POTENTIAL AGROFORESTRY SYSTEMS FOR SEMIARID REGIONS

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Resumo

Potencial de utilização de sistemas agroflorestais para regiões semiáridas. O objetivo deste trabalho foi avaliar o potencial dos sistemas agroflorestais no semiárido, e avaliar a produtividade do eucalipto em três espaçamentos de plantio, em cultivo solteiro em sistemas agroflorestais. A comparação dos sistemas foi em delineado de blocos casualizados com quatro sistemas (monocultivo; sistemas com amendoim; mamona; mandioca) e três espaçamentos de eucalipto (10 m x 2 m, 10 m x 3 m e 10 m x 4 m). Os monocultivos e demais características foram comparados pelo delineamento de blocos casualizados. Aos três meses e meio avaliou-se a produtividade do amendoim, aos cinco e oito meses mensurou-se a produtividade da mamona e aos 21 meses a da mandioca. A produtividade do eucalipto foi mensurada aos 13 e 21 meses de idade. Os resultados mostraram que a produção de madeira foi maior no espaçamento 10 m x 2 m e no sistema com mamona e cultivo solteiro. A produtividade da mamona foi superior em sistema, no espaçamento 10 m x 3 m, enquanto que a produtividade da mandioca foi superior em monocultivo. O índice de equivalência de área dos sistemas fora superior aos monocultivos. Portanto, sistemas agroflorestais de eucalipto consorciados com mamona e mandioca são adequados para a região semiárida. O espaçamento 10 m x 2 m proporcionou maior volume em madeira (m^3 ha^{-1}). A produtividade de mamona foi maior no espaçamento 10 m x 3 m. Para a mandioca, o maior rendimento foi obtido na monocultura e no sistema com espaçamento de 10 m x 3 m ou 10 m x 4 m.
Palavras-chave: Sistemas Silviagrícolas, Consórcio, Espaçamento, Índice de equivalência de área.

Abstract

The objective of this work was to evaluate the potential of agroforestry systems in the semiarid, and to evaluate the productivity of eucalyptus in three planting spacing, in single cultivation in agroforestry systems. The comparison of the systems was in a randomized block design with four systems (monoculture; peanut systems; castor bean; cassava) and three eucalyptus spacing (10 m x 2 m, 10 m x 3 m and 10 m x 4 m). Monocultures and other characteristics were compared by randomized block design. Peanut productivity was evaluated at three and a half months, castor productivity at five and eight months and cassava productivity at 21 months. Eucalyptus productivity was measured at 13 and 21 months of age. The results showed that the wood production was greater in the 10 m x 2 m spacing and in the system with castor and single cultivation. The castor yield was higher in the system, in the 10 m x 3 m spacing, while the cassava productivity was higher in monoculture. The area equivalence index of the systems was higher than that of monocultures. Therefore, eucalyptus agroforestry systems intercropped with castor and cassava are suitable for the semiarid region. The 10 m x 2 m spacing provided a larger volume of wood (m³ ha-1). Castor yield was higher in the 10 m x 3 m spacing. For cassava, the highest yield was obtained in monoculture and in the system with 10 m x 3 m or 10 m x 4 m spacing.
Key words: Agrosilviculture, Consortium, Spacing, Area equivalence index.

INTRODUCTION

Agroforestry systems enable the production of wood and food in the same area, using the natural resources available in the ecosystem in a rational and sustainable way to meet the growing needs of the world population (MACEDO *et al.*, 2018). This system has become an alternative for sustainable development by providing diversified production and the possibility of a steady income with the marketing of agricultural products, while the forest grows in the same production area (MACEDO *et al.*, 2018; NIERI *et al.*, 2018).

Semiarid regions are defined by their climatic features, such as strong insolation, high temperatures, and scarce and irregular rain regimes (SILVA *et al*, 2010). These characteristics undermine agricultural productive capacity, narrowing the possibilities of crops to develop without the increased use of technologies to meet climatic demands. As an example, the Brazilian semiarid regions present a maximum annual precipitation of 800 mm, an average of 2,800 h $year^{-1}$, with average annual temperature of 23 °C to 27 °C, evaporation of 2,000 mm $year^{-1}$, and relative humidity of approximately 50%. This region is home to approximately 22 million people and comprises an area of 982,563.3 km² with 1,133 municipalities.

The most common crops cultivated under such harsh climatic conditions are arable crops (171 ha), castor beans (210 ha), and cassava (17,355 ha), in the semiarid region of Minas Gerais State according to IBGE (2016). These crops are well adapted, and each is economically important.

Castor beans are of tropical origin, are fairly drought-resistant, and thrive in bright sunlight. They adapt to many types of soil, except those heavy in clay or salt. The use of oil for biodiesel production has caused an increase in the demand for this crop (MATEUS *et al.*, 2015). Cassava has wide adaptability and is a culture of social importance in Brazil. Its rhizome provides carbohydrate sources for human nutrition, and rest of the plant can be used as animal feed (SOARES *et al.,* 2017). Peanuts are well adapted to hot climates and sandy soils, and are used in the human diet in the same role as cassava (DUARTE *et al.,* 2013).

Eucalyptus is another well-suited semiarid plant because of its wide ecological plasticity. Some species exhibit drought resistance and a strong growth rate in semiarid environments. Agroforestry systems using *Eucalyptus,* peanut, castor bean, and cassava show good potentials for use in semiarid regions because they have adapted to the edaphoclimatic conditions of these areas.

Another important aspect of agroforestry systems is the plant spacing of the tree lines, in relation to the fact that crops are commonly planted between tree rows. The distances and the growth rate of the tree component in the system define the amount of sunlight at the disposal of the crops, and the length of time that the agricultural component of the system can be productive (SOBBULAKSHMI *et al.*, 2019). The choice of species and the spacing between the tree lines are among the most important decisions when planning agroforestry systems.

In this context, this study aimed to: a) evaluate the production of agroforestry systems with *Eucalyptus* intercropped with peanuts, castor bean, and cassava planted in three spacings of tree rows, and b) compare and quantify the monoculture production of the agricultural and intercropped species with *Eucalyptus*.

MATERIAL AND METHODS

The experimental area was located in the city of Taiobeiras, in the north of the state of Minas Gerais, in a region owned by a charcoal producing company located at coordinates 15º48'28″ S and 42º13'59″ W and altitude of 821 m. The area has a semiarid climate, average annual temperature in the range of 22 °C to 24 ºC, and average annual rainfall of 800 mm, concentrated between the months of November and February (ALVARES *et al.*, 2013).

The tree component of the agroforestry system was *Eucalyptus urophylla* S. T. Blake, a commercial clone (I-60), which was intercropped with the agricultural components of peanut (*Arachis hipogea* L. - variety TatuST), castor bean (*Ricinus communis* L., variety Guarany), and cassava (*Manihot esculenta* Crantz - IAC-12).

The area was prepared by removing the previous vegetation, two soil harrowing of the total area, and subsoiling only in the tree lines. Soil correction and fertilization were specific to each culture and system. For *Eucalyptus*, 1.5 t ha^{-1} of limestone was applied to the strip, and 150 kg ha^{-1} of triple superphosphate with 0.5% of boron was added to the subsoil furrow for soil correction. Fertilization consisted of 108 g $plant^{-1}$ N: P: K (06:30:06 + Cu and Zn) applied in lateral holes and 100 g $plant^{-1}$ (N: P: K 12:00:18 + 0.5% B) applied under the canopy projection 90 days after planting.

For peanut fertilization, 7.0 tons ha^{-1} of limestone, 1.5 ton ha^{-1} of agricultural gypsum, 100 kg ha^{-1} of KCl, and 200 kg ha^{-1} of triple superphosphate was used. The castor beans were allocated 4.0 t ha^{-1} of limestone, 750 kg ha^{-1} of agricultural gypsum, and 200 kg ha^{-1} of N: P: K (08:28:16 + 0,9% Zn). For cassava, 2.0 t ha^{-1} of limestone, 750 kg ha^{-1} of agricultural gypsum, and 170 kg ha^{-1} of N: P: K (08:28:16 + 0.9% Zn) was added.

The monocultures were planted with a cultural spacing: peanut 0.6 m × 0.1 m, castor bean 1.6 m × 1.0 m, and cassava 0.9 m × 0.9 m. To create the agroforestry systems the spacing between trees was 10 m × 2 m, 10 m × 3 m, and 10 m × 4 m, and the crops (peanut, castor bean, and cassava) were cultivated between the tree lines with the same spacing as the monocultures, keeping one and a half meters distant from the trees. The conduction was carried out according to the specifications of each crop, not differentiating the cultural treatments between the monocultures and the systems.

To quantify crop production, random plots were placed in both crop fields, monoculture, and agroforestry systems. The sampling unit consisted of two lines of three linear meters for the peanut, three lines of nine linear meters for the castor bean, and three lines of ten linear meters for the cassava. Peanut production was determined at three and a half months by manual harvesting, weighing, and extrapolating per hectare. Castor beans were harvested at five and eight months, the berries were weighed, and production estimated by extrapolation. At 21 months, the cassava was harvested, the roots were weighed, and the production results were estimated per hectare.

To estimate the volume, eight trees in each spacing were strictly cubed by the Smalian method at 13 and 21 months, and volumetric equations were obtained for each *Eucalyptus* plant spacing at each age. To obtain the volume per hectare, some of the individual parcel volumes were extrapolated to a hectare. In this study, only the productions were presented, with the published equations being a part of the function of their complexity and space limit.

The experiment contained three designs to evaluate the different responses. To understand wood production between the systems, we used a statistical, randomized complete block design in a 4 × 3 factorial with four systems (Eucalyptus as a monoculture, and systems with peanut, castor bean, and cassava), and three tree spacings (10 m × 2 m, 10 m × 3 m, and 10 m × 4 m), with three replicates. A completely randomized design with six replicates was utilized to compare the agricultural crop yield, using four treatments (monoculture, and systems with 10 m × 2 m, 10 m × 3 m, and 10 m × 4 m) per culture. For the area equivalence index (AEI) a completely randomized block design with three replicates was used. The AEI was estimated using the equation of Mead and Willey (1980) (Equation 1).

$$AEI = (PFC/PFM) + (PAC/PAM) \qquad \text{(Equation 1)}$$

Where: AEI = Area Equivalence Index;
PFC = production of the consortium forest component;
PFM = production of the forest component in monoculture;
PAC = production of the consortium agricultural component; and
PAM = production of the agricultural component in monoculture.

The data obtained for the volume and the agricultural production per hectare were submitted to analysis of variance, and if significant at 5% by the Fisher test, the Tukey averages test at 5% of error probability was applied. For the analysis of AEI data, the Scott-Knott averages grouping test was used at a 5% probability of error.

RESULTS

The analysis of variance for volume per hectare showed significant differences ($p < 0.05$) for spacing, system, and their interaction at the 95% confidence level in the 13 and 21 month evaluations. A significant difference ($p < 0.05$) was observed in the production of castor bean and cassava.

We were not able to perform the analysis of variance of peanut production due to missing information in the stand, high production heterogeneity in terms of green grains, and the presence of pathogens. There was a significant difference in the area equivalence index ($p < 0.01$) among the systems studied.

Eucalyptus production

The Tukey test ($p < 0.05$) presents the results of the system interactions for each spacing and age assessed (Table 1). A higher wood volume per hectare was obtained in agroforestry systems intercropped with castor bean, and single cultivated *Eucalyptus* at both ages and tree spacings. An exception was observed for the spacing of 10 m × 3 m at 21 months, in which the highest wood volume per hectare was shown only for the agroforestry systems with castor bean.

Table 1. *Eucalyptus urophylla* initial productivity in volume per hectare (m^3 ha^{-1}) in agroforestry systems for different spacing in semiarid regions at 13 and 21 months.

Tabela 1. Produtividade inicial de *Eucalyptus urophylla* em volume por hectare (m3 ha-1) em sistemas agroflorestais para diferentes espaçamentos no semiárido aos 13 e 21 meses.

System	13 months						21 months					
	10 x 2		10 x 3		10 x 4		10 x 2		10 x 3		10 x 4	
Eucalyptus with peanut	2.51	Ab	1.90	ABb	1.52	Bb	22.53	Aab	16.23	Bb	11.31	Cb
Eucalyptus with castor beans	3.35	Aa	3.46	Aa	1.90	Bab	24.99	Aa	20.95	Ba	13.82	Cab
Eucalyptus with cassava	2.02	Ab	1.64	ABb	1.24	Bb	20.72	Ab	15.48	Bb	11.00	Cb
Eucalyptus	3.40	Aa	2.74	ABa	2.58	Ba	23.48	Aab	17.32	Bb	16.07	Ba
Coefficient of variation (%)	13.82						7.07					
Average (m^3 ha^{-1})	2.35						17.83					

Averages followed by the same lowercase letter in the same column, and upper case in the same row, do not differ significantly, according to the Tukey test ($p < 0.05$).
As médias seguidas da mesma letra minúscula na mesma coluna e maiúsculas na mesma linha não diferem significativamente, de acordo com o teste de Tukey (p <0,05).

Analyzing the consortiums, the spacings of 10 m × 2 m and 10 m × 3 m presented the same performance among all the systems after 13 months. Among all systems, the highest volume per hectare was the 10 m × 2 m spacing after 21 months.

Productivity of the agricultural component

The analysis of variance showed a significant difference in the production of castor bean and cassava, with a 5% error probability. The Tukey test presented the average productivity values of castor bean and cassava at an error probability of 5 % ($p < 0.05$) (Table 2).

Table 2. Average yield of castor bean and cassava (kg ha^{-1}) in monoculture and agroforestry systems with *Eucalyptus* in different spacing in the northern region of Minas Gerais.

Tabela 2. Produtividade média da mamona e mandioca (kg ha^{-1}) nos sistemas monocultivo e agroflorestal com *Eucalyptus* em diferentes espaçamentos na região norte de Minas Gerais.

Spacing	Productivity (kg ha^{-1})			
	Castor beans		Cassava	
10 m x 2 m	393.26	b	8334.17	b
10 m x 3 m	498.06	a	10338.82	ab
10 m x 4 m	296.81	c	10250.14	ab
Monoculture	267.08	c	12486.69	a
Coefficient of variation (%)	15.48		16.29	
Average (m³ ha^{-1})	363.80		10410.21	

Averages followed by the same letter in the column do not differ significantly by Tukey's test at the 5% error probability level.
Médias seguidas pela mesma letra na coluna não diferem significativamente pelo teste de Tukey no nível de probabilidade de erro de 5%.

The production of castor bean was positively affected by the adoption of the system with *Eucalyptus*, as this resulted in higher yields when compared to conventional planting (monoculture). The 10 m × 3 m system resulted in an 86% increase in castor bean production, which highlights the potential for these agroforestry systems in semiarid regions. The lowest production in a system was found in the 10 m × 4 m spacing, which was similar to monoculture production.

Cassava production did not present differences between the systems, at 10 m × 3 m and 10 m × 4 m spacing, and traditional cultivation (monoculture).

Area equivalence indexes (AEI)

The area equivalence index (Table 3) was presented for the agroforestry systems studied, and it was noted that all the agroforestry systems presented results higher than 1.0. The highest values were found in the castor bean consortia, especially with the 10 m × 3 m spacing (3.1). The systems with cassava showed no statistical differences among them.

Table 3. Area Equivalence Index (AEI) of Agroforestry Systems with *Eucalyptus urophylla*, cassava, and castor bean in the semiarid region.

Tabela 3. Índice de Equivalência de Área (IEA) de Sistemas Agroflorestais com Eucalyptus urophylla, mandioca e mamona no semiárido.

Models of cultivation	Castor beans	Cassava	*Eucalyptus*			AEI
			10 x 2	10 x 3	10 x 4	
Castor beans Monoculture	1.0	0.0	0.0	0.0	0.0	1.0 e
Cassava Monoculture	0.0	1.0	0.0	0.0	0.0	1.0 e
Eucalyptus 10m x 2m	0.0	0.0	1.0	0.0	0.0	1.0 e
Eucalyptus 10m x 3m	0.0	0.0	0.0	1.0	0.0	1.0 e
Eucalyptus 10m x 4m	0.0	0.0	0.0	0.0	1.0	1.0 e
Castor beans with *Eucalyptus* 10m x 2m	1.5	0.0	1.1	0.0	0.0	2.6 b
Castor beans with *Eucalyptus* 10m x 3m	1.9	0.0	0.0	1.2	0.0	3.1 a
Castor beans with *Eucalyptus* 10m x 4m	1.1	0.0	0.0	0.0	0.9	2.0 c
Cassava with *Eucalyptus* 10m x 2m	0.0	0.7	0.9	0.0	0.0	1.5 d
Cassava with *Eucalyptus* 10m x 3m	0.0	0.8	0.0	0.9	0.0	1.7 d
Cassava with *Eucalyptus* 10m x 4m	0.0	0.8	0.0	0.0	0.7	1.5 d
Coefficient of variation (%)			10.84			
Average			1.59			

Values followed by the same letter in the column do not differ significantly according to the Scott-Knott test at the 5% error probability level.
Os valores seguidos pela mesma letra na coluna não diferem significativamente de acordo com o teste de Scott-Knott no nível de probabilidade de erro de 5%.

DISCUSSION

Eucalyptus production

The higher planting densities resulted in increased volume per hectare, as found by Moulin *et al.* (2017), who verified the highest production in the area with the closer tree spacing. Ribeiro *et al.* (2017) reported that in smaller tree spacings, it is common to have a higher number of individuals per area, trees with smaller individual volumes, and higher volume per area. This explains why the 10 m × 2 m regions had the highest volume per hectare in all systems and ages. If the objective is to produce lumber or wood with larger dimensions, Oliveira et al. (2009) recommended the use of 10 m × 3 m and 10 m × 4 m tree spacing.

The planting density, mainly in an agroforestry system, depends on a balance between a large total volume per hectare and a large individual volume per tree. A high planting density provides the selection of the best specimens for logging, while the smaller trees are more suitable for firewood or charcoal. With a low planting density, growth stagnation is delayed, resulting in more numerous trees with greater individual volumes. However, the selection aspect is compromised by the smaller number of trees available.

Thinning can be used to solve the impasse between planting density and individual tree volume. This technique is used to manage the competition between trees and to increase usable timber production during forest stand rotation (ASHTON and KELTY, 2018). Furthermore, the use of this procedure in an agroforestry system helps to control competition between trees and crops. Therefore, in an agroforestry system, it may be possible to have higher initial densities and use thinning to manage competition among trees and between trees and crops. For example, a system starting with 10 m × 2 m tree spacing could be thinned to 10 m × 4 m at 21 months, and generate revenue from the wood.

The *Eucalyptus* intercropped with castor bean in 10 m × 3 m spacing showed higher volume production than the other systems at both ages. These results appeared to be related to the positive effects of the intercropped species. In this context, it was noted that the interaction of trees and crops might result in a more efficient use of water, nutrients, and solar radiation than the forest or agricultural monoculture (MACEDO *et al.,* 2018).

In addition to the interaction between components, it is essential to understand the purpose of the agricultural component to the producer since, depending on the spacing of the trees, there will be more or less area available for agricultural production. This assumption influences the area and radiation accessible to the crop.

Some examples of crops that favor the growth and volumetric production of *Eucalyptus* are, most notably, beans (*Phaseolus vulgaris*), maize (*Zea mays*), rice (*Oryza sativa*), and soybean (*Glycine max*) (SCHREINER and BALLONI, 1986; MACEDO *et al.,* 2018). However, the proposed system is considered a pioneer, and this positive relationship requires further studies to better understand the factors involved.

Production of the agricultural component

The amount of light available for the growth of annual crops that comprise the understory of an agroforestry system with *Eucalyptus* can determine the production potential of the system, since solar radiation passing through the canopy is reduced as the density increases. This factor increases the radiation interception by the canopy and reduces the amount and quality of radiation incident on the agricultural components (MACEDO *et al.*, 2018; CARON *et al.*, 2012; PILAU *et al.*, 2015).

The management of radiation in agroforestry systems can be accomplished by selecting species with low dense crowns and shade tolerance, and altering management operations, such as invoking thinning and choosing the most appropriate spacing distance (MACEDO *et al.,* 2018). The 10 m × 3 m spacing of the *Eucalyptus* showed higher castor bean production in the intermediate density of tree lines, where there could be beneficial shading for the crop, which is consistent with the results obtained by Carvalho *et al.* (2010).

Shading in semiarid regions is essential, since temperatures above 40 °C cause abortion of flowers, sexual reversion of female flowers to males, and reduction of essential oil content in seeds, thereby impeding the production of castor oil (SILVA *et al.,* 2007). The presence of trees in the production system improves the microclimate and reduces air temperature and evapotranspiration, thus increasing relative air and soil moisture (PILAU *et al.*, 2015).

The cassava and *Eucalyptus* consortium showed a reduction of 23% of the average production compared to conventional cultivation (monoculture), likely because of the higher requirement for photosynthetically active radiation (GABRIEL *et al.,* 2014). Light restriction causes physiological responses that stimulate the expansion of the leaf limb and elongation of the stalks and petioles, which reduces the development of the root system (GONDIM *et al.,* 2008). This behavior could promote differential partitioning of biomass, since under heavy shading, cassava plants use a greater amount of photoassimilates for leaf maintenance at the end of the cycle, delaying leaf senescence and translocation of assimilates to the reserve organs, reducing final production (OLIVEIRA *et al.*, 2011).

The cassava monoculture was 9% more productive than the average in the northern region of the state of Minas Gerais (11,342 kg ha^{-1}), which highlights the potential for the crop in semiarid regions (IBGE, 2016).

Despite the lower value of cassava production in the agroforestry systems 10 m × 3 m (10,338.82 kg ha^{-1}) and 10 m × 4 m (10,250.14 kg ha^{-1}), there was no statistical difference between the monoculture and the agroforestry system production. However, the production of cassava with agroforestry systems was less than expected; they were close to the regional average production of cassava, which emphasizes the potential use of the system, especially with wide tree row spacing when associating this crop with tree species.

Area equivalence index (AEI)

The comparison between systems focuses mainly on their efficiency compared to monocultures (ALBUQUERQUE *et al.*, 2012). The area equivalence index (AEI) indicates the sum of the areas required to be cultivated in monoculture with both crops in order to achieve a yield of 1.0 ha of the intercropping system; the higher the index, the more advantageous the system (SANTOS *et al.*, 2016; ARENAS-CORRALIZA *et al.*, 2018).

All systems presented an AEI above 1, which indicates that they were more productive than the respective monocultures. The association between the different components of the agroforestry system has shown to provide a more efficient use of the soil.

The high AEI values found in the *Eucalyptus* and castor bean consortia are indicators of the high productive potential of this system. In the intercropping system between *Eucalyptus* and cassava, the AEI values were similar, but varied with increased spacing. This indicates better productive performance with greater tree spacing.

In practice, agroforestry systems should be arranged according to the objectives of the land manager. The results presented can be approached with an agricultural focus, where the space between tree lines should be greater for increased crop area, or they can be interpreted from a forestry perspective, where the tree lines should be closer together to favor wood production.

For example, the productivity of cassava was the same in monoculture and in the system with *Eucalyptus* (10 m × 4 m and 10 m × 3 m). The land manager could focus on agricultural production using the monoculture model, or the system with cassava and *Eucalyptus*, diversifying production. Using a tree spacing of 10 m × 4 m would increase the area devoted to cassava production, or taking a forestry approach, using a tree spacing of 10 m × 3 m would increase timber production in the same area.

CONCLUSION

- Agroforestry systems of *Eucalyptus* intercropped with castor bean and cassava are suitable for the semiarid region.
- A higher wood volume productivity (m^3 ha^{-1}) was obtained at a tree spacing of 10 m × 2 m.
- A higher crop yield was obtained at 10 m × 3 m for castor bean; for cassava, the highest crop yield was obtained with a monoculture and in the system at 10 m × 3 m or 10 m × 4 m tree spacing.

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