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BIOMASS OF TREE SPECIES AS A RESPONSE TO PLANTING DENSITY AND INTERSPECIFIC COMPETITION[1]

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RESUMO – Planting trees is an important way to promote the recovery of degraded areas in the Caatinga region. Experiments (E1, E2, and E3) were conducted in a randomized blocks design, with three, three, and five replicates, respectively. The objectives were to evaluate biomass of the shoots of: a) gliricidia (G) and sabiá (S), as a response to planting density; b) G, S, and neem (N) in competition; c) G, and S in agroforestry. E1 was conducted in split-plots, and planting densities (400, 600, 800, 1000, and 1200 plants ha^{-1}) as subplots. E2 consisted of a factorial comprising the following plots: GGG, NGN, SGS, NNN, GNG, SNS, SSS, GSG, NSN (each letter represents a row of plants). E3 was conducted with G and S in agroforestry experiment. The trees were harvested after 54, 42, and 27 months old, in E1, E2 and E3, respectively. In E1, G presented higher green biomass of the stems and leaf at smaller densities than S, but lower green biomass of branches at most densities. The species did not differ for mean stem dry biomass and leaf dry biomass, but G showed higher branch dry biomass at most densities. Higher planting densities increased green and dry biomass of stems, branches, and leaves in S, but decreased those characteristics in G, with the exception of leaf dry mass, which was not influenced by density. In E2, the behavior of each species was identical in plots containing the same or different species. Griricidia showed the highest green biomass of stems and branches, and the highest values for geren biomass of the leaf were observed for gliricidia and neem. The highest stem, branch, and leaf dry biomass values were obtained for G, S, and N, respectively. In E3, G was superior for stem and leaf green biomass, and for stem and branch dry biomass. There were no differences between species for the other biomass values.

Palavras-chave: *Azadirachta indica; Gliricidia sepium; Mimosa caesalpiniifolia*.

BIOMASSAS DE ESPÉCIES ARBÓREAS EM RESPOSTA A DENSIDADES DE PLANTIO E À COMPETIÇÃO INTERESPECÍFICA

ABSTRACT – Existe interesse na recuperação de áreas degradadas da Caatinga com o plantio de árvores. Experimentos (E1, E2 e E3) foram realizados, em blocos ao acaso com três, três e cinco repetições, respectivamente, para avaliar as biomassas da parte aérea: a) da gliricidia (G) e sabiá (S), em resposta à densidade de plantio; b) da G, S e nim (N) em competição; e c) da G e S em experimento agroflorestal. E1 foi realizado com parcelas subdivididas, com densidades de plantio (400, 600, 800, 1.000 e 1.200 plantas ha-1) nas subparcelas. E2 foi um fatorial com as seguintes parcelas: GGG, NGN, SGS, NNN, GNG, SNS, SSS, GSG e NSN (cada letra representa uma fileira de plantas). E3 foi realizado com G e S em experimento agroflorestal. As árvores foram abatidas aos 54, 42 e 27 meses de idade, em E1, E2 e E3, respectivamente. Em E1, G foi superior à S nas biomassas frescas de caules e folhas, nas menores densidades, mas inferior quanto à biomassa fresca de ramos, na maioria das densidades. As espécies não diferiram quanto às biomassas médias secas de caules e folhas, mas G apresentou maior biomassa seca de ramos, na maioria das densidades. O aumento da densidade

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de plantio aumentou as biomassas frescas e secas de caules, ramos e folhas da S, mas reduziu essas características na G, à exceção da matéria seca de folhas, não influenciada pela densidade. Em E2, cada espécie comportou-se igualmente nas parcelas com a mesma espécie ou com espécies diferentes. As maiores biomassas frescas de caule foram apresentadas por G, as de ramos por G e as de folhas por G e N. As maiores biomassas secas de caules, ramos e folhas foram apresentadas por G, S e N, respectivamente. Em E3, G foi superior quanto às biomassas frescas de caules e folhas e biomassas secas de caules e ramos. Não houve diferenças entre espécies quanto às demais biomassas.

Keywords: Azadirachta indica; Gliricidia sepium, Mimosa caesalpiniifolia.

1. INTRODUCTION

The Northeastern region of Brazil has an area of 1,558,196 km^2, which represents almost 18% of the country's area. The Brazilian semiarid region comprises about 982,563 km^2, and approximately 90% of it lies within the Northeastern region (IBGE, 2007). The Caatinga biome occupies an area of 844,453 km^2 and lies entirely in the Brazilian semiarid region, comprising nine states (IBGE 2007). The Caatinga importance and characterization with regard to its climate and vegetation have been described by Santos et al. (2010), among others.

In spite of its importance, the Caatinga is threatened by desertification, which is the degradation of land in arid, semi-arid and dry sub-humid areas into desert, resulting from several factors, including climatic variations and human activities (UNITED NATIONS, 1994). Inadequate herd management, abandonment of old cropping areas, firewood extraction to meet the demands of brickyards and potteries, and mining have degraded the Caatinga at different intensities (GALINDO et al., 2010).

One of the strategies for degraded area recovery consists in planting forest species (NICHOLS; CARPENTER, 2006). Planting forest species that improve soil properties via litter deposition is a possibility that reconciles both economic benefits and sustainability (MENDONÇA et al., 2008). Revegetation is the initial activity in the recovery of degraded areas. Maintenance and protection of such areas will allow the recovery process to be completed.

In addition to an interest in degraded area recovery by planting forest species, there is an interest in commercial forest plantations for economic objectives. Such plantations have contributed to reduce degradation in additional areas. Forest plantations have expanded globally and are currently responsible for 5% of the global forest cover, producing 35% of the timber currently traded worldwide (FAO, 2011).

One of the most important decisions in the commercial exploitation of a forest species involves defining its planting density. This is explained because planting density influences several aspects in forest formation, including management practices, timber yield (RONDON, 2002, 2006), and timber quality (JIANG et al., 2007), consequently influencing production costs.

Intercropped forest plantations have been increasingly preferred than monocrops, because the latter can be more resistant to the attack of herbivores and stimulate greater fauna and flora diversity (SEIDEL et al., 2011). In an intercropped system, the objectives are to combine species that provide higher productivity in relation to monocrops, reduce market oscillation risks and the impacts of diseases and pests (KELTY, 2006). Due to the importance of intercropping involving forest species there has been an interest in studying interspecific competition between them (SEIDEL et al., 2011; LEI et al., 2012).

Regarding to degraded area recovery in agroforestry systems and other agricultural systems there has been great interest in fast-growing, well-adapted tree species. Sabiá (*Mimosa caesalpiniifolia* Benth.), neem (*Azadirachta indica* A. Juss), and gliricidia [*Gliricidia sepium* (Jacq) Kunth ex Walp.] meet those requirements and can be used for many purposes. Sabiá is native to the Brazilian semiarid region, while neem and gliricidia are exotic species, which are nevertheless well adapted to the Northeastern semiarid region.

The objectives of this study, targeted at reforestation projects, were: a) estimate gliricidia and sabiá biomass as a response to planting density; b) evaluate gliricidia, sabiá, and neem biomass under competition; c) compare gliricidia and sabiá biomass in an agroforestry experiment.

2. MATERIAL AND METHODS

2.1. Common experimental characteristics

Three experiments were carried out at the "Rafael Fernandes" Experimental Farm (-5° 3' 38" latitude, -37° 23' 46" longitude, and 18 m elevation). According to Gaussen's bioclimatic classification, the climate in the Mossoró region is classified as type 4ath, or distinctly xerothermic, which means tropical hot with a pronounced, long dry season, lasting from seven to eight months and with a xerothermic index between 150 and 200. The bioclimate in the region is a BSwh, that is, hot, with heavier precipitations delayed toward the fall (KÖPPEN, 1948). The mean minimum temperature in the region is 32.1°C and the maximum is 34.5°C, with June and July as the coolest months, while the mean annual precipitation is around 825 mm.

The soil in the experiment area is classified as a Red-Yellow Argisol, according to the Brazilian Soil Classification System (EMBRAPA, 2006), and as a Ferric Lixisol, according to the Soil Map of the World (FAO, 1988). Soil analyses were conducted according to recommendations outlined by Embrapa (1999).

The trees were felled by cutting at 0.30 m from the ground. The material was separated into three fractions: stems, branches (ramifications with thickness smaller than the thickness of an adult man's finger, approximately), and leaves. A sample of the three fractions was placed in a forced air circulation oven adjusted at 75°C until constant weight was achieved. In the three experiments, the trees were felled at 54, 42, and 27 months of age, respectively.

We chose to evaluate green and dry biomass, like other authors (BARRETO; FERNANDES, 2001) because the treatment effects on the two types of biomass were often different. In addition, green matter yield can be an interesting parameter for analysis.

The data were submitted to analysis of variance using SAEG - software developed by Universidade Federal de Viçosa (RIBEIRO JÚNIOR, 2001), while regression analyses were made with the software developed by Jandel (1992). The regression equations were selected based on the following criteria: biological explanation of the phenomenon, simplicity of the equation, and testing of equation parameters by Student's t test at 5% probability.

2.2. Experiment 1: Gliricidia and sabiá biomass as a response to planting density

Sabiá (obtained from natural populations in Mossoró-RN) and gliricidia seeds (obtained from Assessoria e Serviços a Projetos em Agricultura Alternativa - AS-PTA, a non-governmental organization with a branch in Campina Grande-PB), were sown in January 2008. The seeds were sown in black plastic bags, 25 cm tall and 15 cm in diameter, perforated in their bottom third. The bags were filled with substrate consisting of 1/3 manure and 2/3 soil (a Red-Yellow Podzol). The manure analysis indicated: pH (water) = 8.1; Ca = 4.0 $cmol_c$ dm^{-3}; Mg = 5.5 $cmol_c$ dm^{-3}; K = 1.72 $cmol_c$ dm^{-3}; Na = 1.84 $cmol_c$ dm^{-3}; Al = 0.00 $cmol_c$ dm^{-3}; and P = 76.7 mg dm^{-3}

Transplanting was performed in March 2008 in a pristine area that was manually deforested. The seedlings were transplanted to non-fertilized pits measuring 40 cm x 40 cm x 40 cm. The soil analysis indicated: pH = 6.8; Ca = 1.80 $cmol_c^{-1}$ dm^{-3}; Mg = 0.40 $cmol_c$ dm^{-3}; K = 0.10 $cmol_c$ dm^{-3}; Na = 0.01 $cmol_c$ dm^{-3}; Al = 0.00 $cmol_c$ dm^{-3}; P = 25mg dm^{-3}; organic matter = 1.90 g kg^{-1}.

Both species were submitted to the following planting densities (plants ha^{-1}): 400 (row spacing of 5.0 m x 5.0 m), 600 (4.0 m x 4.17 m), 800 (4.0 m x 3.12 m), 1000 (4.0 m x 2.5 m), and 1200 (3.0 m x 2.77 m). A complete randomized block design was adopted with five replicates and split-plots (species in plots, planting densities in subplots, and ages in subsubplots). Each subplot consisted of three 30.0 m-long rows of plants. The evaluation (usable) area in each subplot was considered as the space occupied by the plants on the central row, with the elimination of one plant at each end. Control of pests and diseases was performed as needed. Weeds were controlled by hoeing with a harrow attached to a tractor, between plant rows and lines, and by manual hoeing near each plant.

2.3. Experiment 2: Interspecific competition between gliricidia, neem, and sabiá

Sabiá seeds (obtained from natural populations) and gliricidia and neem seeds (obtained from cultivated populations) were sown on January 20, 2009. The seeds were sown in black plastic bags, 20 cm tall and 15 cm in diameter, perforated in their bottom third. The bags were filled with substrate consisting of 1/3 vermicompost and 2/3 soil (a Red-Yellow Argisol).

Transplanting was performed in March/2009, to a soil of the same type previously mentioned, in an area previously cultivated with corn. The seedlings were transplanted to pits measuring 40 cm × 40 cm × 40 cm. The analysis of a soil sample from the experiment area gave the following results: pH = 6.90; P = 40.0 mg dm $^{-3}$; K^+ = 59.0 mg dm $^{-3}$; Ca^{2+} = 2.90 $cmol_c$ dm $^{-3}$; Mg^{2+} = 1.50 $cmol_c$ dm $^{-3}$; Al^{3+} = 0.00 $cmol_c$ dm $^{-3}$; Na^+ = 7.6 mg dm $^{-3}$; org. matter = 1.29%; textural class corresponding to sand.

A randomized block design with four replicates was adopted. The cropping systems were compared in plots containing three rows, with four plants in each row, at a spacing of 5.0 m × 5.0 m. In addition to monocrops for the three species, six intercrop combinations were compared: one row of sabiá plants between two rows of gliricidia or neem plants; one row of gliricidia between two rows of sabiá or neem; and one row of neem between two rows of sabiá or gliricidia. In each plot, the area considered for species growth evaluation (usable area) was the area occupied by the two central plants in the central row. A distance of 5.0 m was left between blocks and beside each block. No diseases or pests occurred in the experiment. Weeds were controlled by hoeing with a tractor between plant rows and lines, and by manual hoeing near each plant.

2.4. Experiment 3: Comparison between gliricidia and sabiá biomass in an agroforestry experiment

An agroforestry experiment was set up in April, 2010 in which corn (*Zea mays* L.), cowpea [*Vigna unguiculata* (L.) Walp.], gliricidia, and sabiá were grown both as monocrops and intercrops. The experiment was conducted under dryland conditions but received supplementary irrigation as needed. The tree species, with seedlings produced in a similar way as described for experiment-2, were grown at a row spacing of 4.0 m x 4.0 m in plots consisting of three rows, with four trees per row. The analysis of a sample taken from the experimental soil indicated: pH = 7.6; P = 22.6 mg dm $^{-3}$; K^+ = 223.1 mg dm $^{-3}$; Ca^{2+} = 3.8 $cmol_c$ dm $^{-3}$; Mg^{2+} = 2.2 $cmol_c$ dm $^{-3}$; Al^{3+} = 0.00 $cmol_c$ dm $^{-3}$; Na^+ = 99.7 mg dm $^{-3}$; org. matter = 15.9% ; textural class corresponding to sand.

The experiment was carried out as random blocks with five replicates. Only trees grown as monocrops were felled. Therefore, in the analysis of variance, we considered the data as two treatments organized in five blocks.

3. RESULTS

3.1. Experiment 1

We observed effects of species (E), planting densities (D), and the E x D interaction on green biomass of stem, branch, and leaf. At the two smaller planting densities, gliricidia was superior to sabiá for stem and leaf green biomass (Table 1). At the other densities, no differences were found between species for those characteristics. As to green biomass of the branch, sabiá was superior to gliricidia at the four higher planting densities (Table 1). Increased planting densities reduced gliricidia green biomass of stem, branch, and leaf; in sabiá, however, those characteristics increased (Table 1). The difference in behavior between the two species as a response to increased planting density caused the E x D interaction.

Regarding dry biomass, we also found effects of species (E), planting densities (D), and the E x D interaction on stem, branch, and leaf. Gliricidia was superior to sabiá for stem dry biomass only at the two lower densities. At the other densities, the species did not differ for this parameter. At the four higher densities, sabiá had the greatest branch dry biomass. The two species did not differ for leaf dry biomass at any of the densities evaluated. Increased planting density decreased gliricidia stem and branch dry biomass, but increased those two characteristics as well as leaf dry biomass in sabiá (Table 2).

3.2. Experiment 2

We observed an effect of the plot's central row (C), but not of the lateral rows (L), or of the C x L interaction, on stem, branch, and leaf green biomass. In other words, the species were different in terms of those biomass values, but all of them showed the same growth when cultivated between rows of plants of the same species or of different species. For this reason, the means comparison test was only applied to the main effect means in both groups of treatments (Table 3). Gliricidia was superior to the other species for stem and branch green biomass, but was only superior to sabiá in terms of leaf green biomass (Table 3).

The results of the analysis of variance for dry biomass data of stems, branches, and leaves were similar to those obtained in the analysis of green biomass data for those fractions. That is, in the three characteristics, there was a central row effect (C), but not an effect of the lateral

Table 1 – Mean green biomass yield for stems, branches, and leaves of tree species, at 54 months of age, as a response to planting density[1].

Tabela 1 *– Médias dos rendimentos de biomassas frescas de caules, ramos e folhas de espécies arbóreas, aos 54 meses de idade, em resposta à densidade de plantio[1].*

Planting densities (Plants ha^{-1})	Species		Species		Species	
	Gliricidia	Sabiá	Gliricidia	Sabiá	Gliricidia	Sabiá
	Stems		Branches		Leaves	
	Green biomass (kg ha^{-1})					
400	37,859 a	11,201 b	3,771 a	3,937 a	6,181 a	1,840 a
600	33,037 a	15,870 b	4,101 b	7,143 a	4,458 a	2,760 b
800	28,213 a	22,496 a	3,816 b	9,712 a	4,597 a	2,973 a
1000	23,693 a	18,098 a	3,030 b	6,505 a	3,100 a	2,363 a
1200	23,058 a	21,506 a	3,081 b	10,959 a	4,302 a	2,722 a
CV_{plots} (%)	13.6		7.7		35.5	
$CV_{subplots}$ (%)	27.0		13.2		22.2	

Regression analysis for stem green biomass

Species	Regression equation	Coefficient of determination
Gliricidia	y = 44,182.00 – 18.05 x	0.97
Sabiá	y = 26,593.48 – 6040900.00/x	0.78

Regression analysis for branch green biomass

Species	Regression equation	Coefficient of determination
Gliricidia	y = 4,899.0 – 1.45 x	0.95
Sabiá	y = 9,711.43 – 903,570,000.00/ x^2	0.82

Regression analysis for leaf green biomass

Species	Regression equation	Coefficient of determination
Gliricidia	y^2 = 1,060,780.00 + 4,155,000,000,000.00/ x^2	0.56
Sabiá	y^2 = 8,001,750.00 – 688,720,000,000.00/ x^2	0.59

[1]For each trait, means followed by the same letter in the row do not differ from each other at 5% probability by Tukey's test. All equation parameters are significant at 5% probability by Student's t test. CV = experimental coefficient of variation.

[1]Em cada característica, médias seguidas pela mesma letra na linha não diferem entre si, a 5% de probabilidade, pelo teste de Tukey. Todos os parâmetros das equações são significativos a 5% de probabilidade, pelo teste t de Student. CV = coeficiente de variação experimental.

rows (L), or the C x L interaction, indicating a lack of differences under interspecific competition. However, the means comparison test indicated different results from those obtained for green biomass. Respectively, gliricidia, sabiá, and neem showed the highest stem, branch, and leaf yield values (Table 4).

3.3. Experiment 3

Gliricidia was superior to sabiá regarding to green and dry biomass, with the exception of branch green biomass and leaf dry biomass, characteristics for which the two species did not differ (Table 5).

4. DISCUSSION

4.1. Experiment 1

In plants under relatively small planting densities there is a surplus of resources (water, light, and nutrients) for growth, and competition for those resources is relatively small. However, as planting density increases, competition also increases and plant growth tends to decrease. Therefore, there is an optimal planting density, i.e., densities smaller than the optimum favor growth, while densities greater than the optimum reduce growth. In trees, this was demonstrated, for example, by Rondon et al. (2002) in *Schizolobium amazonicum* (Huber) Ducke, and by Kanjanakot and Sahunalu (1999) in *Azadirachta indica* A. Juss. In this investigation, the amplitude of planting densities tested (from 400 to 1200 plants ha^{-1}) were above the optimal density for gliricidia, but below the optimal density for sabiá (Tables 1 and 2), since gliricidia biomass decreased while sabiá biomass increased as planting density increased.

The differences in behavior between gliricidia and sabiá in terms of green and dry biomass, is likely associated, at least in part, to growth habit of those species. Gliricidia plants emitted 4.38 shoots per stem,

Table 2 – Mean dry biomass yield for stems, branches, and leaves of tree species, at 54 months of age, as a response to planting density[1].
Tabela 2 – *Médias dos rendimentos de biomassas secas de caule, ramos e folhas de espécies arbóreas, aos 54 meses de idade, em resposta à densidade de plantio[1].*

Planting densities	Species		Species		Species	
(Plants ha^{-1})	Gliricidia	Sabiá	Gliricidia	Sabiá	Gliricidia	Sabiá
	Stems		Branches		Leaves	
	Dry biomass (kg ha^{-1})					
400	22,027 a	8,496 b	1,632 a	2,243 a	1,739 a	951 a
600	19,661 a	11,894 b	1,719 b	4,939 a	1,325 a	1,550 a
800	16,017 a	16,817 a	1,706 b	6,514 a	1,307 a	1,797 a
1000	14,634 a	13,732 a	1,391 b	4,844 a	813 a	1,526 a
1200	13,673 a	16,497 a	1,200 b	6,597 a	1,259 a	1,657 a
CVplots (%)	21.2		18.8		59.9	
CVsubplots (%)	26.6		25.4		20.0	

Regression analysis for stem green biomass

Species	Regression equation	Coefficient of determination
Gliricidia	y = 25,896.40 - 10.87 x	0.95
Sabiá	y = 20,211.11 - 4,637,200.00/x	0.80

Regression analysis for branch green biomass

Species	Regression equation	Coefficient of determination
Gliricidia	y2 = 3,000,750.00 - 0.00091 x	0.88
Sabiá	y2 = 39,368,000.00 - 5,476,200,000,000.00/ x2	0.80

Regression analysis for leaf green biomass

Species	Regression equation	Coefficient of determination
Gliricidia	y = 1,496.27	-
Sabiá	y2 = 395,490.00 - 1,175,600,000.00/ x	0.77

[1]For each trait, means followed by the same letter in the row do not differ from each other at 5% probability by Tukey's test. All equation parameters are significant at 5% probability by Student's t test. CV = experimental coefficient of variation.
[1]Em cada característica, médias seguidas pela mesma letra na linha não diferem entre si, a 5% de probabilidade, pelo teste de Tukey. Todos os parâmetros das equações são significativos a 5% de probabilidade, pelo teste t de Student. CV = coeficiente de variação experimental.

on average, while sabiá emitted almost half that value (2.45 shoots per stem). In addition, sabiá shoots form smaller angles with the stem than gliricidia shoots. At the same planting density, a higher number of horizontal shoots would imply greater mutual shading in gliricidia plants than in sabiá plants. Under increased planting density, there would be greater mutual shading, which would result in smaller growth. Evidently, other factors associated with the above-ground part as well as with the root system must be related to the difference between growth periods in those two species. For example, Câmara and Endres (2008) verified that sabiá is very tolerant to shading, which suggests higher tolerance at greater planting densities, as observed in this investigation.

No studies were found comparing gliricidia and sabiá biomass. Moura et al. (2006) evaluated sabiá biomass in two stands (containing 1111 and 494 plants ha^{-1}, respectively) and, contrary to our observations, verified that total biomass was smaller at a lower planting density. However, the comparison between two stands made by those authors should be conducted cautiously, since their stands were eight and eleven years old, respectively, and age is an important factor that should be taken into consideration in planting density studies involving trees (OLIVEIRA NETO et al., 2003). On the other hand, our results obtained for sabiá were similar to the findings of other authors, that increased planting densities increased biomass (RONDON et al., 2006).

Karim and Savill (1991) observed that increased planting densities in gliricidia increased total biomass per unit area, thus differing from our observations. However, their objective was to evaluate initial growth in that species for alley cropping; they tested planting densities from 1,250 to 20,000 plants ha^{-1}. As highlighted

Table 3 – Mean green biomass yield of stems, branches, and leaves of tree species at 42 months of age, in the central row of the plot[1].
Tabela 3 – *Médias dos rendimentos de biomassas frescas de caule, ramos e folhas de espécies arbóreas, aos 42 meses de idade, na fileira central da parcela[1].*

Stem green biomass (kg ha^{-1})				
Species in the plot's central row	Species in the plot's lateral rows			Means
	Gliricidia	Neem	Sabiá	
Gliricidia	25,685	24,875	33,037	27,866 A
Neem	14,408	10,253	11,741	12,134 B
Sabiá	5,803	7,104	9,432	7,446 B
Means	15,298 a	14,077 a	18,070 a	-
Experimental coefficient of variation = 39.2%				
Branch green biomass (kg ha^{-1})				
Species in the plot's central row	Species in the plot's lateral rows			Means
	Gliricidia	Neem	Sabiá	
Gliricidia	3,506	4,573	5,800	4,625 A
Neem	2,333	2,119	2,643	2,365 B
Sabiá	2,751	3,069	3,679	3,166 B
Means	2,862 a	3,254 a	4,040 a	-
Experimental coefficient of variation = 33.6%				
Leaf green biomass (kg ha^{-1})				
Species in the plot's central row	Species in the plot's lateral rows			Means
	Gliricidia	Neem	Sabiá	
Gliricidia	4,275	2,826	6,075	4,393 A
Neem	4,631	3,897	5,488	4,672 A
Sabiá	656	931	772	786 B
Means	3,188 a	2,552 a	4,112 a	-
Experimental coefficient of variation = 49.6%				

[1]In each trait, means followed by the same upper case letter in the column, and by each lower case letter in the row do not differ from one another at 5% probability, by Tukey's test.
[1]*Em cada característica, médias seguidas pela mesma letra maiúscula na coluna e pela mesma letra minúscula na linha não diferem entre si, a 5% de probabilidade, pelo teste de Tukey.*

by Oliveira Neto et al. (2003), the planting density adopted depends on the objective for which the species is exploited.

4.2. Experiment 2

Under interspecific competition, two processes may occur: competition and facilitation (KELTY, 1992). Competition occurs when two or more plants or populations interact, so that one exerts a negative effect on the other (VANDERMEER, 1989). Such negative effect is manifested via suppression of resources (light, water, and nutrients) or space, or by allelopathy (JOSE et al., 2006). Facilitation occurs when a species has a positive impact on another one (VANDERMEER, 1989). Facilitation may occur in a number of ways a very common example is the interaction between legumes and non-legumes. Species that are associated with nitrogen-fixing bacteria would increase nitrogen availability for the non-legume species, resulting in superiority of the intercrop over the non-legume monocrop (FORRESTER et al., 2006). Abiotic conditions (PUGNAIRE et al., 2004), such as weather conditions or availability of nutrients (KUNSTLER et al., 2011) will determine the occurrence of competition or facilitation. The biomass of the interacting species will be the net result of the interaction (PUGNAIRE; LUQUE, 2001). Several authors (PUGNAIRE; LUQUE 2001; KUNSTLER et al., 2011) advocate the idea that the role of competition decreases and the role of facilitation increases under stress conditions. The conditions under which this work was conducted were stressful. The region has

Table 4 – Mean dry biomass yield of stems, branches, and leaves of tree species at 42 months of age, in the central row of the plot[1].

T*abela 4* – *Médias dos rendimentos de biomassas secas de caules, ramos e folhas de espécies arbóreas, aos 42 meses de idade, na fileira central das parcelas[1].*

Stem dry biomass (kg ha^{-1})				
Species in the plot's central row	Species in the plot's lateral rows			Means
	Gliricidia	Neem	Sabiá	
Gliricidia	15,119	15,032	18,827	16,326 A
Neem	8,947	6,407	7,081	7,478 B
Sabiá	4,276	5,418	6,919	5,537 B
Means	9,447 a	8,952 a	10,942 a	-
Experimental coefficient of variation = 36.1%				
Branch dry biomass (kg ha^{-1})				
Species in the plot's central row	Species in the plot's lateral rows			Means
	Gliricidia	Neem	Sabiá	
Gliricidia	1,124	1,521	2,082	1,576 AB
Neem	973	906	1035	971 B
Sabiá	1,730	2,108	2,334	2,057 A
Means	1,276 a	1,511 a	1,817 a	-
Experimental coefficient of variation = 34.9%				
Leaf dry biomass (kg ha^{-1})				
Species in the plot's central row	Species in the plot's lateral rows			Means
	Gliricidia	Neem	Sabiá	
Gliricidia	1,161	754	1,537	1,151 B
Neem	1,748	1,441	2,095	1,761 A
Sabiá	326	482	377	395 C
Means	1,078 a	893 a	1,337 a	-
Experimental coefficient of variation = 44.9%				

[1]In each trait, means followed by the same upper case letter in the column, and by each lower case letter in the row do not differ from one another at 5% probability, by Tukey's test.

[1]Em cada característica, médias seguidas pela mesma letra maiúscula na coluna e pela mesma letra minúscula na linha não diferem entre si, a 5% de probabilidade, pelo teste de Tukey.

poor soils and rains are poorly distributed in time and space. As an example, it practically did not rain in the year 2012. Such stressful conditions could contribute to explain why each of the three species studied had the same biomass of the above-ground part when grown between rows of plants of the same species or of different species. In addition, it may have occurred what Kelty (1992) refers to as competitive reduction. Such process may occur spatially, via stratification of leaves or roots, or temporarily due to phenological differences (FORRESTER et al., 2006). Finally, the lack of interspecific competition observed in this work may have been due to the young age of the trees (42 months), in combination with the row spacing adopted (5.0 m x 5.0 m). Some authors have indicated the distance between trees as an important factor in the competition between trees, with a strong negative correlation with competitive intensity (SEIDEL et al., 2011).

Some authors (YOSHIDA; KAMITANI, 2000) observed different results from those reported in the present study. In other words, they verified that some species grow less than others, depending on which species were competing. On the other hand, similarly as observed in this study, other authors (KUBOTA; HARA, 1995) observed little interspecific competition between three tree species.

4.3. Experiment 3

The results from experiment-3, in which gliricidia biomass and sabiá biomass were evaluated when grown at a row spacing of 4.0 m x 4.0 m were quite similar to those obtained in experiment-1, at the same planting density (Tables 1 and 2), i.e., gliricidia was

Table 5 – Mean green and dry biomass yield for stems, branches, and leaves of tree species at 27 months of age[1].
Tabela 5 *– Médias dos rendimentos de biomassas frescas e secas de caules, ramos e folhas de espécies arbóreas aos 27 meses de idade[1].*

Species	Green biomass (kg ha^{-1})			Dry biomass (kg ha^{-1})		
	Stems	Branches	Leaves	Stems	Branches	Leaves
Gliricidia	31,791 a	4,519 a	3,681 a	17,498 a	1,735 a	951 a
Sabiá	15,716 b	3,194 a	1,525 b	11,506 b	988 b	708 a
CV (%)	17.0	33.8	21.7	15.3	46.7	21.1

[1] For each trait, means followed by the same letter do not differ from each other at 5% probability by Tukey's test.
[1] *Em cada característica, médias seguidas pela mesma letra não diferem entre si, a 5% de probabilidade, pelo teste de Tukey.*

superior to sabiá for green and dry biomass, with the exception of branch green biomass and leaf dry biomass, which showed no differences between species.

5. CONCLUSIONS

In E1 gliricidia was superior to sabiá for stem and leaf green biomass at the smaller densities, but was inferior for branch green biomass at most densities. The species did not differ for mean stem dry biomass and leaf dry biomass, but gliricidia showed higher branch dry biomass at most densities. Higher planting densities increased green and dry biomass of stems, branches, and leaves in sabiá, but decreased those characteristics in gliricidia, with the exception of leaf dry matter, which was not influenced by density. In E2, the behavior of each species was identical in plots containing the same species or different species. The highest stem green biomass was obtained for gliricidia; the highest branch green biomass was presented by gliricidia; and the highest leaf green biomass values were obtained for gliricidia and neem. The highest stem, branch, and leaf dry biomass values were obtained for gliricidia, sabiá, and neem, respectively. In E3, gliricidia was superior for stem and leaf green biomass, and for stem and branch dry biomass. There were no differences between species for the other biomass values.

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