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Initial Growth of Eucalyptus with Different Spatial Arrangements in Agrosilvopastoral Systems

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Abstract

Success of integrating livestock farming with forestry systems or SAF´s (Agroforestry Systems) highly depends on correct chose of the tree component and the best spatial arrangement of plants, for which eucalyptus has proven as an excellent option. Therefore, the objective of this study was to evaluate eucalyptus wood yield under different spatial arrangements in agrosilvipastoral system. The arrangements were: single rows 10 × 2 m, double rows (2 × 3) + 15 m and (2 × 3) + 20 m and triple rows (3 × 2 × 3) +20 m. Silvicultural evaluations (DBH, tree height, tree volume and volume per hectare) were done eighteen months after experiment installation. The experimental design was randomized blocks with six repetitions and two trees per plot. Trees were arbitrarily identified in each spatial arrangement, numbered from 1 to 5, totaling 30 plots in each system. The DBH increased as the alleys became closer to each other, being higher in the10 × 2 m and (2 × 3) + 15 m systems; tree height increased in denser spacing—10 × 2 m, (2 × 3) + 15 m and (3 × 2 × 3) + 20 m; the volume of wood per plant and per hectare showed higher values in the 10 × 2 m and (2 × 3) + 15 m systems. The lowest yield was found in the system with the least amount of trees, *i.e.* (2 × 3) + 20 m (576 trees/ha).

Keywords

ASPS, Productivity, Sustainability, Agrosilvipastoral System

1. Introduction

The crop-livestock-forest integration system shows up as an alternative to recover degraded areas using no-till and having mulch constantly coverings oil which prevents erosion, cushions impact of raindrops, provides an environment for beneficial microorganisms as well as retains moisture. Furthermore, trees facilitate recycling of nutrients and provide improved chemical characteristics of soil.

The crop-livestock-forest integration systems were developed in order to solve serious problems of environmental degradation caused by inappropriate pasture management [1]. These systems help diversify activities, intensify land use while reducing costs and increasing income of rural properties. The pasture-crop rotation strategies in the presence of the tree component and under proper management promote consistent agronomic, zoo technical, environmental and socioeconomic improvements.

Crop-livestock-forest system or an agroforestry system can be defined as a production system which combines in the same area an agricultural crop, a pasture and a woody component, concomitant or not, so that there is synergy between the components [2].

With this system we can gain efficiency of the following aspects: agronomic-improvement of soil conditions, economic-diversification of production, ecological-improved biodiversity, hydrology and microclimate, in addition to direct and indirect social benefits [3].

The tree component must include features which do not interfere in the consortium. Preferably, it should be erect with small canopies to prevent shading in the understory, which can harm the productivity of crops and pasture, while producing wood and other by-products such as oil, fruits, seeds, etc.

Most eucalyptus species show rapid growth and good adaptation to existing climatic and soil conditions in Brazil [4]. Its wood is used in production of paper, pulp, charcoal, boards, oils, poles and stakes, construction, furniture industry, ornamentation, among others.

Still, there is a need for more knowledge about the spacing of the tree component which should be used. Studies must help better understand the relationship between the trees and the other components of the system to define the variations of minimum distances between trees and agricultural crops at different ages of the system, which will favor positive interactions among them [5].

The establishment of adequate spacing for the tree species is especially important for regions where soils have low fertility and water availability is relatively low and irregular, as in the Savanna region [6]. According to the author, in the condition of scarce resources, the spacing becomes very relevant, since denser system can generate intense competition for resources, while more open spacing may result in under-utilization and lower productivity. For *Eucalyptus grandis* a smaller spacing induces growth in height as a result of competition for light [7].

Another issue, but not less important, is related to the spatial arrangement of agricultural plants in the systems. The ideal arrangement is determined by the spacing between rows and the amount of plants in the rows helping efficiently explore natural resources and inputs provided by the producer.

The decision on how many rows of trees to plant depends on several factors, including the desired end product, the intensity of silvicultural management and the initial expectation of survival of seedlings. Furthermore, one must consider the effect of initial spacing on biological variables as diameter, canopy, wood quality, the area and volume, and operations as soil preparation, silvicultural treatments, thinning and harvesting [8].

Studies involving different spatial arrangements of ASPS systems are essential for the aggregation of innovative knowledge in forest sciences. However, search results regarding performance of cultures involved in consortium systems, especially forest species with annual grain crops are incipient [3]. In addition, knowledge of distribution of diameter, height, area and volume is a primary requirement to ensure good management, either in homogeneous plantations or ASPS [9].

Therefore, the objective of this work was to evaluate tree attributes and eucalyptus wood yield with different spatial arrangements of ASPS-agrosilvipastoral in the municipality of the city Uberlândia, MG.

2. Material and Methods

The experiment was conducted in the municipality of Uberlandia, MG. The site is located at coordinates 18˚50'S and 48˚14'W, at an altitude of 785 m.

The climate is Aw, rainy tropical, exothermal, typical in savannah, with dry winter, average annual rainfall of 1550 mm and annual average temperatures of 23.1˚C, according to the classification of Köppen.

The soil is classified as dystrophic red latosol of medium texture [10].

Table 1 shows soil chemical properties prior to implantation of the experiment, in 2011.

Eucalyptus hybrid I144 was used which is a cross between *E. urophylla* × *E. grandis*. This genetic material is widely planted in Brazil. Its wood has several purposes such as source of energy, and material for poles and stakes.

2.1. Spatial Arrangements

The following spatial arrangements of the tree component (eucalyptus) were evaluated: single rows 10 × 2 m (500 trees ha^{-1}); double rows (2 × 3) + 15 m (555 trees ha^{-1}) and (2 × 3) + 20 m (434 trees ha^{-1});and triple rows (3 × 2 × 3) + 20 m

Table 1. Soil chemical properties in the layers of 0.00 - 0.20 m and 0.20 - 0.40 m. before any planting. Uberlândia, 2011.

Layer	pH H_2O	P	K	Al	Ca	Mg	H+Al	SB	t	T	V	m	MO
M		mg dm^{-3}				cmol$_c$ dm^{-3}					%		dag kg^{-1}
0.00 - 0.20	4.90	1.10	19.00	0.50	0.10	0.10	6.70	0.25	0.75	6.95	4.0	67.0	1.30
0.20 - 0.40	4.80	0.70	12.00	0.40	0.10	0.10	2.20	0.23	0.63	2.43	10.0	64.0	0.40

P, K = (HCl 0.05 mol·L^{-1} + H_2SO_4 0.0125 mol·L^{-1}) available P (extrator Mehlich-1); Ca, Mg, Al, (KCl 1 mol·L^{-1}); H + Al = (Buffer Solution – SMP a pH 7.5); SB = the sum of the bases; t = CTC effective; T = CTC at pH 7.0; V = Base saturation; m = Aluminum saturation [10].

(576 trees ha^{-1}).

2.2. Deployment and Conducting the Experiment

Liming (4.6 $t \cdot ha^{-1}$ of dolomitic limestone) was followed by plowing and harrowing. The objective was to increase the base saturation to 70%. Four months later, eucalyptus was planted into furrows (25 cm) made by a sugarcane furrower, with phosphate fertilizer distributed at the bottom. Eucalyptus was planted following level curves on the terraces in the area, positioning the trees in north-south direction.

Magnesium thermo phosphate was applied (120 $kg \cdot ha^{-1}$ P_2O_5) into the furrows. Forty five days after planting the seedlings of eucalyptus were fertilized with 240 g of 08-28-16 (NPK-nitrogen, phosphorus and potassium). In Brazil it is common for the expression of this formula that we say, nitrogen, phosphorus and potassium) using lateral furrows 30 cm away from the plants, along with 3g of borax through topdressing. The fertilization followed the indications of Soil Fertility Commission of the State of Minas Gerais (CFSEMG) [11].

Pesticides were applied during the experiment to control pests, diseases and weeds, following recommendations and practices commonly adopted in the region. Irrigation management was carried out according to the need of the crop in the region. The plantations are made in the rainy season. From May to September the rains are scarce. At this time are made irrigation on agricultural crops. Already the eucalyptus does not need irrigation. The spaces between the trees in the same row were kept clean. Sorghum was grown 2 m from trees during the first year of the experiment.

Silvicultural assessments were made eighteen months after planting. The experimental design was randomized blocks with six repetitions. The smallest experimental unit (plot) consisted of two trees. Trees were arbitrarily identified in each spatial arrangement, numbered from 1 to 5, totaling 30 plots in each system.

2.3. Silvicultural Parameters

Total height of the plants was estimated with the help of a hypsometer. Total height of all selected individuals was measured on each plot. The average total height of the individuals on each plot was obtained by the arithmetic mean of the individual heights.

The circumference at breast height of all trees found in the area of each parcel was measured with the aid of a tape. The diameter was calculated using the formula: DBH = CBH × π^{-1}; where: DBH (1.30 m)-diameter at breast height; CGH-circumference at breast height. The average DBH of each plot was obtained using the arithmetic average of the individual diameters obtained on the same plot.

The volume per hectare was estimated by multiplying the average volume per plant by the number of trees per hectare for each specific evaluated arrangement [12].

The volume of each individual was obtained by taking the height (H) and DBH of trees from the useful area of the parcels using the following formula:

$$V/plt = \frac{\pi \cdot DBH^2}{40000} \cdot H \cdot f$$

where,

v/pl: volume per plant (m^3);

DBH: diameter at breast height (cm);

H: tree height (m);

f: predetermined form factor (0.49).

The volume per hectare was obtained multiplying the volume per plant by the number of trees per hectare for each specific spacing.

2.4. Statistical Analysis

Errors normality tests and homogeneity of variances were followed by joint analysis of variance. The means were grouped by the Scott-Knott test at 5% probability.

3. Results and Discussion

The diameter at breast height, plant height, wood volume per plant and volume of wood per hectare of eucalyptus showed difference ($P < 0.05$) among the spacings of trees (**Table 2**).

The highest DBH values were found with spatial arrangements of single rows, 10 × 2 m and double rows, (2 × 3) + 15 m (**Table 3**).

The highest DBH values were found in spatial arrangements with the biggest distance between the rows of trees. These results corroborate those found by Paula (2011) [13] where the diameter decreased with the proximity of plants, and by Magalhães *et al.* (2007) [14] where a greater distance between the trees favored growth in diameter. Furthermore, Kruschewky *et al.* (2007) [15] also found larger DGH values in less dense spatial arrangements, 3.33 × 3 m, 5 × 2 m and 10 × 2 m, in comparison with smaller spacing of 3.33 × 2 m.

On the other hand, Ferreira *et al.* (2012) [1] found no differences between DBH of two spatial arrangements of eucalyptus with rows of 14 × 2 and 22 × 2 m,

Table 2. Analysis of variance for diameter at breast height (DBH), plant height (PH), volume per plant (Vol/P), volume per hectare (Vol / ha) in different Eucalyptus spacings.

Fv	Gl	DBH (cm)	PH (m)	Vol./P (m^3)	Vol/ha (m^3/ha)
		QM			
Arrangement	3	2.196211*	0.655349*	0.000100*	39.51336*
Bloc	5	0.031617	0.065254	0.000007	0.441868
Error	15	0.123908	0.058505	0.000013	1.629970
Total	23				
CV(%)		3.96	2.65	15.65	10.32

*: Significant at 5% error probability by F test. ns: Not significant at 5% error probability by F test.

Table 3. Average diameter at breast height (DBH), plant height (PH), volume per plant (Vol/P) and volume per hectare (Vol/ha) of eucalyptus plants with different spacing's.

Sparings (m)	DBH (cm)	PH (m)	Vol/P (m^3)	Vol/ha ($m^3 \cdot ha^{-1}$)
10 × 2	9.47 A	9.48 A	0.028 A	14.05 A
(2 × 3) + 15	9.32 A	9.15 A	0.025 A	14.59 A
(2 × 3) + 20	8.48 B	8.68 B	0.020 B	8.94 C
(3 × 2 × 3) + 20	8.25 B	9.19 A	0.020 B	11.89 B

Means followed by different capital letters in columns differ by Scott-Knott test at 0.05 significance.

also at 18 months of age. The authors hoped to detect the impact of spacing son other ASPS components with older plants. The height of trees was lower only in the double spatial arrangement with wider spacing, (2 × 3) + 20 m. In the other row spacing's, this variable was higher and did not differ statistically (Table 3). It can be explained by the increased competition for light, which causes the plant to elongate for light.

These results are in agreement with the findings by Oliveira *et al.* (2009) and Kruschewky *et al.* (2007) [15] [16], wherein the tree height was higher in dense eucalyptus spacing's. The latter author states that greater initial growth of plants occurs with smaller spacing's. However, there is no direct and consistent correlation between height and spacing regarding growth of young trees, since there are cases where there is increased height with greater row spacing and there are also cases with opposite results, showing the need for new reviews at subsequent stages [6].

Regarding the volume of wood per tree, the spatial arrangements of 10 × 2 m and (2 × 3) + 15 m were the most productive, with volumes of 0.028 m^3 and 0.025 m^3 (Table 3). These results contrast those reported by Oliveira *et al.* (2009) [16] who did not find difference in silvicultural parameters of plants among the different arrangements up to 18 months of age. However, difference was found at 27 months of age, where larger floor area per plant showed higher volume. These authors also report that the volume per plant is defined by the spatial arrangement. In this study, the plants showed higher volume in single rows and in the most dense double-row spacing, (2 × 3) + 15 m. These results can be explained by young plant age and should be confirmed in subsequent assessments, closer to harvest age. Regarding wood volume per hectare, the systems of 10 × 2 m and (2 × 3) + 15 m were the most productive, while (2 × 3) + 20 m showed the lowest value (Table 3). This result can be explained by the fact that the spatial arrangement of (2 × 3) + 20 m had a lower number of trees per hectare (434) comparing with the others, therefore the volume per hectare was smaller.

These results corroborate those reported by Oliveira *et al.* (2009) [16], who obtained higher values in denser arrangements. The highest production per area unit occurs in the smallest spacing due to a larger number of individuals, assessed 32-month-old trees [17] [18].

The influence of the number of trees per area unit on productivity, higher productivity of wood volume was found in the densest spatial arrangement of 14

× 2 m comparing with the spacing of 2 × 22 m [1].

The spacing to be adopted should be selected according to the desired forest product [18]. Other factors that should be considered are characteristics of accompanying crop, as in wider spacing, dry matter production of shoots and in particular of wood per tree is high because of higher growth in diameter, while smaller spacing favors biomass production per unit area due to a larger number of individuals.

4. Conclusion

The DBH increased with the approach of rows of trees in the arrangements of 10 × 2 m and (2 × 3) + 15 m; plant height was greater in the more dense spatial arrangements of 10 × 2 m, (2 × 3) + 15 m and (3 × 2 × 3) + 20 m; wood volume per plant and per hectare was the highest in systems of 10 × 2 m and (2 × 3) + 15 m, the smallest amount of wood per hectare was found in eucalyptus system with greater number of trees (2 × 3) + 20 m.

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