); banana - 6 x 4 m; cupuaçu - 6 x 4 m and taperebá 30 x 10 m. In the first year, rice (first semester) and pigeon pea (second semester) were also planted. After the first five years of planting, pepper and banana trees were eliminated, remaining in the system the consortium between taperebá and cupuaçu. In the planting lines of taperebá, plants were thinned, leaving the final spacing of 30 x 20 m.

In order to evaluate the possible competition promoted by taperebá, cupuaçu plants were stratified (Figure 2) and measured at four distances (levels) of taperebá plants: Level 1 = 3.6 m; Level 2 = 6.7 m; Level 3 = 9.2 m; Level 4 = 13.4 m, the latter being used as a control due to its amplitude. Each level was composed of four plants. Therefore, 16 cupuaçu plants were measured in relation to each taperebá plant, totaling 240 cupuaçu plants in the trial. Five taperebá clones were collected in the districts of Mosqueiro (MOS 12, MOS 13, MOS 23), Igarapé Açu (IA 24) and Belém (CIFOR), with three replicates each and one plant per plot.

The following response variables were used for cupuaçu tree: plant height (m) and stem diameter at 50 cm from the soil (cm); number, average weight of fruits and estimation of fruit production in kilograms per plant and per harvest. The eight harvests: 2007/2008, 2008/2009, 2009/2010, 2010/2011, 2011/2012, 2012/2013, 2013/2014 and 2014/2015, were individually evaluated according to the levels of the cupuaçu x taperebá spacing. The average of the last five harvests was estimated, when there is greater stability of cupuaçu production; the final mortality rate of plants, as well as visual observations to verify damages in cupuaçu plants.

In taperebá, the following variables (averages) were collected: plant height (m); diameter (m) at breast height (DAP); diameter (m) and canopy area (m^2).

Data were submitted to analysis of variance

(ANOVA) followed by the Tukey test to compare means at 5% probability level. Analyses were performed in the GENES statistical software, version 2014.6.1 (CRUZ, 2013).

Results and discussion

In the first two years of AFS implementation, it was possible to observe a small interference in the development of the cupuaçu plants closer to taperebá, in relation to those more distant, both in height and stem diameter (Table 1). It should be emphasized that in AFS, several factors act to provide beneficial or harmful effects such as: spacing, cultural treatments, as well as the particular characteristics of each culture such as root, growth rate, airspace occupation and suitability or not for consortia, among others (BARROS et al., 2009). According to Oliveira Neto et al. (2010), plant diameter is the characteristic, among those normally evaluated, that is more influenced by plant spacing, usually with positive responses. When analyzing the effect of cocoa spacing under agroforestry system in Medicilândia (PA), Silva Neto et al. (2017) found that there was lower mortality rate, tendency to decrease stem diameter and increase in plant height for individuals submitted to smaller spacing. In addition, the authors point out that there was greater damage of fruits by fungus *Moniliophthora perniciosa* at larger spacing.

Leles et al. (*Eugenia uniflora*) studied the growth of 44 tree species at different spacing for reforestation among them urucum (*Bixa orellana*), cedar (*Cedrela fissilis*), Surinam cherry (*Eugenia uniflora*), guava (*Psidium guajava*) and yellow ipe (*Tabebuia chrysotricha*) and observed that the increase in plant spacing provided greater growth in diameter at soil level. However, height was not influenced by plant spacing. Nascimento et al. (2012) also found significant influence of spacing on diameter growth at soil level and canopy area of six forest species: *Anadenanthera macrocarpa*, *Schinus terebinthifolius*, *Schizolobium parahyba*, *Inga marginata*, *Cordia sp.* and *Chorisia speciosa*. They concluded that, in larger spacing, growth was favored.

In the present trial, the production of cupuaçu fruits began in the third year. Production, along harvests and by levels of distance, is shown in Figure 3.

In the first three harvests, it was not possible to observe any decrease in fruit production, due to the competition with taperebá. Competition only intensified after the fourth harvest (10/11), in which it was possible to observe that plants more distant from taperebá (control) had full production, while close ones (level 1) suffered from productive depression. With competition intensification, more and more distant plants were also affected, and at the end of observations, only those distant more than nine meters (level 4) did not present production reduction. This more distant treatment represented a reduction of 13.4; 32.7 and 40.9%, for levels 3, 2 and 1, respectively.

Cupuaçu is a species extremely sensitive to water deficit. In places like Tomé-Açu - PA, which, as previously shown, presents significant reduction of rainfall in the period from June to November, there is a need for water supplementation. Carr and Lockwood (2011) describe the symptoms of water deficit in cacao, also belonging to the genus *Theobroma*, which include size reduction, yellowing and premature leaf fall, trunk growth, flowering cessation, delayed development, fruit size reduction and consequently plant productivity. In this work, the competition with the other AFS species and the lack of irrigation during this critical period led to a reduction in the production of cupuaçu plants, contributing, as will be shown later, to reduce survival rate. Thus, if water is supplied in the required period, it will mitigate the competition effect by water, and the cupuaçu plant response may be different.

The yields of agroforestry systems are the result of interactions between the different production components. Interactions between arboreal and non-arboreal components may be complementary, neutral or competitive (BARROS et al., 2009). In the present research, it is a competitive interaction, because, a reduction in yield when compared to yields of components more distant was evidenced.

Restricting the analysis for the last five harvests, when production stability of cupuaçu usually occurs and competition becomes more intense, the results were found to be similar (Table 2). However, only when cupuaçu plants were more than 13 m away (level 4), they were not affected by taperebá plants. Production variation between this level and the nearest plants was approximately 36%. In other words, it was evidenced that competition, at close levels, affected both the development of cupuaçu trees in the first two years and fruit production in the stability phase.

In addition, as plants developed, competition became more intense, especially at the two levels where the species were closer, and generated high mortality rates in cupuaçu plants (Table 2). In addition, some plants were damaged due to the fall of twigs from taperebá plants. Only the farthest level maintained 100% survival, with no damage. Other investigations attest to these disadvantages of AFS, where competitions among tree species by nutrients, space, solar energy and soil moisture occur, and it is difficult to differentiate the impacts of competition for light from that of water and nutrients (JARAMILLO-BOTERO et al., 2010).

In order to verify if there was variability among taperebá clones for adaptation to AFS, trees were evaluated for vegetative performance (Table 3). The results showed that MOS 23 clone was the most vigorous in height, DAP,

diameter and canopy area. On the other hand, MOS 13 clone was the one that had the poorest development in the related aspects. IA24, MOS 12 and CIFOR clones showed intermediate behavior.

It was expected that more compact taperebá plants with small canopy area would probably cause less competition for light with neighboring cupuaçu plants, and consequently would cause less damage. In this context, intermediate CIFOR, IA 24 and MOS 12 clones were those that promoted the lowest mortality rates. However, the less developed clone, MOS 13, did not exhibit the expected behavior. Therefore, in addition to competition for light, other factors such as competition for water and nutrients at root level must have more expressively contributed to this result (Table 3).

Zandavalli (2006) evaluated the effect of competition on the establishment and growth of *Araucaria angustifolia* seedlings in aerial and root competition reduction experiments in the National Forest of São Francisco de Paula (RS) and concluded that root competition showed greater importance for the growth of *A. angustifolia* when light availability was high, in comparison to treatments of absence of competition and with permanence of the competition both aerial and root.

The interaction of taperebá clones with cupuaçu plants at the different levels is reported in Table 4. The results indicated variations in cupuaçu fruit production, both as a function of taperebá clones and the proximity levels of these two species. It was verified that IA 24 was the clone that favored the average production of cupuaçu plants, followed by MOS 13 and CIFOR. On the other hand, MOS 12 induced the lowest productivity, corresponding to a 28% difference between it and IA 24.

Comparing the effect of levels within each taperebá clone, it was verified that all taperebá clones promoted depression in the production of cupuaçu plants at the closest level (level 1). However, IA 24, MOS 13 and MOS 23 clones were the least aggressive at this distance, making cupuaçu plants not so harmed. From the next level (level 2 = 6.7 m), production depression was no longer significant. It was also found that the most distant cupuaçu plants (level 4) apparently did not suffer competition from taperebá clones (Table 4).

After evaluating several crops among forest species, perennial and semi-perennial fruit trees, and annual crops, Arco-Verde (2008) concluded that cupuaçu presented the best productive response in the different models evaluated, classifying it as the most attractive species to compose AFS in the Amazon region.

Table 1 - Vegetative development of cupuaçu plants (plant height and stem diameter), in the first two years in the field (2006 to 2007), according to the four distance levels in relation to taperebá plants. Tomé Açu - PA, 2018.

Level	Height (m)	Diameter (cm)
1	1.50b	3.29b
2	1.66a	3.45ab
3	1.61ab	3.49ab
4	1.66a	3.64a
Mean	1.61	3.47
V.C. (%)	7.82	8.43

Level 1 = 3.6 m; Level 2 = 6.7 m; Level 3 = 9.2 m; Level 4 = 13.4 m.
* Averages followed by the same letter do not differ from each other at significance of 5% by the Tukey test.

Table 2 - Production of cupuaçu fruits / plant / (average five harvests), final mortality rate and damages to cupuaçu plants according to the levels of competition established between cupuaçu and taperebá plants. Tomé Açu - PA, 2018.

Level	Production (kg)		Mortality rate (%)	Damages (%)
1	7.83	c	20	14
2	10.20	b	20	6
3	10.88	b	6	0
4	12.20	a	0	0
Mean	10.27			
V.C. (%)	6.74			

Level 1 = 3.6 m; Level 2 = 6.7 m; Level 3 = 9.2 m; Level 4 = 13.4 m.*Averages followed by the same letter do not differ from each other at significance of 5% by the Tukey test

Table 3 - Biometric variables of taperebá clones; mortality rate and damage to cupuaçu trees, as a specific function of taperebá clones (average of eight years). Tomé Açu - PA, 2018.

Clone	ALT (m)		DAP (m)		DC (m)		AC (m²)		Dead (%)	Broken (%)
MOS 12	14.60	b	0.94	b	19.75	a	311.26	a	12.5	2.5
CIFOR	15.05	ab	0.62	c	21.53	a	365.72	a	5	2.5
MOS 23	15.85	a	1.39	a	22.53	a	400.20	a	15	5
MOS 13	10.75	d	0.90	bc	12.93	b	131.35	b	15	2.5
IA 24	12.60	c	0.73	bc	23.25	a	424.56	a	10	12.5
Mean	13.77		0.92		20.00		326.62			
V.C. (%)	2.96		11.52		7.69		15.39			

ALT = Height; DAP = Diameter at Chest Height; DC = Canopy diameter; AC = Canopy Area.
*Averages followed by the same letter do not differ from each other at significance of 5% by the Tukey test.

Table 4 - Production of cupuaçu fruits (kg / plant / crop), according to five taperebá clones and four levels of competition between species, in the last five harvests (2010/2011 to 2014/2015). Tomé Açu - PA, 2018.

Level	Clones														
	MOS 12			CIFOR			MOS 23			MOS 13			IA 24		
1	8.51	b	B	8.22	b	B	9.15	b	AB	9.51	c	AB	13.20	b	A
2	10.54	b	B	13.27	a	AB	12.76	ab	AB	12.70	bc	AB	14.93	ab	A
3	11.71	ab	B	15.12	a	AB	13.44	a	AB	15.92	ab	AB	16.36	ab	A
4	14.73	a	AB	15.21	a	AB	13.97	a	B	16.81	a	AB	18.45	a	A
Mean	11.37			12.95			12.33			13.73			15.73		
V.C. (%)	20.28			13.99			16.88			10.63			8.41		

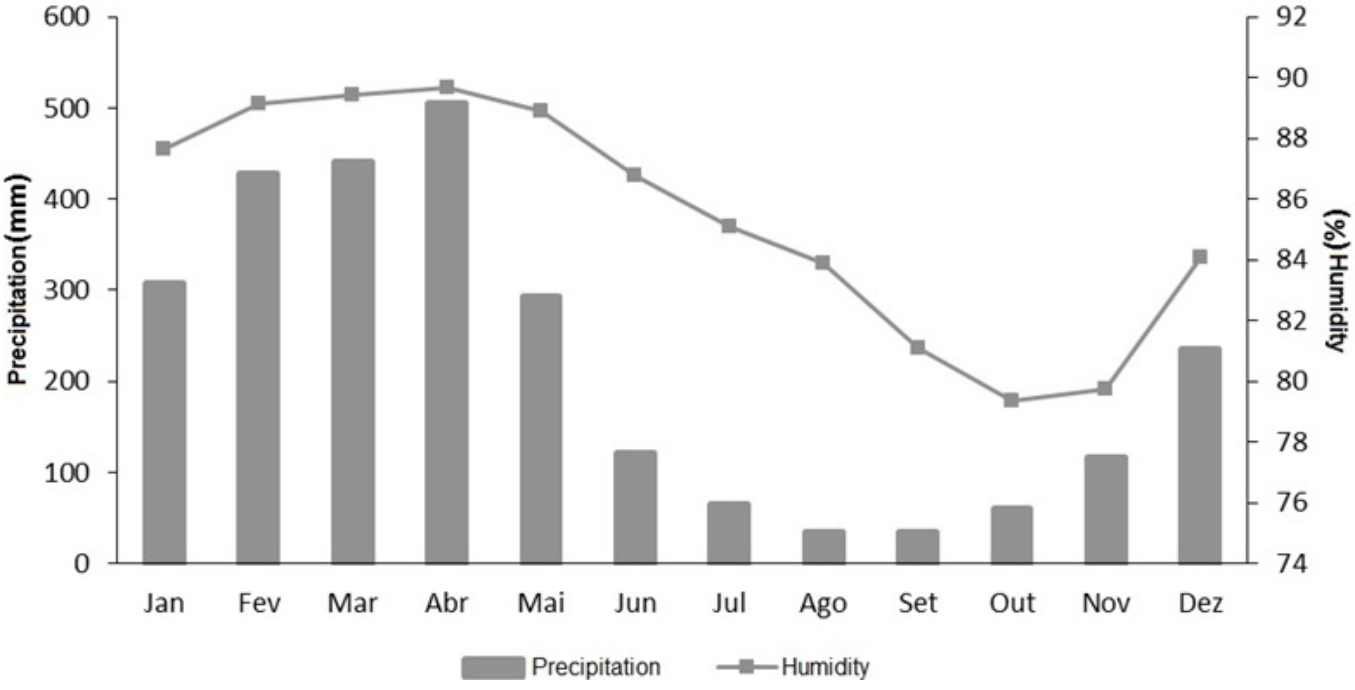

Figure 1 - Monthly rainfall averages (mm) and relative air humidity (%) obtained at the agro-meteorological station of Embrapa Amazônia Oriental, installed in Tomé Açu, PA during the period from 2005 to 2015. Tomé Açu, 2018.

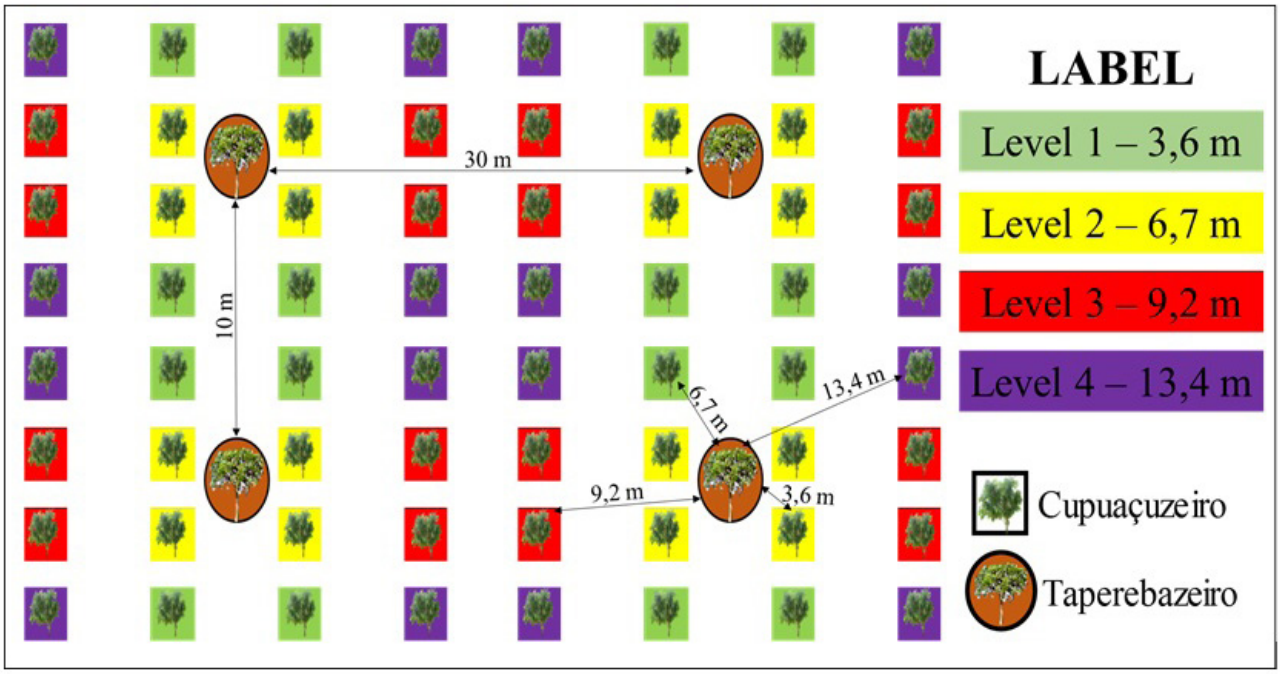

Figure 2 - Spatial distribution of plants in AFS, which defined the four levels of distance between cupuaçu and taperebá plants. Tomé Açu, 2018.

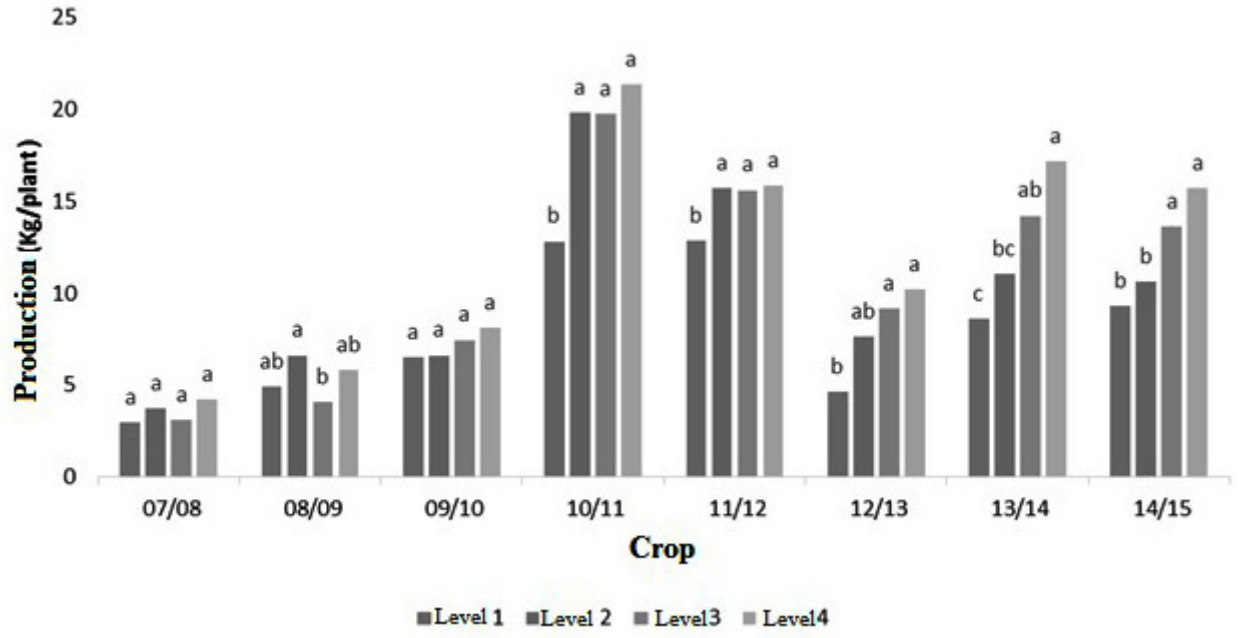

Figure 3 - Production of cupuaçu fruits (in kg / plant), in the eight harvests evaluated (from 2007/2008 to 2014/2015), according to the four levels of competition established. Tomé Açu - PA, 2018. Level 1 = 3.6 m; Level 2 = 6.7 m; Level 3 = 9.2 m; Level 4 = 13.4 m.* Averages followed by the same letter do not differ between treatments within each crop at significance of 5%, by the Tukey test.

Conclusions

In AFS involving taperebá and cupuaçu plants, the spacing between plants should not be less than 30 x 10 m, and taperebá plants should be at least 3.6 m away from cupuaçu plants in order not to harm cupuaçu productivity;

Taperebá clones IA 24 and CIFOR do not affect production and preserve the survival of cupuaçu plants, being the most favorable to be used in agroforestry systems with this species.

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