GROWTH, YIELD AND ECONOMIC ANALYSIS OF AN EUCALYPT-SOYBEAN CONSORTIUM: EFFECT OF THE DISTANCE BETWEEN TREES WITHIN THE ROW[1]

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ABSTRACT – Agroforestry systems (AGF) design should benefit all components of the consortium. The objective of this study was to evaluate the effect of the distance between plants within the row on growth and yield of trees and agricultural crop and on the economic viability of the consortium. The eucalypt was planted in 9.5 x 1.5 m, 9.5 x 2.0 m, 9.5 x 3.0 m and 9.5 x 40 m arrangements, in consortium with soybean. The tree diameter (dbh) and total height (Ht), and the leaf area index (LAI) were measured at 14, 38 and 51 months. Soybean yield was evaluated 24 months after planting eucalypt. An economic evaluation of the consortium was carried out for a planning horizon of seven years. The distance between trees within the row did not affect the tree height, however, larger distances promoted a higher dbh and individual volume. Higher values of basal area and yield were achieved in the 9.5 x 1.5 m arrangement. The LAI was smaller (1.43) in the 9.5 x 4.0 m arrangement, at 38 months, compared to the other arrangements (mean LAI = 1.66). Soybean had it's highest yield (2,317 kg ha^{-1}) in the 9.5 x 4.0 m arrangement. In the economic evaluation, the wood produced in the two denser arrangements was destined for energy, with low market value, making these two arrangements unfeasible economically, although the tree component yield was the highest in the arrangement 9.5 x 1.5 m. The 9.5 x 4.0 m spatial arrangement was the most economically viable, considering the allocation of 40% of the wood for sawing, and the prices and costs assumed in this study. In this arrangement, the soybean yield was the highest, and the planting costs were the lowest when compared to the other arrangements.

Keywords: Agroforestry system; Leaf area index; Multi-products

PRODUÇÃO E ANÁLISE ECONÔMICA DE SISTEMAS AGROFLORESTAIS COM VARIAÇÃO NA DISTÂNCIA ENTRE LINHAS DE PLANTIO DE EUCALIPTO EM CONSÓRCIO COM SOJA

RESUMO – Os sistemas agroflorestais (SAF) devem beneficiar todos os componentes do consórcio. O objetivo deste trabalho foi avaliar o efeito da distância entre plantas na linha de plantio sobre o crescimento e a produção do componente arbóreo e da cultura agrícola e, sobre a viabilidade econômica do consórcio. Para isso plantou-se clone de eucalipto nos arranjos de 9,5 x 1,5 m, 9,5 x 2,0 m, 9,5 x 3,0 m e 9,5 x 40 m, em consórcio com soja. O diâmetro (dap) e a altura total (Ht) da árvore e o índice de área foliar (IAF) foram medidos aos 14, 38 e 51 meses. A produção de soja foi avaliada aos 24 meses após o plantio do eucalipto. A avaliação econômica do consórcio foi realizada para um horizonte de planejamento de sete anos. A distância entre as plantas na linha de plantio não afetou a altura das árvores, no entanto, maiores distâncias promoveram maior DAP e volume individual. Valores mais altos de área basal e produção foram alcançados no arranjo de 9,5 x 1,5 m. O IAF foi menor (1,43) no arranjo 9,5 x 4,0 m, aos 38 meses, em comparação aos demais arranjos (média de IAF = 1,66). A produção de soja foi a maior (2.317 kg ha^{-1}) no arranjo de 9,5 x 4,0 m. Na avaliação econômica, a madeira produzida nos dois povoamentos mais densos foi destinada à energia, com baixo valor de mercado, inviabilizando economicamente esses arranjos, embora o rendimento do componente arbóreo tenha sido o mais elevado no 9,5 x 1,5 m. O arranjo espacial de 9,5 x 4,0 m foi o mais viável economicamente, considerando a alocação de 40% da madeira para serraria, e os preços e custos assumidos neste estudo. Neste arranjo de plantio, o rendimento da soja foi o mais elevado e os custos de plantio foram os menores, quando comparados aos demais arranjos.

Palavras-Chave: Sistemas agrolofrestais; Índice de área foliar; Multi-produtos.

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1. INTRODUCTION

The eucalypt genotype diversity and a advances in the management techniques allow the high productivity of planted forests in different site conditions. Nowadays, the average productivity of commercial eucalypt plantation in Brazil is about 36 m^3 ha^{-1} and it can reach up to 62 m^3 ha^{-1} with irrigation (Stape and Binkley, 2010; Stape et al., 2010; Gonçalves et al., 2013; IBÁ, 2016; Santos et al., 2016; Binkley et al., 2017). Most of these eucalypt plantations have been established in spacings ranging from 9 to 12 m^2 to obtain wood for energy, pulp, and paper, among others (Stape and Binkley 2010; Eloy et al., 2016; Binkley et al., 2017).

The agroforestry systems (AGF), in which wide spaces are used for the consortium with agricultural crops and, or forage, have received greater attention in Brazil, mainly because of their environmental and social benefits. Eucalypt genotypes have been the tree component most used for the establishment of these systems by forest companies and farmers (Dubè et al., 2002; Macedo et al., 2004; Oliveira et al., 2009; Paula et al., 2013).

The adoption of eucalypt in AGF is an important strategy for food production since it reduces timber production costs (Prasad et al., 2010; Amorim, 2016). According to Dubè et al. (2002), the agricultural crop of the consortium in the first two years reduced the costs of the AGF by up to 37%.

Variation in the tree spacing and spatial arrangement could lead to a higher yield and profitability of the consortium since they modify the degree of intra- and inter-specific competition. The acquisition and use of the growth resources are modified with both the tree spacing and its spatial distribution in the field (Bernardo et al., 1998; Kruschewsky et al., 2007; Oliveira et al., 2013; Leite et al., 2014; Oliveira et al., 2016).

In a consortium, there is a need to consider the yield of all components of the system. The increasing distance between rows favors the production of agricultural crops or pasture in the AGF`s (Prasad et al., 2010; Oliveira et al., 2016; Paciullo et al., 2011). The proximity of the trees within the row can accentuate the competition between them, mainly due to the rapid closure of the canopies and root occupancy (Melido, 2012; Kruschewsky et al., 2007; Oliveira et al., 2009; Oliveira et al., 2013).

The tree planting arrangement, which includes the distance between rows, and within rows, interferes directly in the availability of radiation to the trees and to the intercropping plants. Through the determination of the leaf area index (*LAI*), it is possible to estimate the transmittance of the photosynthetically active radiation (t%) in forest stands, helping to define management techniques to maintain a high yield of trees and agricultural crops in an AGF. Usually, in the studies about the spatial arrangement of the tree component, only the tree growth and yield has been evaluated, although the agricultural crop yield should also be monitored (Dubè et al., 2002; Kruschewsky et al., 2007; Oliveira et al., 2009;Oliveira et al., 2016).

The objective of this study includes the evaluation of the yield of an eucalypt clone, and the intercropped soybean, in four tree planting spatial arrangements and, the viability of the consortium.

2. MATERIAL AND METHODS

This study was carried out in Vazante, MG (17º36'09"S, 46º42'02"W and 550 m altitude) with the clone 58 (*E. camaldulensis* x *E. grandis*) planted in the following spatial arrangements: T1 - 9.5 x 1.5 m (14.25 m² plant-1); T2 - 9,5 x 2,0 m (19 m² $plant^{-1}$); T3 - 9.5 x 3.0 m (28.5 m² plant-11), and T4 - 9.5 x 4.0 m (38 m² $plant^{-1}$). These treatments were arranged in a completely randomized design, with eight replications. The measurement unit consisted of two central lines, with 10 plants each, with a single border. The distance of 9.5 m between the rows was the same in all treatments, with variation in the distance of plants within the row (1.5, 2.0, 3.0, and 4.0 m).

The soil of the site is Dystrophic Dark-Red Latosol, with clayey texture, cerrado phase, with low fertility, and high acidity. The climate of the region is Aw (Köppen), with dry winter and rainy summer, a mean annual temperature of 26.5°C, mean annual precipitation of 1,350 mm, and a high water deficit between April and October (Souza et al., 2016).

The site preparation included desiccation with glyphosate, subsoiling (60cm deep in the planting row) and two disking. Limestone was applied in the planting row (1 ton ha^{-1}), according to the soil chemical analysis. Eucalypt was planted in April 2005, with the following fertilization: 130 g $plant^{-1}$ of NPK 10-28-06 + 0.5% of Zn + 0.3% B, applied after planting in lateral furrows (10cm from the seedling) to a depth of 10 cm. In February 2006, it was applied 20 g $plant^{-1}$ (10 g on each side) of Borogram (10% B) in lateral furrows.

The soybean (*Glycine max* L. Merrill) was sown after the application of glyphosate, in December 2006 (the second rainy season after the eucalypt planting), with application of 500 kg ha^{-1} of NPK 02-30-15 + 0.3% of B. The soybean was planted in a 7.50 m strip, in the eucalypt inter-row (1 m distant from the tree, on each side), in three replications, with planting density of 22 seeds per linear meter, 0.45 m between soybean rows.

At 14, 38, and 51 months after tree planting, *LAI* readings were taken with the LAI-2000 Licor canopy analyzer, with a sensor installed in an open area near the stand and another used for measurements inside the stand, 0.5 m above the soil surface. The readings were obtained under diffused light, at dawn or late afternoon. The *LAI* measured inside the stand was obtained in six positions across the inter-row, in the center of each of the three plots. Two positions were located at the intermediate point between the plants in the planting line (points 1 and 6); four points in the inter-row, being two under the tree canopy at 0.5 m away from the trunk (points 2 and 5), and two at 2 m from the tree (points 3 and 4) (Figure 1).

Soybean was sampled when the eucalypt trees were 24 months old, in the three plots. Two soybean sampling areas of 0.5 m x 3.75 m were obtained in each plot (one meter from the eucalypt planting line to half the distance between two planting lines (Figure 1). That is, the length of the plot corresponds to half of the distance in the tree inter-row. A soybean sampling area was located between the seventh and the eighth tree on the right side of the first planting line of the measurement plot, and the other between the second and third plant on the left side of the second line of the measurement area. Grain yield of the AGF was calculated only for the soybean cultivation area to allow comparison with single soybean yield.

The tree diameter at the height of 1.3 m (*dap*) and the total height (*Ht*) was measured at 14, 38, and 51 months after planting. At 32 months, only *dbh* was measured.The height was estimated by means of linear regression, using the height measured previously.

At 51 months, three trees per replicate were sampled for scaling, in three plots per treatment, with measurements taken at heights of 0.3; 1.3; 2.3; 3.3 and 4.3 m. The volume with bark was estimated up to the height of 4.3 m, based on these data. The volume from 4.3 m to the top was estimated considering a cone with base equal to the last section measured. The amplitude of the total height was 11.4 to 21.7 m. The assumption is that the shape differentiation between the arrangements, for the same *dbh,* occurs at the base of the trunk up to the height of 4.3 m.

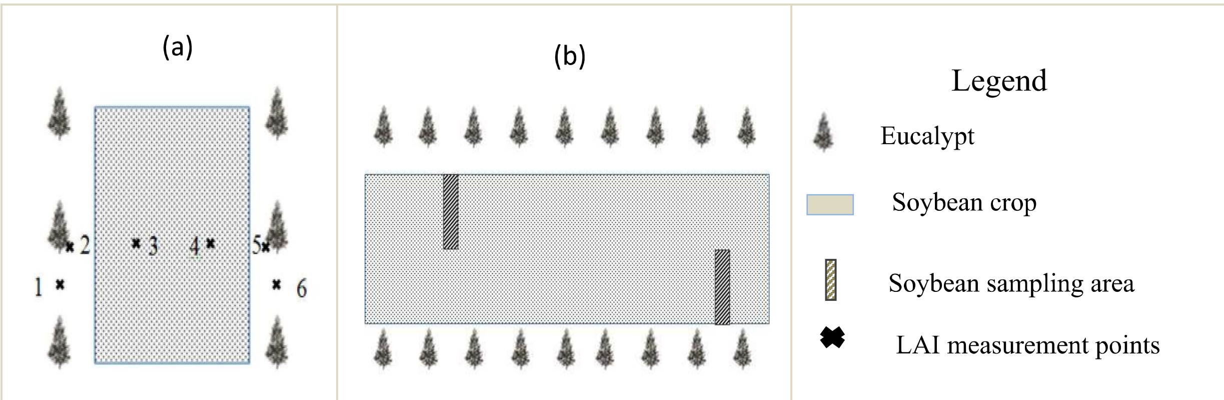

Figure 1 – Schematic profile showing the leaf area index (LAI) measurements points (a), and soybean sampling sites (b), in Vazante, MG.
Figura 1 – *Perfil esquemático mostrando os pontos de coleta de índice de área foliar do povoamento do clone 58 de eucalipto (a) e dos locais de amostragem da produção de soja (Glycine Max), em Vazante, MG.*

The with bark volume of each tree was obtained with the Smalian formula up to 4.3 m and the cone formula was used for the rest of the trunk. Then, it was adjusted the linearized volumetric model of Schumacher and Hall:

$$\text{Ln } V = \beta 0 + \beta 1 \, (\text{Ln}\,dbh) + \beta 2 \, (\text{Ln}\,Ht) + \epsilon, \quad (1)$$

where: V = volume per tree, in m³; *dbh* = diameter at 1.3 m height, in cm; *Ht* = total height, and β0, β1 and β2= model parameters; ϵ = random error.

To estimate height according to age, the following model was adjusted:

$$\text{Ln } (Ht) = \beta 0 + \beta 1 \, (1 / \text{i}) + \epsilon \quad (2)$$

where: *Ht* = total tree height in m, β0 and β1 = model parameters, i = age in months, ϵ = random error.

The height of each tree at 32 months was obtained by transforming the equation 2, as follows:

$$Ht\,32i = Ht38i * \frac{Exp\left(\frac{\beta 0 + \beta 1}{32}\right)}{Exp\left(\frac{\beta 0 + \beta 1}{38}\right)} \quad (3)$$

where: *Ht32i* = height of the i tree projected for the age of 32 months; *Ht38i* = height of the i tree at the age of 38 months.

The logistic model for diameter, basal area, and volume, as a function of age, were adjusted with the Curve Expert 1.4 (HYAMS, D., 2009):

$$Y_i = \frac{\alpha}{1+\beta e^{-\gamma I}} + \epsilon \quad (4)$$

where: Yi = variable of interest; α, β and γ = model parameters; *I* = age in months, εi = random error.

These adjustments were evaluated by the correlation coefficient between the values observed and those estimated (ryŷ), by the residual standard error (Syx), and by the root mean square error (RMSE), being:

$$RMSE = \sqrt{\frac{\Sigma_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{n}} \quad (5)$$

$$Syx = \sqrt{MSRs} \quad (6)$$

where: *MSRs* = mean squared residues; Yi = observed value of the variable under analysis; Ŷi = estimated value of the variable under analysis; n = number of cases.

The current annual increment (*CAI*) and the mean annual increment (*MAI*) were obtained from the estimated production for each tree planting spatial arrangement until a certain age.

The adjusted equations for diameter, basal area, and volume were compared with the identity test for non-linear models (α = 5%) (Regazzi, 2003). Normality test (Lilliefors) of *LAI* data at 14, 38 and 51 months indicated a normal distribution only for the data at 38 months. The Cochran, Hartley, and Bartlett test was applied to the 38 months data, and it was observed homogeneity of variance. *LAI* data at the age of 38 months provided such assumptions for ANOVA. The Tukey test (0.05) was applied to these data.

The economic analysis carried out for the 9.5 x 1.5 m and 9.5 x 2.0 m arrangements took into account that all wood produced would be used for charcoal production, due to the reduced tree diameter, in these arrangements. For the spatial arrangements of 9.5 x 3.0 m and 9.5 x 4.0 m, it was considered that 40% of the wood produced could be used for sawing, and 60% for charcoal production. The selling price of standing timber was R$38.70 per m³ for charcoal production (noticiasagrícolas.com.br), and R$90.00 per m³ for sawmills (price obtained from sawmills of Minas Gerais state). The costs to plant and manage the AGF were informed by the company that provided the experimental area (Barbosa, 2015). The soybean price was R$62.67 per bag of 60 kg.

The criteria used for the economic analysis were: net present value, internal rate of return and, equivalent periodic benefit (Rezende and Oliveira, 2008). The discount rate was 8% per year. The expressions to calculate the economic criteria were:

$$NPV = \Sigma_{j=0}^{n} Rj(1+i)^{-j} - \Sigma_{j=0}^{n} Cj(1+i)^{-j} \quad (7)$$

$$\Sigma_{j=0}^{n} Rj(1+IRR)^{-j} - \Sigma_{j=0}^{n} Cj(1+IRR)^{-j} \quad (8)$$

$$\text{EPB} = \frac{NPV\,((1+i)^t - 1)(1+i)^{nt}}{(1+i)^{nt} - 1} \quad (9)$$

where: *NPV* = the net present value; *IRR* = the internal rate of return; *EPB* = the equivalent periodic benefit (cost); R = the total revenue in year j; C = the total cost in year j; i = the annual discount rate; n = the duration of the project, in years; t = the number of capitalization periods.

3. RESULTS

The survival of the AGF tree component was 94.7% and 97.1%, respectively, for the 9.5 x 4.0 m and 9.5 x 3.0 m and 100% for the other arrangements.

The adjusted equations for the individual volume (Schumacher and Hall linearized model) presented high values of correlation coefficient: 0.9370 (9.5 x 1.5 m); 0.9194 (9.5 x 2.0m); 0.9123 (9.5 x 3.0m), and 0.9776 (9.5 x 4.0 m) (Table 1).

The spatial arrangements did not influence height ($p > 0.05$), with the equation $Ln(Ht) = 3.0443 - 20.5192 (1/i) + \epsilon$ being used to estimate height in all four treatments. The correlation coefficient ($r_{y\hat{y}}$) was 0.8162 and the residual standard error (Syx) was 0.1972.

Diameter differed ($p < 0.05$) between spatial arrangements (Table 2, Figure 2). The 9.5 x 4.0 m arrangement had a higher asymptotic value (21.30 cm) and the ones with a higher population density (9.5 x 1.5 m and 9.5 x 2.0 m) had lower asymptotic values (14.5 and 15.9 cm, respectively).

The individual volume showed higher asymptotic values ($p < 0.05$) in the arrangements with larger distances in the tree planting line (Table 2, Figure 2). The asymptotic value for treatments with smaller distances between trees was similar (0.11718 m^3 $tree^{-1}$) but substantially lower than in the other treatments.

The highest values ($p < 0.05$) of basal area (α = 11.55 m^2 $ha^{\cdot}$) and yield (133.31 m^3 ha^{-1}) were observed in the 9.5 x 1.5 m (Table 2, Figure 2). In the 9.5 x 3.0 m and 9.5 x 4.0 m arrangements, represented by the same equation, basal area and yield were lower than in the denser stands. The trees in the 9.5 x 2.0 m arrangement showed high growth rate after planting, however, there was growth stagnation earlier than for the other arrangements.

The *MAI* was higher for the 9.5 x 1.5 m arrangement (20 m^3 ha^{-1} $year^{-1}$), 71 months after planting. The arrangement 9.5 x 2.0 m showed a

Table 1 – Estimates of the parameters of the Schumacher and Hall linearized model and corresponding correlation coefficients (ryŷ) and residual standard error (Syx) for the individual volume of the eucalypt clone 58, in spatial arrangements with variation in distance between plants within the row, in Vazante, MG.

Tabela 1 *– Estimativas dos parâmetros do modelo Schumacher e Hall linearizado e correspondentes coeficientes de correlação (rŷy) e erro padrão residual (Syx) para o volume individual do clone 58 de eucalipto, em arranjos espaciais com variação na distância entre plantas na linha de plantio, em Vazante, MG*

Spatial arrangements (m^2)	Spacing (m^2 $tree^{-1}$)	Planting density (trees ha^{-1})	Parameters β_o	β_1	β_2	$r_{y\hat{y}}$ (1)	S_{yx} (2)
9,5 x 1,5 (T1)	14,25	701	-9,18461	1,922161	0,65935	0,9370	0,0601
9,5 x 2,0 (T2)	19,00	526	-8,91474	2,09079	0,41444	0,9194	0,0730
9,5 x 3,0 (T3)	28,50	350	-8,70435	1,024334	1,384659	0,9123	0,0580
9,5 x 4,0 (T4)	38,00	263	-10,6165	2,173237	0,895117	0,9776	0,0397

Table 2 – Logistic model parameters (α, β and γ), adjusted for mean diameter, basal area, individual volume and yield, and corresponding correlation coefficients (rŷy), residual standard error (Syx), and root mean square error (RMSE), for eucalypt clone 58, in spatial arrangements with variation in distance between plants within the row, in Vazante, MG.

Tabela 2 – *Estimativas dos parâmetros do modelo Logístico (α, β e γ), ajustado para diâmetro médio, área basal, volume por árvore e volume por hectare, e correspondentes coeficientes de correlação (rŷy), erro padrão residual (Syx) e raiz quadrada do erro médio (RMSE), para o clone 58 de eucalipto, em arranjos espaciais com variação na distância entre plantas na linha de plantio, em Vazante, MG*

Treatments	α	β	γ	$r_{\hat{y}y}$	*Syx*	RMSE	Treatments	α	β	γ	$r_{\hat{y}y}$	*Syx*	RMSE
	------------ Mean diameter (cm) -----------							------------- Basal area (m^2 ha-1) --------------					
T1	14,4635	8,5764	0,1016	0,9940	0,7592	0,3822	T1	11,5045	35,1220	0,1179	0,9882	1,0563	0,5282
T2	15,9281	12,4771	0,1141	0,9994	0,2921	0,1479	T2	10,4987	43,8189	0,1188	0,9985	0,3380	0,3939
T3	18,1803	11,0757	0,0975	0,9985	0,4911	0,2452	T3-T4	8,8433	33,8874	0,0993	0,9869	0,4786	0,3784
T4	21,3003	11,5644	0,0885	0,9985	0,5648	0,2852							
	------- Individual volume (m^3 planta -1) ------							----------------- Yield (m^3 ha-1) ----------------					
T1-T2	0,1718	98,0966	0,1075	0,8959	0,0191	0,0191	T1	133,3165	75,8005	0,0915	0,9902	3,4006	11,6534
T3	0,3624	147,6177	0,0935	0,9553	0,0151	0,0151	T2	93,6251	106,2921	0,1130	0,9995	0,6641	10,0957
T4	0,3362	305,7364	0,1180	0,8974	0,0297	0,0293	T3-T4	99,3238	182,3671	0,1031	0,9926	1,9145	6,9458

T1= 9,5 x 1,5 m; T2= 9,5 x 2,0 m; T3= 9,5 x 3,0 m e T4= 9,5 x 4,0 m

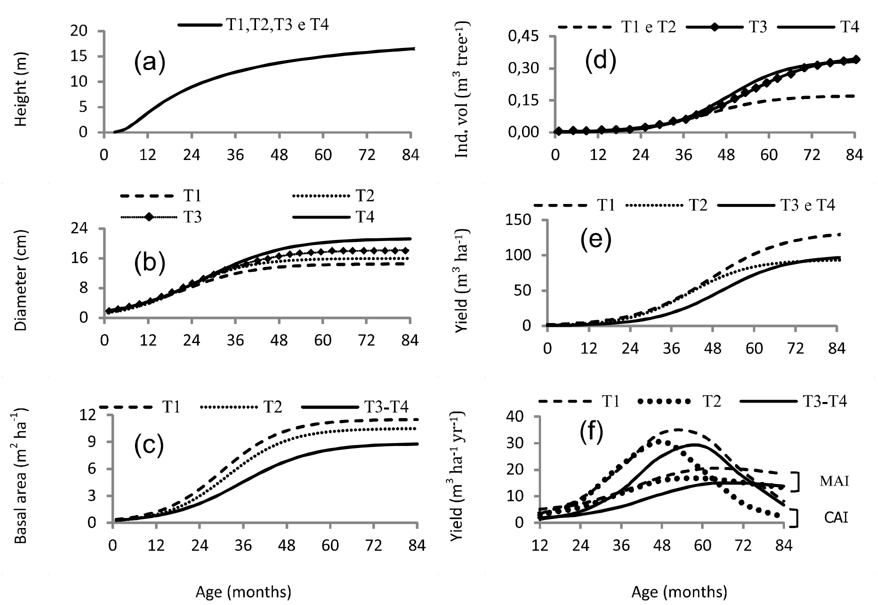

Figure 2 – Height (a), diameter (b), basal area (c), individual volume (d), yield (e), and mean and current annual increment (f) of the eucalypt clone 58, in spatial arrangements with distance variation between plants within the row, in Vazante, MG. Being: T1 = 9,5 x 1,5 m; T2 = 9,5 x 2,0 m; T3 = 9,5 x 3,0 m e T4 = 9,5 x 4,0 m.

Figura 2 *– Crescimento em altura (a), diâmetro (b), área basal (c), volume individual (d), produção (e); e, incrementos médio anual (m³ ha-1 ano-1) e corrente (m³ ha-1) (f) do clone 58 de eucalipto, em arranjos espaciais com variação na distância entre plantas na linha de plantio, em Vazante, MG. Sendo: T1= 9,5 x 1,5 m; T2= 9,5 x 2,0 m; T3= 9,5 x 3,0 m e T4= 9,5 x 4,0 m*

maximum yield at 63 months, anticipating the rotation, while in the 9.5 x 3.0 m and 9.5 x 4.0 m arrangements, the rotation age happened at 74 months (Figure 2).

The *LAI* at 38 months were similar (mean of 1.66) for the 9.5 x 1.5 m; 9.5 x 2.0 m (mean of 1.66); being the *LAI* of the 9.5 x 3.0 m arrangement higher ($p \leq 0.05$) than that of the 9.5 x 4.0 m (*LAI* = 1.44).

The yield of soybean grains did not differ ($p > 0.05$) between the sampling positions (left or right side of the tree planting line). The average soybean grains yield, considering only the 7.5 m wide area planted with soybean (79% of the total area), did not differ ($p < 0.05$) among the 9.5 x 1.5 m; 9.5 x 2.0 m, and 9.5 x 3.0 m arrangements, being 1,248, 1,454, and 1,565 kg ha^{-1}, respectively. The highest ($p < 0.05$) soybean yield was obtained for the 9.5 x 4.0 m (2,317 kg ha^{-1}).

There was a positive balance in the cash flow for the consortium in the 9.5 x 4.0 m arrangement, which was characterized by a larger *dbh*, allowing the use of 40% of the wood for the sawmill, and presented the highest soybean yield (Table 3). The economic analysis showed the viability of the AGF only for the 9.5 x 4.0 m arrangement, with *IRR* of 14.31% per year and *EPB* of R$175.25. The *NPV* indicated by the positive difference between revenues and costs for this spatial arrangement, updated according to the discount rate, was R$ R$912.42 ha^{-1}. The arrangement 9.5 x 3.0 m presented a low IRR (8.46%), *NPV* of R$77.07 and *EPB* of R$14.80, and all other values were negative. The 9.5 x 1.5 m and 9.5 x 2.0 m arrangements were considered economically unviable.

4. DISCUSSION

Spatial arrangements did not influence growth in height, as observed by Leles et al. (2001) and Oliveira (2014), however, Leite et al. (2006) and Sartório (2014) reported the influence of planting density on height growth. These differences in height growth response may be related to the genotype (Magalhães et al., 2007; Oliveira, 2014), and, or, water, nutrient availability and light availability for the plants (Barton and Montagu, 2006).

The increasing diameter with the increase of the area per plant, as observed in the 9 x 4 m, is certainly due to the greater availability of growth resources. There is a tendency to increase the tree diameter with

Table 3 – Cash flow (R $ ha-1) for seven years of the consortium of the eucalypt clone 58 and soybean, in spatial arrangements with variation in distance between plants within the row, in Vazante, MG.
Tabela 3 *– Fluxo de caixa (R$ ha-1) para sete anos do sistema consorciado soja x clone 58 de eucalipto, em arranjos espaciais com variação na distância entre plantas na linha de plantio, em Vazante, MG*

	9,5 x 1,5 m				9,5 x 2,0 m			
Year	Cost	Revenue	Balance	Cumulative balance	Cost	Revenue	Balance	Cumulative balance
0	2847,65		-2847,65	-2847,65	2600,08		-2600,08	-2600,08
1	2081,81	1297,46	-784,35	-3632,01	2041,48	1518,98	-522,496	-3122,58
2	311,61		-311,61	-3943,62	311,61		-311,61	-3434,19
3	196,97		-196,97	-4140,59	196,97		-196,972	-3631,16
4	196,97		-196,97	-4337,56	196,97		-196,972	-3828,14
5	196,97		-196,97	-4534,53	196,97		-196,972	-4025,11
6	196,97		-196,97	-4731,51	196,97		-196,972	-4222,08
7	0	5159,35	5159,35	427,84	0	3623,29	3623	-598,79
	9,5 x 3,0 m				9,5 x 4,0 m			
Year	Cost	Revenue	Balance	Cumulative	Cost	Revenue	Balance	Cumulative
0	2351,041		-2351,04	-2351,04	2227,52		-2227,52	-2227,52
1	2000,92	1634,18	-366,73	-2717,77	2124,31	2420,23	295,92	-1931,60
2	311,61		-311,61	-3029,38	311,61		-196,98	-2128,58
3	196,97		-196,97	-3226,35	196,97		-196,97	-2325,56
4	196,97		-196,97	-3423,33	196,97		-196,97	-2522,53
5	196,97		-196,97	-3620,3	196,97		-196,97	-2719,51
6	196,97		-196,97	-3817,27	196,97		-196,97	-2916,49
7	0	5506,50	5506,50	1689,24	0	5506,50	5506,50	2590,01

tree density reduction (Kruschewsky et al., 2007; Paula et al., 2013; Oliveira, 2014). The increase in distance between trees within the row favors the diameter growth (Oliveira Neto, 1996; Oliveira et al., 2009; Cardoso et al., 2013). Oliveira Neto (1996) reported a positive diameter growth as the distance of the plants in the row changed from 2 m to 5 m, with a fixed distance of 3 m between rows.

Basal area growth is related to plant diameter and density (Curtis and Marshall, 2000; Campos and Leite, 2013). In the present study, the denser arrangements presented larger basal area than those with smaller planting density. Oliveira et al. (2009) found a smaller basal area for the arrangement (3x4) +10 m, with double rows, compared to the arrangement of 10 x 3 m, at 51 months.

The greater distances between plants resulted in higher individual volume as also reported for eucalypt by Magalhães et al. (2007). Oliveira et al. (2009) reported an increase of 47.7 and 49.6% in the individual plant volume in the 10 x 3.0 m and 10 x 4.0 m, respectively, compared to the 10 x 2.0 m arrangement, at 51 months after planting. The number of rows can also affect plant growth. Oliveira (2014) reported a higher individual volume of eucalypt clones, in AGF system, for single row arrangement (9.0 x 3.0 m), as compared to double rows ((3x3) + 9 m). The tree plant spacing affects the availability of water (Barton and Montagu, 2006), nutrients (Oliveira Neto et al., 2013), solar radiation (Oliveira, 2014), and changes the partitioning of assimilates (Bernardo et al. al., 1998; Leles et al., 2001; Oliveira Neto et al., 2013). Barton and Montagu (2006) and Leles et al. (2001) observed an increase in the biomass partition to the roots by decreasing the planting density of *E. camaldulensis*.

The decision about tree planting arrangement should take into account other factors in addition to the tree growth and yield, such as its effect on tree harvesting cost and the use of the final product. For example, in the 9.5 x 4.0 m arrangement, individual tree volume is higher and the yield is lower than in the 9.5 x 1.5 m. The 9.5 x 4.0 m is recommended for multi-products, which includes the possibility of wood for sawing, while the 9.5 x 1.5 m, with higher yield and small individual trees, is better recommended for energy. Also, the reduced tree individual size in the 9.5 x 1.5 m, increases harvesting costs, as the yield of the forest harvester decreases (Martins et al., 2009; Leite et al., 2014).

In the analysis of the AGF as a whole, one should consider the canopy density variation with different tree planting arrangements, as there is an effect on photosynthetically active radiation transmittance (t%) (Binkley et al., 2013; Oliveira et al., 2016). The *LAI*, which is associated to t%, was the lowest in the 9.5 x 1.5 m arrangement, at 38 months after planting, a similar result was reported by Paula (2011), for *E. camaldulensis* clone, at the same age.

Soybean cultivation was carried out in the second rainy season after planting the tree component and, when consorted in the 9.5 x 4.0 m arrangement, the grain yield reached values close to those obtained for monocultures (2,340 kg ha^{-1} in Minas Gerais). In the present study, there was no agricultural crop in the first year of the establishment of the tree component. If an agricultural crop was planted in the first year, the crop yield could have been higher than that obtained in the second rainy season, due to the reduced *LAI* in the inter-row at that age, in all the arrangements, as the height of the trees were still low.

The low market value of wood intended for energy and the low soybean yield made economically unviable the AGF system with the studied eucalypt clone in dense stands. On the other hand, the lowest planting density (9.5 x 4.0 m arrangement) was the most profitable, due to the higher soybean yield, lower stand establishment costs, as well as the possibility of obtaining higher value-added wood (for sawing, for example) due to larger tree diameters. Melido (2012) also observed variation in the economic viability of eucalypt plantation as a function of spatial arrangement.

The use of wood for multi-products (energy + sawmill) is more economical when compared to wood intended for energy only. The high value of lumber for sawing is the main factor responsible for the higher viability of the AGF (Soares et al., 2013). Silva (2016) reported a significant increase in income (R$16,530 ha^{-1}) for *Eucalyptus grandis* x *E. urophylla hybrid*, in the spatial arrangement of 12 x 4 m, at the age of eight years, when the wood harvested was used for multi-products, in comparison to the exclusive destination for firewood.

5. CONCLUSIONS

The low market value of wood intended for energy in relation to sawing timber resulted in economic unfeasibility for the 9.5 x 1.5 m and 9.5 x 2.0 m arrangements, even though the wood production was the highest in the arrangement 9.5 x 1.5 m. On the other hand, the 9.5 x 4.0 m stand, with larger trees and higher soybean yield, was the most economically viable considering the allocation of 40% of the wood for sawing, and the prices and costs assumed in this study.

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7. REFERENCES

Amorim JS. Viabilidade de sistemas agroflorestais em alto fuste e talhadia de plantas jovens de eucalipto com ciclos agrícolas estendidos [dissertação]. Viçosa, MG: Universidade Federal de Viçosa; 2016.

Barbosa RA. Crescimento de clone de eucalipto em espaçamentos amplos com variação na distância entre plantas na linha de plantio [dissertação]. Viçosa, MG: Universidade Federal de Viçosa; 2015.

Barton CVM, Montagu, KD. Effect of spacing and water availability on root-shoot ratio in *Eucalyptus camaldulensis*. Forest Ecology and Management. 2006;221:52-62.

Bernardo AL, Reis MGF, Reis GG, Harrison RB, Firme DJ. Effect of spacing on growth and biomass distribution in Eucalyptus camaldulensis, *E. pellita* and *E. urophylla* plantations in southeastern Brazil. Forest Ecology and Management. 1989;104(1):1-13.

Binkley D, Campoe OC, Gspaltl M, Forrester DI. Light absorption and use efficiency in forests: Why patterns differ for tree and stands? Forest Ecology and Management. 2013;288:5-13.

Binkley D, Campoe OC, Alvares C, Carneiro RL. The interactions of climate, spacing, and genetics on clonal *Eucalyptus plantations* across Brazil and Uruguai. Forest Ecology and Management. 2017;405:271-83.

Campos JCC, Leite HG, Mensuração florestal: perguntas e respostas. 4ª.ed. Viçosa: MG: Universidade Federal de Viçosa; 2013.

Cardoso DJ, Lacerda AEB, Rosot MAD, Garrastazú MC, Lima RT. Influence of spacing regimes on the development of loblolly pine (*Pinus taeda* L.) in Southern Brazil. Forest Ecology and Management. 2013;310:761-9.

Curtis RO, Marshall DD. Why quadratic mean diameter? Western Journal Applied Forestry, 2000;15(3):37-139.

Dubè F, Couto L, Silva ML, Leite HG, Garcia R, Araujo GAA. A simulation model for evaluating technical and economic aspects of an industrial eucalyptus-based agroforestry system in Minas Gerais, Brazil. Agroforestry Systems. 2002;55:73-80

Eloy E, Silva DA, Schmidt D, Trevisan R, Caron BO, Elli EF. Effect of planting age and spacing on energy properties of *Eucalyptus grandis* W. Hill Ex Maiden. Revista Árvore. 2016;40(4):749-58.

Indústria Brasileira de Árvores - IBÁ. [acesso em: 14 mar. de 2017]. Disponível em: http://iba.org/images/shared/Biblioteca/IBA_RelatorioAnual2016_.pdf.

Gonçalves JLM, Alvares CA, Higa AR, Silva LD, Alfenas AC, Stahl J, et al. Integrating genetic and silvicultural strategies to minimize abiotic and biotic constraints in Brazilian eucalypt plantations. Forest Ecology and Management, 2013;301:6-27.

Kruschewsky GC, Macedo RLG, Venturin N, Oliveira TK. Arranjo estrutural e dinâmica de crescimento de *Eucalyptus spp*., em sistema agrossilvipastoril no Cerrado. Cerne. 2007;13(4):360-7.

Leite HG, Nogueira GS, Moreira AM. Efeito do espaçamento e da idade sobre variáveis de povoamentos de *Pinus taeda* L. Revista Árvore. 2006;30(4):603-12.

Leite ES, Minette LJ, Fernandes HC, Souza AP, Amaral EJ, Lacerda EG. Desempenho do *Harvester* na colheita de eucalipto em diferentes espaçamentos e declividades. Revista Árvore. 2014;38(1):1-7.

Leles PSS, Reis GG, Reis MGF, Morais EJ. Crescimento, produção e alocação de *Eucalyptus camaldulensis* e *E, pellita* sob diferentes espaçamentos na região de cerrado, MG. Scientia Forestalis. 2001;59:77-87.

Macedo RLG, Bezerra RG, Venturin N, Salgado BG, Vale RS, Higashikawa EM. Produção agroflorestal de sistemas consorciados de soja com clones de eucalipto na Região de cerrado, em Paracatu, Minas Gerais. Agrossilvicultura. 2004;1(2):175-85.

Magalhães WM, Macedo RLG, Venturin N, Higashikawa EM, Yoshitani Junior M. Desempenho silvicultural de clones e espécies/procedências de *Eucalyptus* na região noroeste de Minas Gerais. Cerne. 2007;13(4):368-75.

Martins RJ, Seixas F, Stape JL. Avaliação técnica e econômica de um harvester trabalhando em diferentes condições de espaçamento e arranjo de plantio em povoamento de eucalipto. Scientia Forestalis. 2009;37(83)253-63.

Melido RCN. Avaliação técnica e econômica de dois projetos florestais com eucalipto para fins energéticos [dissertação]. Brasília, DF: Universidade Federal de Brasília; 2012.

Oliveira CHR. Produção de eucalipto em alto fuste e talhadia e de braquiária em sistemas silvipastoris em diferentes arranjos espaciais [tese]. Viçosa, MG: Universidade Federal de Viçosa; 2014.

Oliveira CHR, Reis GG, Reis MGF, Leite HG, Souza FC, Soares RF, et al. Dynamics of eucalypt clones and *Brachiaria brizantha* production in silvopastoral systems with different spatial arrangements. Agroforestry Systems. 2016:90(6):1077-88.

Oliveira Neto SN. Biomassa, nutrientes e relações hídricas em Eucalyptus camaldulensis Dehn em resposta à adubação e ao espaçamento [dissertação]. Viçosa, MG: Universidade Federal de Viçosa; 1996.

Oliveira Neto SN, Salles TT, Leite HG, Ferreira GB, Melido RCN. Tree modeling and economic evaluation of agroforestry systems in southeastern Brazil. Silva Lusitana. 2013;21(1):43-60.

Oliveira TK, Macedo RLG, Venturin N, Higashikawa EM. Desempenho silvicultural e produtivo de eucalipto sob diferentes arranjos espaciais em Sistema Agrossilvipastoril. Pesquisa Florestal Brasileira. 2009;60:1-9.

Paciullo DSC, Gomide CAM, Castro CRT, Fernandes PB, Müller MD, Pires MFA, et al. Características produtivas e nutricionais do pasto em sistema agrossilvipastoril, conforme a distância das árvores. Pesquisa Agropecuária Brasileira. 2011;46(2):1176-83.

Paula RR. Avaliação silvicultural de eucalipto em monocultivo e em sistema agroflorestal com diferentes arranjos espaciais [dissertação]. Viçosa, MG: Universidade Federal de Viçosa; 2011.

Paula RR, Reis GG, Reis MGF, Oliveira Neto SN, Leite HG, Melido RCN, et al. Eucalypt growth in monoculture and silvopastoral systems with varied tree initial densities and spatial arrangements. Agroforestry Systems. 2013; 87(6):1285-307.

Prasad JVNS, Korwar GV, Rao KV, Mandal UK, Rao CAR, Ramakrishna YS, et al. Tree row spacing affected agronomic and economic performance of Eucalyptus-based agroforestry in Andhra Pradesh, Southern India. Agroforestry Systems. 2010;78(2):253-67.

Regazzi AJ. Teste para verificar a igualdade de parâmetros e a identidade de modelos de regressão não-linear. Revista Ceres. 2003;50(287):9-26.

Rezende JLP, Oliveira AD. Análise econômica e social de projetos florestais. Viçosa, MG: Universidade Federal de Viçosa; 2008.

Santos GA, Nunes CP, Resende MDV, Silva LD, Higa A, Assis TF. Genetic control and genotype-by--environment interaction of wood weight in Eucalyptus clones in the state of Rio Grande do Sul, Brazil. Revista Árvore. 2016;40(5):867-76.

Sartório IP. Avaliação e modelagem do crescimento de florestas energéticas de eucalipto plantadas em diferentes densidades [dissertação]. Curitiba: Universidade Federal do Paraná; 2014.

Silva S. Eficiência de redes neurais artificiais para estimar variáveis dendrométricas em sistemas agrossilvipastoris na zona da mata mineira [dissertação]. Viçosa, MG: Universidade Federal de Viçosa; 2016.

Soares TS, Carvalho RMM, Vale AB. Avaliação econômica de um povoamento de *Eucalypttus grandis* destinado a multiprodutos. Revista Árvore. 2013;27(5):699-4.

Souza FC, Reis GG, Reis MGF, Leite HG, Faria RS, Caliman JP, et al. Growth of intact plants and coppice in short rotation eucalypt plantations. New Forest. 2016;47(2):195-208.

Stape JL, Binkley D. Insights from full-rotation Nelder spacing trials with Eucalyptus in São Paulo, Brazil. Southern Forest: A Journal of Forest Science. 2010;72:91-8.

Stape JL, Binkley D, Ryan MG, Fonseca S, Loos RA, Takahashi EM, et al. The Brazil *Eucalyptus* Potential Productivity Project: Influence of water, nutrients and stand uniformity on wood production. Forest Ecology and Management. 2010;259:1684-94.