

Effects of tree species and planting density on the total productivity of an agroforestry system

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Abstract

The agroforestry system consists of crop, forest, and pasture cultivation in combination, succession, or rotation, with the goal of increasing resource-use efficiency and, consequently, productivity. This system is an important strategy to recover degraded land. Our goal with this study was to assess the effects of the spacing and stand density of three *Eucalyptus* species on the total productivity of an agroforest system. For this purpose, an agroforest was planted in a degraded pasture in the central-eastern region of Brazil. The system consisted of three *Eucalyptus* species alongside maize and *Crotalaria juncea* in the first year, maize and grass-to-silage production in the second year, and pasture during the third and fourth years. The increase in tree density led to greater wood production; however, it decreased the productivity of the other system compounds, indicating that the prioritization of one compound decreased the productivity of the others. Despite this negative correlation between tree growth and the growth of the other compounds, the most productive treatment (simple rows of *E. urophylla*) during the four years after the system implantation was 3 Mg ha⁻¹ of maize, 15.6 Mg ha⁻¹ of *Crotalaria juncea* for soil enhancement, 6.2 Mg ha⁻¹ of silage (maize with grass), 13.8 Mg ha⁻¹ of pasture, and 180 m³ ha⁻¹ of wood.

Introduction

The global demand for food will increase at a rate of 1.15% per year until 2050, driven by populational growth and global average per capita income (Gouel e Guimbard, 2017). Furthermore, agroforestry products such as biomass and ethanol play an important role in the development of a global renewable energy matrix. In other words, the global demand for food, fiber, and energy will increase, and soil is the most important supplier of these products. In addition, soil is responsible for many other ecosystem services, such as water production, carbon stock and sequestration, nutrient cycling, and biodiversity (Rodrigues et al., 2021; Hatfield et al., 2017; Amundson et al., 2015). Thus, sustainability, in its wider concept, depends on adequate soil use and management, with a focus on maximizing the yields of all ecosystem services.

The Brazilian territorial area is around 851 million hectares and is one of the biggest countries by territorial area feasible for agricultural crops. From this total area, around 66.5% is still covered by native vegetation, 7.5% is used for agriculture, 19.7% is used for pasture, and less than 1% for planted forests (MapBiomas, 2020). Consequently, around 30% of Brazilian territory is used for crops, livestock, and wood production. Brazil has some of the highest crop and wood productivity levels in the world, but also has large areas, especially pastures, with high levels of degradation, resulting in low yields (FAO, 2015).

The total area of pasture in Brazil is approximately 167 million hectares (MapBiomas, 2020), and the country's total cattle herd is an estimated 214 million animals (IBGE 2020). The average occupation rate is approximately 1.3 animal per hectare, which is particularly low (Dias-Filho, 2014). According to the MapBiomas (2020) platform, more than 40% of Brazilian pastures are in medium or advanced levels of degradation.

Agroforestry systems are an important option for recovery of degraded areas, increasing total yield and farmers' income, whilst contributing to the mitigation of greenhouse gas emissions (GGE) (Ramos-Font et al., 2021; Almeida et al., 2011; Carvalho et al., 2014; Salton et al., 2014). Agroforestry systems consist of crop, forest, and pasture cultivation in combination, succession, or in rotation. The goal of these production-integrated systems is to increase the efficiency of growth-resource use (light, water, and nutrients) and consequently the overall productivity of the system. This efficiency gain is a result of the synergistic and/or complementary relationships among the system components. Furthermore, these systems increase product diversification and, consequently, farmer income, especially for small-scale farms (Bharanthi et al., 2020).

Despite the positive relationship between synergy and complementarity, the system components (crops, trees, and pasture) compete with each other. Consequently, the prioritization of one component can reduce the productivity of others (Tadesse et al., 2021; Santos et al., 2018; Pezzopane et al., 2021). Once the forest component is perennial, it should be planned carefully. Therefore, understanding and quantifying the effect of the forest component on other system components is important for the correct planning of agroforest systems, especially in the tropical zone of the globe, where there have been fewer studies. The goal of this study was to assess the effects of the spacing and stand density of three *Eucalyptus* species on the total productivity of an agroforest system.

Material And Methods

Study site

The study was conducted at the Experimental Farm of Goiás State University, São Luis dos Montes Belo, Goiás State, Brazil (16° 32' 30" S, 50° 25' 21" W; 569 m above sea level). The Köppen climate classification is a tropical savanna climate with a dry winter (Aw). It has a mean annual temperature of 23.5 °C [20.7°C in the coldest month (June) and 25.0°C in the hottest month (December)], and mean annual rainfall of 1785 mm, with 87% concentrated between October and March, alongside around four months with a high water deficit (Alvares et al., 2013). Mean annual precipitation during the study period was 1455 mm, and the mean annual temperature was 25.8 °C (Fig. 1).

The topography of the region is gently undulating, and the soil is a very deep Ferralsol (IUSS Working Group WRB, 2015; LATOSSOLO VERMELHO Distrófico by Brazilian classification - EMBRAPA, 2018). The A1 horizon has approximately 39%, 10%, and 51% of clay, silt, and sand, respectively. Before the experimental installation the soil layer from 0–20 cm had a pH (CaCl₂) of 4.9; 11.6 g dm³ of organic C; 3 mg dm³ of available P; 0.266, 3.6, and 1.1 mmolc dm³ of exchangeable K, Ca, and Mg, respectively.

The original vegetation of the region was Cerrado *Strictu sensu* (Ribeiro and Walter, 1998). Before the trial setup, the site was used as a pasture with *Uroclhoa brizantha* cv. Marandu for at least 14 years without fertilizer application or management.

Experimental design and treatments

The experiment was designed to assess the effects of tree species, density, and spacing in a factorial scheme of $3 \times 2 \times 3$, totaling 18 treatments with two tree rows each. The tree species assessed were *Corymbia citriodora* (seedlings), *Eucalyptus cloeziana* (seedlings), and an *E. urophylla* clone (cuttings, clone AEC 0144). The trees were planted in simple, and triple rows, with spacings between trees of 1, 2, and 3 m. Thus, it was possible to assess six tree densities, ranging from 476–1428 trees per hectare (Fig. 2).

Site management

The establishment of the experimental site began in November 2016 with soil preparation. The soil was prepared using one plowing, before two harrowings. Following regional recommendations (Martha Junior et al., 2007) and based on soil analysis, 1 Mg ha^{-1} of limestone (45% de CaO, 14% de MgO) was applied. The limestone was spread across the total area and incorporated into the soil with the second harrowing.

Tree compound

The seedlings of the trees were planted after subsoiling the planting lines, following the aforementioned designs. Fertilizer application in the tree compound was divided into one planting and two topdressing fertilizers. The planting fertilizer was buried in two lateral pits, 15 cm apart from the seedlings. The initial topdressing was applied 120 days after planting, then again 240 days after planting. Topdressing fertilizer was applied to the soil surface at the canopy projection limit. Fertilizer rates were changed with tree spacing to maintain the same fertilizer rate per area. Fertilizer rates are listed in Table 1.

Table 1
Fertilizer rate applied in the experimental site.

Tree spacing	N	P	K	B
m	g tree ⁻¹			
Planting				
1	2.4	18	6	
2	4.8	36	12	
3	7.2	54	18	
First topdressing (120 days after planting)				
1	7.6		8.4	1.2
2	15.1		16.4	2.3
3	22.7		24.9	3.4
Second topdressing (240 days after planting)				
1				1.8
2				3.6
3				5.4

Sources: monoammonium phosphate, potassium chlorate, ammonium sulfate and boric acid.

First crop season

Maize intercropped with *C. juncea* was planted between the tree rows in December 2016. *C. juncea* was planted to fix N from the atmosphere for subsequent soil recovery. We planted 70 thousand seeds per hectare of maize with spacing between lines of 0.75 cm. *C. juncea* was planted among the maize lines using 20 kg ha⁻¹ of seeds. During the planting of the maize and the *C. juncea*, 20, 43.7, and 49.8 kg ha⁻¹ of N, P, and K, respectively were applied. Thirty days after planting, 70 kg ha⁻¹ of N and 58.1 kg ha⁻¹ of K were applied as topdressing fertilization.

Maize was harvested 120 days after planting, just after the assessment of maize production and *C. juncea* biomass. After harvest, the total area was mowed to deposit *C. juncea* biomass on the soil until the next crop season.

Second crop season

Maize intercropped with grass (*Urochloa brizantha* cv. Marandu) was planted in January 2018. Before planting, the weeds were controlled with glyphosate (5 l ha⁻¹) application, and a no-tillage system was adopted. We planted 70 thousand seeds per hectare of maize with spacing between lines of 0.45 cm.

Grass seeds (8 kg ha^{-1} of pure and viable seeds) were mixed with the fertilizer used for maize planting. The grass was planted in the same line as the maize, but 6 cm deeper than the maize seeds. During the planting 20, 43.7, and 49.8 kg ha^{-1} of N, P, and K, respectively were applied. Thirty days after planting a further, 80 kg ha^{-1} of N and 58.1 kg ha^{-1} of K were applied as topdressing fertilization.

Ninety days after planting, the maize and grass were harvested 25 cm above the soil, for silage production, after the assessment of biomass production. After harvest, the grass was subjected to pasture formation.

Pasture management

After the maize was harvested for silage production in the second crop season, pasture was conducted until it reached a height of 50 cm (growth cycle). Once this height was reached, the pasture mass was assessed, and cattle were released for grazing (grazing cycle). When the grass reached a height of 25 cm, the cattle were removed and a new growth cycle was started. This intercalation of growth and grazing cycles was repeated until the end of the study period. The duration of each cycle was affected by the season and soil water availability.

Assessments

Tree heights and diameter at breast height (DBH – after the first year) were assessed quarterly. The wood volume was calculated using the tree height, DBH, and considering a form factor of 0.45 for all species.

The assessment of the crop compound during the first crop season was performed just before the harvest, at 120 days after planting. For this, we collected all the ear maize in two lines of 5 m per treatment into the experimental plots, excluding the buffer. After ear maize collection, the grains were removed from the cobs. The grains were then oven-dried at 105°C until a constant weight was achieved, and the dry mass was determined. The mass was corrected to 15.5% humidity to present the data.

The biomass of *C. juncea* was determined in the same plot as maize. All plants along the two 5 m length lines were harvested at a height of 20 cm. After harvest, all the plants were weighed (fresh weight), and a 300 g sample was collected. The sample was oven-dried at 65°C until a constant weight was achieved. The total dry mass of *C. juncea* was calculated based on the humidity of the sample.

The silage production assessment was performed immediately before harvest, at 90 days after planting. For this, two lines of 5 m were harvested at a height of 25 cm. Both maize and grass were weighed (fresh weight), and 300 g of each sample was collected. The sample was oven-dried at 65°C until a constant weight was achieved. The total dry mass of maize, and grass-to-silage ratio was calculated using the humidity content of the samples.

All productivity data (i.e., wood, grain, dry mass of *C. juncea*, and silage) were extrapolated to a per hectare basis. For this extrapolation, we considered the total area of the system, not the alley with crops.

As a result, in the triple tree row treatments, the uncultivated range between the trees was also considered, as the goal with this study was to assess the total productivity of the system.

After the silage was harvested, the pasture was subjected to five cycles of growth and grazing. All assessments were performed at the end of the growth cycle, between November 2018 and February 2020. To assess the pasture productivity, a 0.25 m² wooden jig was released three times randomly at 2.5, 5.0 and 7.5 m distance from the tree row. All grass in the jig was harvested at a height of 5 cm, and dry mass was determined for silage assessment.

Data analysis

The Box-Cox test was used to check homoscedasticity, and the normal distribution of the residuals was checked using the Shapiro-Wilk test. When necessary, the data were log-transformed to compensate for the heterogeneity of variance before being analyzed. The analysis of variance (F test) was applied using tree species, spacing among trees, and arrangement as variables, with simple and triple interactions. When significant ($p < 0.05$), means were compared using the LSD test ($\alpha = 0.05$). The interaction among the integration systems was assessed using Pearson correlation. All data were processed using software R-Project 3.6.3 (www.r-project.org).

Results

Crop and pasture productivity

The spacing between trees in the planting lines did not affect crop and pasture productivity ($p = 0.723$). In contrast, the arrangement affected the productivity of all the system compounds ($p < 0.005$). The triple row arrangement, due to the larger area with trees, decreased the first-year maize productivity by 36%, the second-year silage productivity by 40%, and the pasture productivity by approximately 30%. Tree species affected silage productivity in the second year and pasture productivity in the fourth year. In both cases, higher productivity of the crops and pasture was found in *E. cloeziana* (Table 2).

Table 2
Crop productivity across four years after the installation of
a crop-livestock-forest system in the center-east of Brazil.

Specie	Rows			<i>p</i>
	Simple	Triple	Mean	
Year 1 – Maize (Mg ha ⁻¹)				
<i>C. citriodora</i>	2.90	2.00	2.45	
<i>E. cloeziana</i>	2.66	2.09	2.38	
<i>E. urophylla</i>	2.96	1.33	2.15	
Mean	2.84a ⁽¹⁾	1.81b		0.005 ⁽²⁾
<i>p</i>			0.723 ⁽³⁾	0.396 ⁽⁴⁾
Year 1 – Crotalaria – dry matter (Mg ha ⁻¹)				
<i>C. citriodora</i>	16.20	8.62	12.41	
<i>E. cloeziana</i>	13.77	9.65	11.71	
<i>E. urophylla</i>	15.58	8.28	11.93	
Mean	15.18a	8.85b		< 0.001
<i>p</i>			0.780	0.328
Year 2 – Silage – dry matter (Mg ha ⁻¹)				
<i>C. citriodora</i>	5.74	3.75	4.75b	
<i>E. cloeziana</i>	6.23	4.03	5.50a	
<i>E. urophylla</i>	6.16	3.24	4.70b	
Mean	6.04a	3.60 b		< 0.001
<i>p</i>			0.024	0.219
Year 3 – Pasture – dry matter (Mg ha ⁻¹)				
<i>C. citriodora</i>	7.07	5.46	6.27	
<i>E. cloeziana</i>	6.93	5.96	6.45	
<i>E. urophylla</i>	6.33	5.23	5.78	
Mean	6.78a	5.55b		< 0.001
<i>p</i>			0.156	0.609

Specie	Rows			
	Simple	Triple	Mean	<i>p</i>
Year 4 – Pasture – dry matter (Mg ha ⁻¹)				
<i>C. citriodora</i>	7.42b	5.43c	6.42	
<i>E. cloeziana</i>	8.55a	4.74c	6.65	<i>< 0.001</i>
<i>E. urophylla</i>	7.44b	4.72c	6.08	
Mean	7.80	4.96		
<i>p</i>			<i>0.147</i>	<i>0.014</i>

⁽¹⁾ Values with the same or no letter are not significantly different by the LSD test at $p = 0.05$; ⁽²⁾ equality probability of the F test among rows; ⁽³⁾ equality probability of the F test among species; ⁽⁴⁾ equality probability of the F test among interaction species: rows.

The effect of the tree species on the crops and pasture productivity was larger at 2.5 m from the trees. At this distance, the *E. urophylla* decreased ($p < 0.001$) the pasture productivity by 20% when compared with the other species. The pasture productivity at 2.5 m from the *E. urophylla* was $0.58 \text{ kg m}^{-2} \text{ ano}^{-1}$ and at 5 and 7.5 m was around $0.98 \text{ kg m}^{-2} \text{ ano}^{-1}$. Considering only the distances of 5 and 7.5 m from the trees, the tree species did not affect pasture productivity (Fig. 3).

Tree growth

At 55 months of age, greater wood productivity ($234 \text{ m}^3 \text{ ha}^{-1}$) was found of *E. urophylla*, which was higher than that of *C. citriodora* ($75 \text{ m}^3 \text{ ha}^{-1}$) and *E. cloeziana* ($90 \text{ m}^3 \text{ ha}^{-1}$). Tree species ($p < 0.001$), arrangement ($p < 0.001$), and spacing among trees ($p < 0.001$) affected total wood volume productivity. A significant interaction ($p = 0.095$) was observed only for tree spacing and arrangement. For *C. citriodora* and *E. cloeziana*, the number of trees per hectare explained more than 95% ($p = 0.002$) of the variance in the wood volume, independent of the arrangement. In contrast, the wood volume of *E. urophylla* was highly affected by the number of trees per hectare ($p < 0.001$), but was also affected by the arrangement ($p < 0.001$). For this species, a larger wood volume was observed in the triple-row arrangement (Fig. 4).

Wood volume and tree height at the beginning of each crop season negatively affected the productivity of the crop and pasture. Consequently, the treatments that resulted in larger wood volumes also resulted in lower silage and pasture productivity (Fig. 5).

Discussion

Crop and pasture productivity

Maize productivity found in this study (2.4 t ha^{-1}) was lower than the Brazilian average for the season (5.6 t ha^{-1}), independent of the treatment. This was an effect of competition with *Crotalaria juncea* planted alongside the maize (Conab, 2021). The productivity of *C. juncea* (12 t ha^{-1} of dry mass) was higher than that reported in other studies (Collier et al., 2020; Pissinatti et al., 2018). Chieza et al. (2017) found reduction of approximately 50% in maize productivity when planted in consortium with *C. juncea* in the summer season due to the fast initial growth of the *C. juncea*. Thus, we can assume that the productivity of the crops planted simultaneously are limited by their spatial and temporal adequation, being affected by the growth architecture, habits, and physiology of each crop.

We found no effect of tree species on crop productivity during the first year (Table 2). This was because of the smaller size of trees in the first year of the agroforestry system. The triple tree row arrangement reduced the productivity of the maize and *Crotalaria juncea* planted in the first season by approximately 40%. This was due to the reduction in the occupation percentage of these crops. This also resulted in lower silage production in the second year.

In the second year, the tree species affected silage productivity. Greater silage production was observed in *E. cloeziana*, which has a lower growth rate. A greater tree growth rate increased competition for growth resources, especially light and water. Shading caused by the trees can also decrease maize productivity (Pezzopane et al., 2019).

A reduction in the productivity of crops in agroforestry systems, when compared with monospecific plantations, is often observed (Adhikari et al., 2020; Pardon et al., 2020). However, the low productivity of a single crop is compensated by the higher production for other crops or forests, increasing land use efficiency. Other ecosystem services include carbon sequestration, soil quality, biodiversity, and nutrient cycling (Adhikari et al., 2020; Pardon et al., 2020).

Pardon et al. (2020), working with the agroforestry system of Juglans aged 75 years growing alongside wheat, triticale, and barley, found an increase in the crop protein level when compared with monospecific cultivation.

Pasture productivity

As in the first two years with crops, the triple row arrangement also reduced pasture productivity because of the reduction in the proportion of the area with pasture. Similar results were found by Cabral et al. (2017) in an agroforestry system of *Tectona grandis* with pasture. These authors found pasture productivity of 0.258 kg m^2 in the agroforestry and 0.327 kg m^2 (reduction of 27%) in monospecific pasture cultivation.

The reduction in pasture productivity at 2.5 m from the tree rows found in our study was stronger in the *E. urophylla* because of the large growth rate of this species. A larger growth rate means greater resource consumption and increased light interception, which decreases resource availability for the pasture. Pacciullo et al. (2011) found that in an agroforestry system, the shading caused by trees affects the

intensity and quality of the radiation reaching the understory, and above a certain level, shading affects the productivity of tropical grass. Owing to the east-west orientation of the tree rows and the low latitude of the experimental site (16 °S), the pasture at 5 and 7.5 m from the tree rows was almost unaffected by tree shading. In contrast, the pasture 2.5 m from the tree rows was under shading, especially in winter. Furthermore, close to the trees, there is greater competition for water and nutrients.

Some authors, such as Pent (2020), reported higher productivity of pastures under an agroforestry system. This is mostly because the implementation of agroforestry systems, demands higher technology and care with soil chemistry, especially pH correction and fertilization, resulting in higher productivity.

It is clear that trees affect pasture productivity, especially next to the tree rows, as found in this, and other studies (Gamarra et al., 2017; Paciullo et al., 2011). Thus, the tree population and distance between rows should be carefully planned according to the primary goal of the agroforestry system.

Tree growth dynamics

E. urophylla planted in triple rows at 1 m among trees resulted in the highest wood productivity. The wood volume produced by this treatment at 55 months of age was approximately $230 \text{ m}^3 \text{ ha}^{-1}$, resulting in a mean annual increment (MAI) of $50 \text{ m}^3 \text{ ha}^{-1} \text{ ano}^{-1}$. This productivity is considered high even for monospecific *Eucalyptus* plantations (Binkley et al., 2020). The higher productivity of *E. urophylla* in comparison with other tree species was expected because of its genetic characteristics, tree breeding level, and plasticity of cutting (Binkley et al., 2020). Despite their low growth rate, *C. citriodora* and *E. cloeziana* have a higher wood density; thus, their productivity difference in terms of biomass tends to be lower (Segundinho et al., 2019).

The increase in wood volume produced with an increase in the number of trees per hectare (Fig. 4) is usually found in monospecific forest plantations (Stape and Binkley, 2010; Binkley et al., 2020). The rate of this increment, as well as the inflection found in *C. citriodora* (Fig. 4), was an effect of the assessment age and growth rate of each species. The inflection found in *C. citriodora* is a result of intraspecific competition for growth resources (Binkley et al., 2020).

Interaction among the system compounds

When the amount of growth resources (light, water, and nutrients) is limited, system compounds (trees, crops, and grass) compete in an intra-and interspecific manner. Intraspecific competition, especially among trees, has been previously discussed, therefore, we investigated interspecific competition and, furthermore, the interaction between these compounds.

We found a negative relationship between tree growth and pasture productivity, starting in the second year (Fig. 5). This effect was even stronger for pastures distanced 2.5 m from the tree line (Fig. 3). With *E. urophylla*, the species with the larger growth rate, the pasture productivity was 40% lower at 2.5 m from the trees, when compared with the productivity at 5 and 7.5 m from the tree line. Many authors have reported deleterious effects of excessive shading on pasture productivity, especially in tropical African

grass (Feldhake et al., 2015). In addition to shading, water competition, especially due to the long dry season in winter (Fig. 1), can also be responsible for the reduction in pasture productivity, as reported by Vieira et al. (2021).

In the triple row arrangement, owing to the aforementioned reason, grass was not found between the three tree lines, resulting in a 6 m band of bare soil. This reduced the overall pasture productivity under this treatment. Furthermore, this bare soil band could increase the risk of soil erosion, especially in this region, due to the large volumes of rain in the summer.

Despite competition among the system compounds, the area also exhibits complementarity interactions. Complementarity consists of the different niche occupations by species, which increases the total amount of available resources. Despite the lack of direct evaluation, we believe that the exploration of different soil layers by crops and trees is the main complementarity relationship in agroforest systems. *Eucalyptus* trees can access deep soil layers and uptake water and nutrients below the root zone of crops (Germon et al., 2018; Christina et al., 2017; Christina et al., 2011; Silva et al., 2011).

Management considerations

Integration systems, especially with trees, increase the overall productivity, particularly in tropical areas, owing to their complementarity. This results in different niches being occupied by trees, crops, and pastures, which increases the amount of available resources. However, there is a negative relationship between the productivity of system compounds. As a result, there is no ideal arrangement, or tree density, for an agroforest system, because it depends on the main goal of the system. If wood production is prioritized, planting more trees per hectare reduces pasture productivity. However, even when the goal is prioritizing wood production, triple rows are not recommended in regions with strong climatic seasonality. This is because the triple row results in a band of bare soil, increasing the risk of soil erosion (field observations). Some studies suggest that simple tree rows increase the exposure of the trees to wind, improving the growth tensions of the wood and reducing the wood quality, especially for sawlogs (West and Smith, 2019), however this was not assessed in this study.

In this study, we found that up to 333 trees per hectare of *C. citriodora* or *E. cloeziana* planted in simple rows did not affect pasture productivity (Table 2). Only a slight reduction in pasture growth was observed next to tree lines. This reduction in pasture growth can be compensated for by an increase in pasture protein content (Xavier et al., 2014; Lopes et al., 2017); plants next to the trees had larger access to N from the nutrient cycling provided by the trees, alongside an increase in the leaf proportion of the pasture. This alteration could result in an increase in the protein concentration of pastures next to the trees.

Beyond the complementarity and overall productivity increase found in agroforestry systems, secondary effects were also noted. The main related effect is the improvement of animal well-being. Tree shading promotes better thermal comfort during grazing and rumination, resulting in better productive and reproductive zootechnical indices (Reis et al., 2021; Giro et al., 2019; Martins et al., 2020).

Declarations

Competing Interests: The authors have no competing interests to declare that are relevant to the content of this article.

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Figures

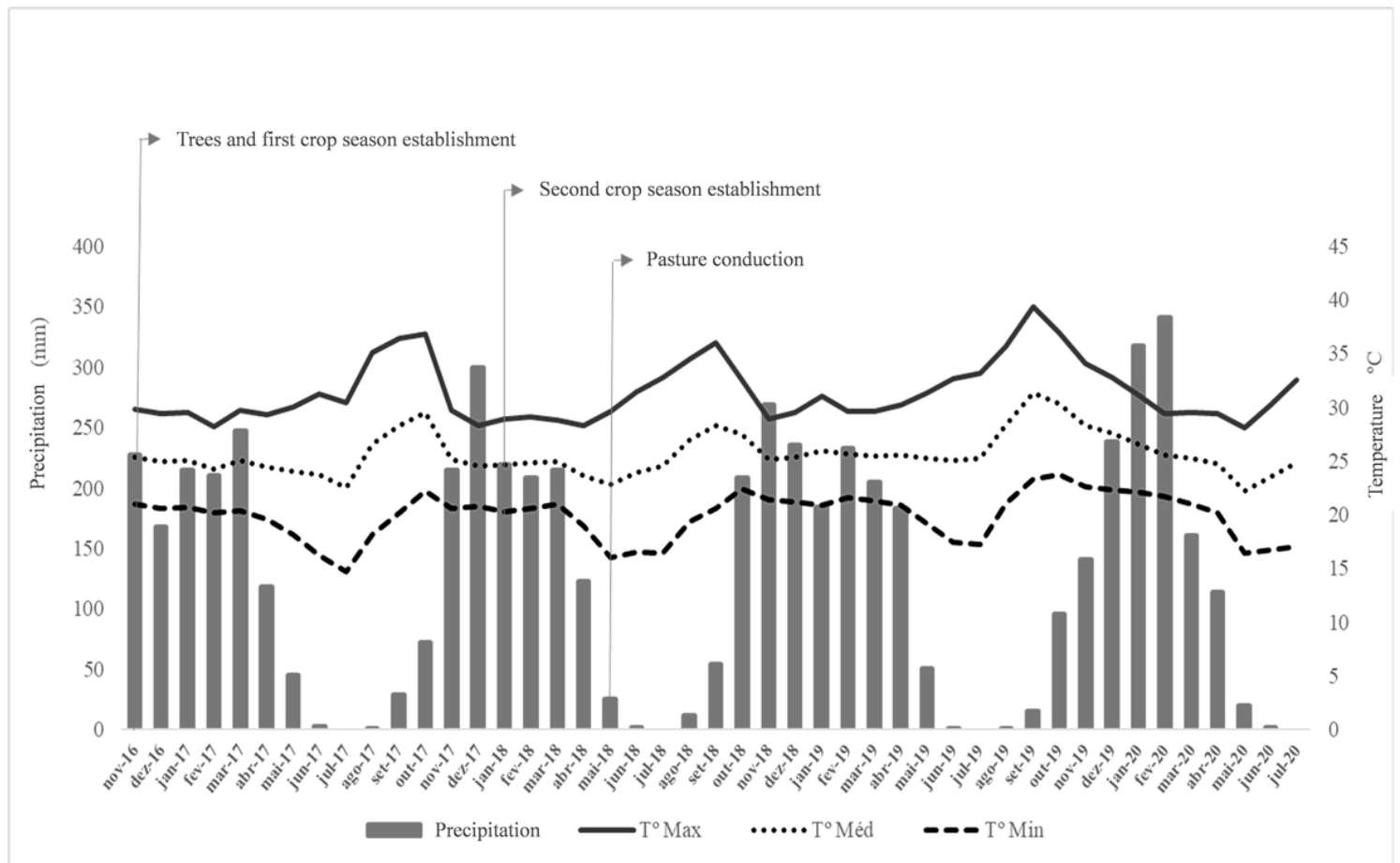


Figure 1

Monthly temperature and rainfall during the period of study conduction.

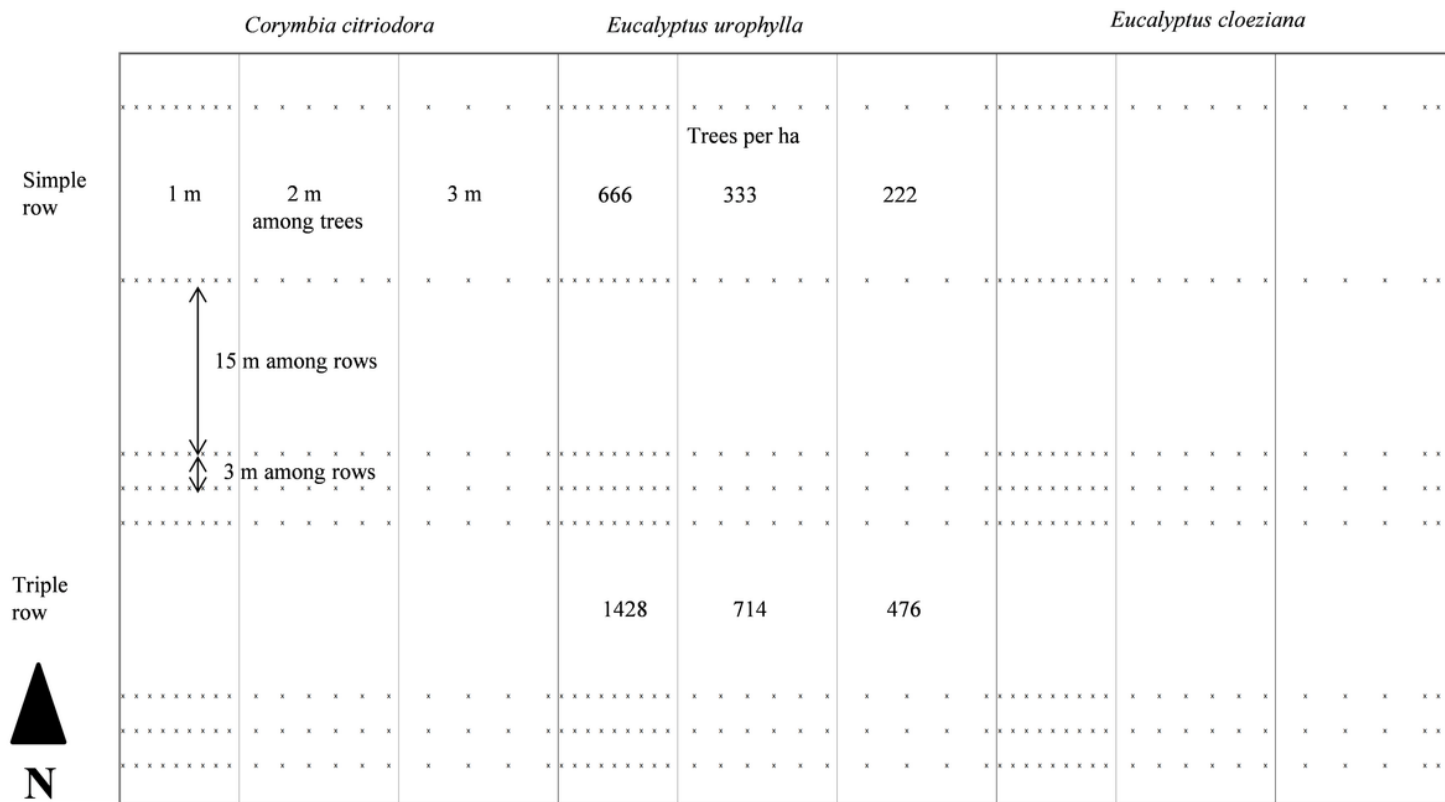


Figure 2

Design of the agroforestry system experimental site installed at the Goiás State University.

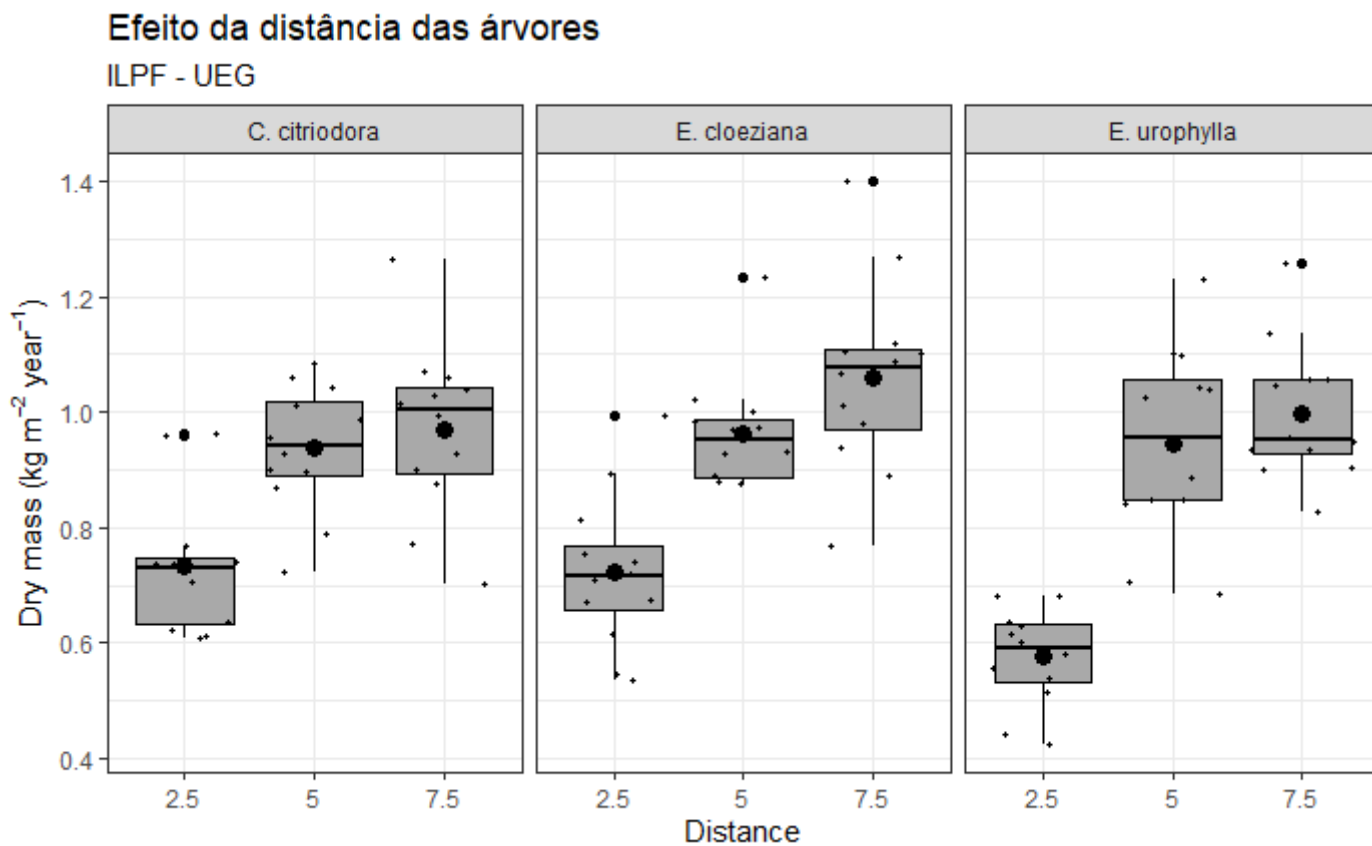


Figure 3

Effect of the distance from the tree planting line on the pasture productivity during the third and fourth years after the agroforestry system establishment.

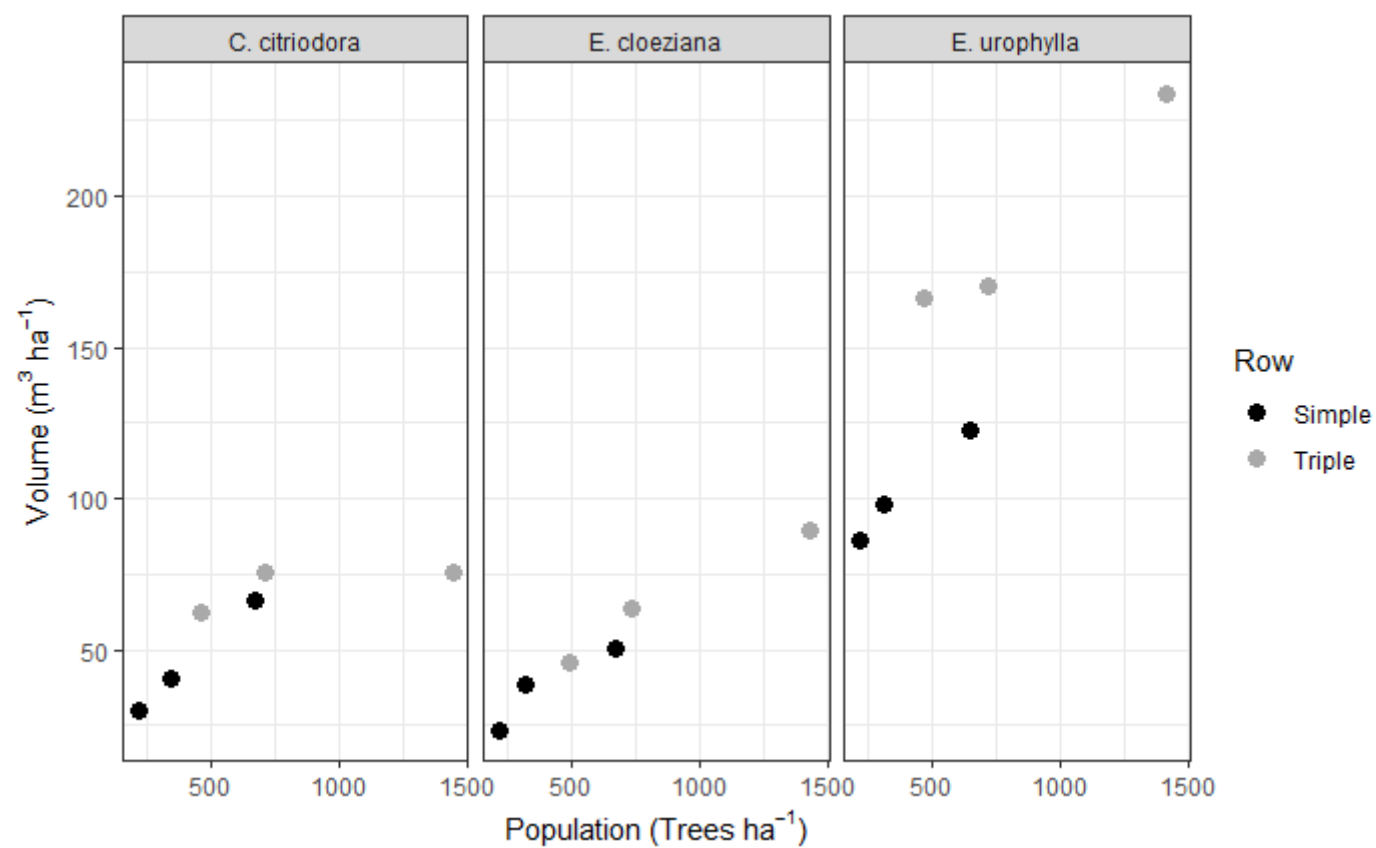


Figure 4

Relationship among the number of trees per hectare (population) and the total wood volume produced at 55 months of age by different trees species in an agroforestry system.

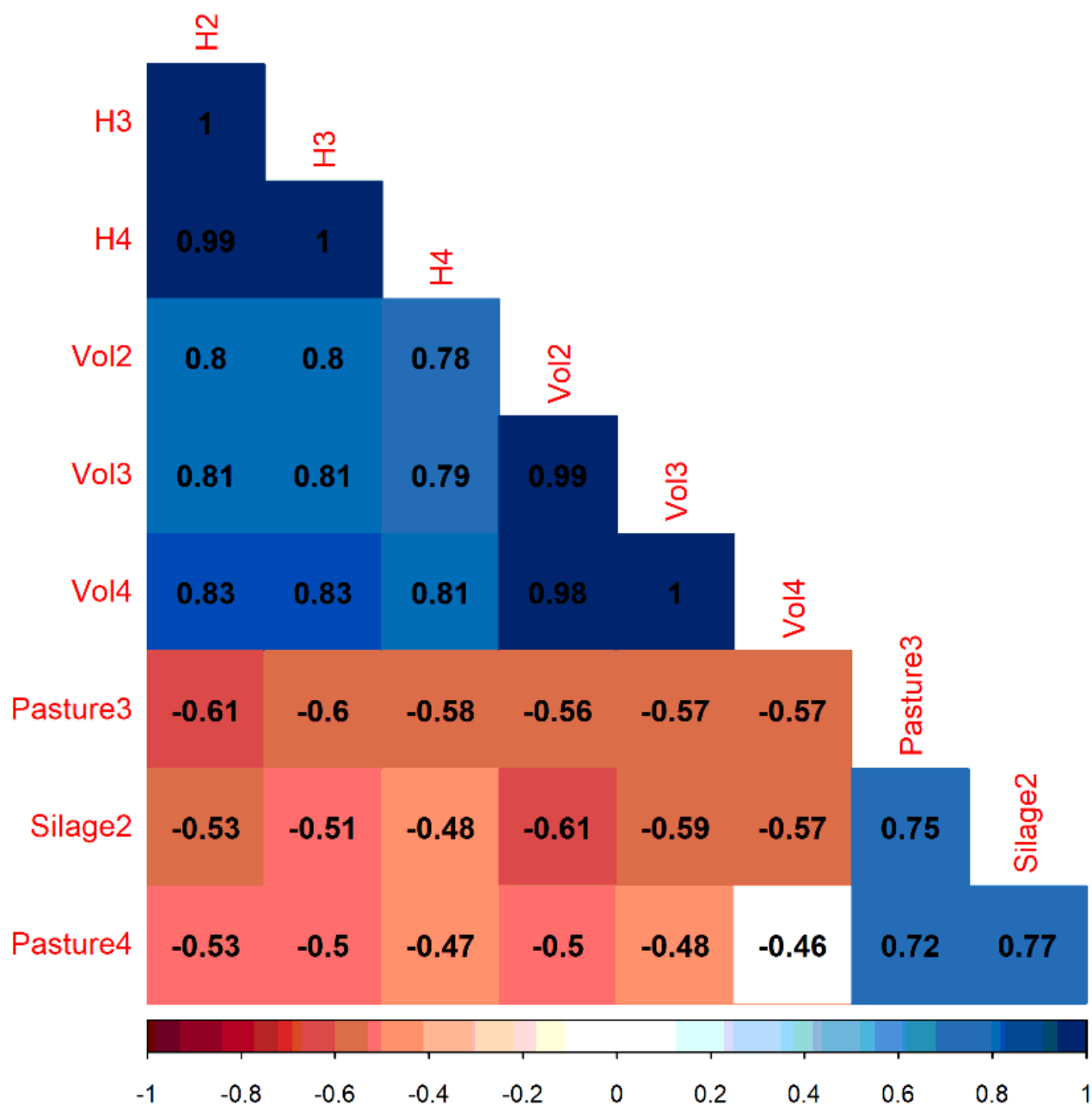


Figure 5

Correlation among tree height (H2 to H4) and wood volume (Vol2 to Vol4) in the beginning of each crop season, with silage (second crop season) and pasture (third and fourth crop season). Correlation coefficients without color are not significant ($p > 0.05$).