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Growth and Yield of *Schizolobium parahyba* var. *amazonicum* According to Soil Management in Agroforestry Systems: A Case Study in the Brazilian Amazon

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Abstract: Studies on applying of soil management practices in the management of paricá and the effects on growth and yield are essential to auxiliary its cultivation and would allow us to inform management and conservation decisions to reconciliate biodiversity, wellbeing, and sustainable production. This case study aimed to evaluate the growth and yield of paricá at different soil management practices, including consortium with an agricultural production, in the Brazilian Amazon. Paricá was implanted, consorted with soybean in the first year, and maize in the second, in a 5 × 2 m spacing. The treatments T1 = subsoiling, basal dressing, top-dressing, inoculation of microorganisms and consortium with soybean/maize were applied. In T2, T3, T4, and T5, we applied the same practices of T1, except subsoiling (T2), basal dressing (T3), top-dressing (T4) and inoculation of microorganisms (T5). T6 was the control, which used none of these practices, including the consortium with soybean/maize. The results indicate that the highest rate of plant survival occurred in T2, while T3 and T4 promoted greater intraspecific competition, compromising the growth in *dbh* and the yield (m^3 ha^{-1}) of plants in future ages. Growth in *dbh* and *th* and the yield of plants in the soybean/maize consortium period was higher in T2 and T6. In future ages, the *dbh* and yield of plants demonstrated higher growth trends in T6, T1, and T5. Agroforestry practices of soil management influence the growth and yield of paricá plants. However, there is a tendency for greater growth and yield for paricá plants cultivated in the absence of agroforestry practices for soil management proposed in this case study. When opting for AFS (paricá intercropped with soybean and maize), it is recommended for paricá a subsoiling, fertilization, and inoculation of microorganisms.

Keywords: forest fertilization; forest modeling; inoculation of microorganisms; paricá; soil preparation; taungya system; identity test models

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1. Introduction

Historically, logging in the Amazon has been conducted in an extractive way with negative environmental impacts. In view of the importance of this biome in the international scenario, alternatives have been demanded, such as the sustainable management plan in native forests and, or alternative means of wood production, such as the cultivation of native tree species in monocultures and in agroforestry systems (AFS). Among these tree species, paricá (*Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby) stands out, A large-sized tree species, belonging to the Caesalpiniaceae family, which occurs in the forests of Amazon [1,2].

Paricá has been the main source of raw material for the industry of veneers and plywood [3,4] with more than 90 thousand hectares of planted area, mainly in the Brazilian Amazon. However, the cultivation of paricá in monocultures and in AFS come up against a series of technical, scientific, and operational problems mainly caused by the scarcity of research in the field of plantation forestry.

Planning horizon (clearcutting) of parica both in monoculture and in AFS is generally concentrated between five to seven years, with yield between 10 and 38 m^3 ha^{-1} $year^{-1}$ [4–8]. In monoculture, the square spatial arrangement at 3.5 m × 3.5 m spacing is usually used [6,9–11]. In AFS, several spatial arrangements were tested for paricá, among them, 4 × 3 m [5,7], 7 × 7 m [12], 4 × 4 m, and 10 × 10 m [13].

AFS with paricá aim to produce wood in synergy with food production, as well as contributing to ecosystem services such as improving soil fertility, reducing erosion, increasing biodiversity and sequestering carbon [14,15]. Due to the closing of the canopy of the AFS, several environmental services are produced, such as the reduction of solar radiation reaching the ground, enabling the creation of a beneficial microclimate, conserving the temperature of the litter and the soil, favoring the maintenance of soil moisture, as well as increased diversity and functionality of macrofauna and edaphic microbiota, contributing to the decomposition of organic residues, favoring nutrient cycling [16–18].

Paricá is cultivated through direct seeding in full sun. It is considered a "rustic" tree species, with good adaptation to soils of low fertility and managed with relatively basic silvicultural practices [8]. In general, for the implementation of paricá, the soil is commonly prepared with plowing and harrowing in the total area, and planting, in most cases, is carried out without the application of fertilizers or following recommendations for other tree species [8,19].

Although paricá responds positively to soil fertilization [20–23], studies show that paricá is able to develop in low fertility soils, which leads most producers, motivated by reducing costs, not to use fertilizers in the implantation and maintenance of the species [6,8]. The cost of fertilizers for the paricá represents about 54% of the total cost of its implementation. The basal dressing and top-dressing are cultural treatments considered essential to improve the development of paricá in the first stages of growth [24–26].

Among the soil preparation methods, plowing/harrowing in total area has been the most used, as it facilitates planting and favors sprouting and root development of the system components [18,27]. However, subsoiling in the arboreal component planting line reaches deeper compacted layers than in plowing/harrowing, which can contribute to deeper root development [28,29] and reduce competition for soil growth resources with crops that present greater root volume in the superficial layers [30]. Subsoiling in the paricá planting line in an AFS carried out together with the plowing/harrowing operations in the total area generates an average increase of 70% in soil preparation costs [31]. The effects of subsoiling on the growth and production of paricá are unknown, indicating a need for research.

Regarding the application of inoculants in the cultivation of paricá, in the study presented by [32], evaluated its growth up to 390 days of age, in Dom Eliseu/PA, Brazil, with application of arbuscular mycorrhizal fungi associated with nitrogen-fixing bacteria. It was observed that the presence of microorganisms significantly stimulated plant growth compared to those not inoculated, indicating that microbial combinations are effective in stimulating the initial growth of paricá, but it is necessary to investigate whether the stimulus occurs at older ages. In general, when the nutrient supply in the soil is relatively high, the effect of the inoculant on plant growth is little noticed and application becomes unnecessary [33–35].

When an AFS is implemented where the main component is the tree species (less wide spacing between trees, similar to monoculture), it is necessary to know the possible effects of soil management practices and intercropping crops on the growth and yield of tree species [6,36]. In AFS, soil management practices should be defined in order to benefit all crops of the system, mainly soil preparation, phytosanitary control and the management of fertilizers and inoculants [37–39]. In addition, the value of the ecosystem services that biodiversity of AFS provides to productive lands has been acknowledged.

These practices are often referred to as "ecological intensification", which is becoming increasingly common in agricultural production.

Thus, shifting from intensive monoculture or agriculture to a biodiversity-friendly model represents a win–win situation. Based on all this information, it is assumed that studies on applying of soil management practices in the management of paricá and the effects on growth and yield are essential to auxiliary its cultivation and would allow us to inform management and conservation decisions to reconcile biodiversity, wellbeing, and sustainable production. This case study aimed to evaluate the growth and yield of paricá at different soil management practices, including consortium with an agricultural production.

2. Materials and Methods

2.1. Study Area

The experiment was carried on the Fazenda Jaspe (Jaspe Farm) (altitude of 160 m above sea level, 4°0′58″ S and 47°52′32″ W), in the town of Ulianópolis, southeastern state of Pará, Brazil (Figure 1) from 2014 to 2019, being 2014 to 2017 with observed data and 2018 to 2019 with estimated data. Fazenda Jaspe belongs to the Grupo Arboris®, an enterprise that works with agriculture and forestry in the Amazon.

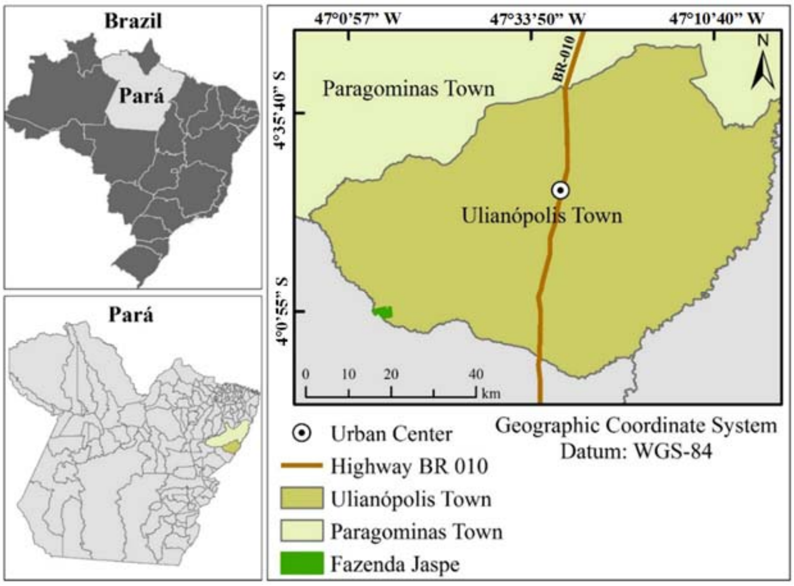


Figure 1. Location of the study area, Fazenda Jaspe, town of Ulianópolis, Pará, Brazil.

The original vegetation of the area is classified as dense tropical submontane forest. The climate is mesothermic and humid, Aw type (Köppen classification). The most common soil is ferralsols with clayey texture, the terrain is even to gently undulated [40–42]. The annual average temperature is 27 °C, with relative humidity oscillating between 42 and 92%. The average annual rainfall is 2000 mm, with rainy season from December to May [43]. Figure 2 presents the data of temperature, precipitation, and water balance for the period of the study (January 2015 through January 2018).

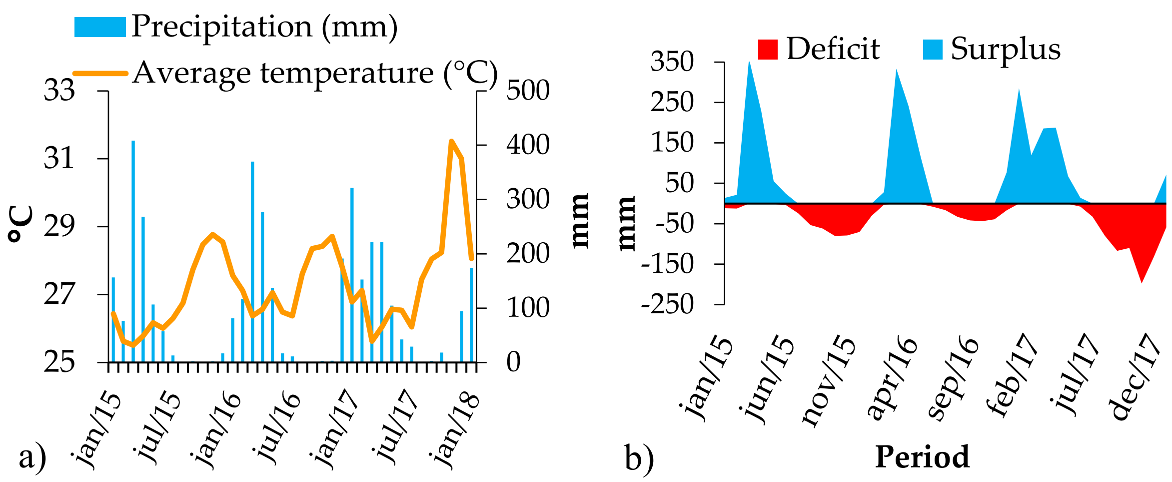


Figure 2. Average temperature and precipitation (**a**), extract from the water balance (**b**), during the period from January 2015 to January 2018, in the mesoregion of southeastern of Pará, Brazil.

The management history of the case study area is shown in Table 1.

Table 1. Study area, Fazenda Jaspe, town of Ulianópolis, Pará, Brazil.

Year	Components of the System	Area Management
1970	Area with various species	Removal of native forest
1971	*Panicum maximum* cv. colonião	Pasture implantation
1971–1979	*Panicum maximum* cv. colonião	Not managed
1980	*Brachiaria humidicola*	Pasture renewal
1980–2000	*Brachiaria humidicola*	Not managed
2001	*Brachiaria brizantha* cv. marandu	Pasture renewal
2001–2004	*Brachiaria brizantha* cv. marandu	Not managed
2004–2011	Area under restoration process	Fallow
2011–2013	*Oryza sativa* (rice)	Conventional cultivation
2013–2014	*Glycine max* (soybean)	Conventional cultivation

In 2015, prior to the implementation of the experiment, chemical and physical analyses of soil were performed at the depth of 0–20 cm, using the methodology proposed by [44] (Table 2).

Table 2. Physical and chemical attributes of soil of the study area, depth of 0–20 cm, Fazenda Jaspe, town of Ulianópolis, Pará, Brazil.

pH	MO	P	K	Ca	Mg	Al	H + Al	Sand	Silt	Clay
H_2O	dag kg^{-1}	mg dm^{-3}			$cmol_c$ kg^{-1}				g kg^{-1}	
5.01	3.39	4.33	0.24	2.23	0.81	0.47	5.70	56	284	660
N	**Mn**	**Fe**	**Zn**	**Cu**	**Na**	**SB**	**t**	**T**	**V**	**m**
%		mg dm^{-3}				$cmol_c$ kg^{-1}			%	
0.36	33.71	55.38	9.43	5.28	0.13	2.47	2.94	8.17	27.18	15.13

MO = organic matter; P = phosphorus; K = potassium; Ca = calcium; Mg = magnesium; Al = aluminium; H + Al = hydrogen + aluminium. N = nitrogen; Mn = manganese; Fe = ferro; Zn = zinc; Cu = copper; Na = sodium; SB = base sum; t = cation exchange capacity; T = cation exchange capacity to pH 7; V = base saturation; m = aluminium saturation.

2.2. Experimental Design

The AFS evaluated in this experiment were composed of paricá plants planted in intercropping with agricultural crops. In the first year, the paricá plants was intercropped with soybean (*Glycine max* (L.) Merr.). In the second year, paricá plants was intercropped with maize (*Zea mays* L.). From the third year onwards, there was no more consortium, with only the paricá remaining in the system.

For the installation of the AFS, in October 2014 the soil was prepared to receive the seeds, with plowing/harrowing, application of 2.000 kg ha^{-1} of dolomitic limestone (PRNT 95%) to raise the soil saturation by around 60%, and pre-planting desiccation with glyphosate (2 kg ha^{-1}).

Soybeans and maize were cultivated between the lines of paricá plants. The planting of paricá and soybeans took place simultaneously, in January 2015, and maize in February 2016. Paricá was planted in a 5 × 2 m spacing with a density of 1000 trees ha^{-1}. Soybean (cultivar AN93101) was planted in a spacing of 0.45 × 0.08 m, occupying 80% of the area with 278,000 plants ha^{-1}. Maize was planted in a spacing of 0.70 × 0.23 m, occupying 56% of the area with 62,000 plants ha^{-1}.

The planting of parica, in January 2015, was performed via direct sowing with three seeds per hole. The first thinning of plants was performed at 60 days after planting and the second, at 150 days. At 90 days after planting, manual weeding (crowning) was performed around the plants in a radius of 50 cm. The control of ants was carried out with the application of 10 g of commercial sulfluramide-based bait per m^2 of loose soil near the anthill.

The planting of soybean, in January 2015, was carried out together with basal dressing of 400 kg ha^{-1} of NPK, in a 02-25-20 formula, in the planting line. 30 days after planting, top-dressing was carried out with foliar application of 7 L ha^{-1} of macro and micronutrients (5% of N; 8% of P_2O_5; 5% of K_2O; 10% of Ca; 5.6% of Mg; 0.4% of B; 0.2% of Cu; 10.5% de Mn and 1% of Zn). Phytosanitary control was conducted according to the technical recommendation, with periodic applications of insecticides, herbicides, and fungicides. Four months after planting, the soybean harvest was carried out mechanically (April 2015).

In November 2015, the soil between the lines of parica plants was prepared with plowing/harrowing for the planting of maize. In February 2016, maize was planted together with basal dressing of 200 kg ha^{-1} of NPK, in 10-28-20 formula, in the planting line. Top-dressing was carried out 30 days after planting, with 200 kg ha^{-1} of NPK in 20-00-20 formula, in the planting line. Phytosanitary control was conducted according to technical recommendation, with periodic applications of insecticides, herbicides, and fungicides. Five months after planting, the maize harvest was carried out mechanically (June 2016).

We defined six treatments, combining the soil management practices (applied only once) used in the implantation and for the conduction of the species, with 1 hectare destined to each treatment:

T1 = subsoiling + basal dressing + top-dressing + inoculation of microorganisms + consortium with soybean/maize;

T2 = without subsoiling + basal dressing + top-dressing + inoculation of microorganisms + consortium with soybean/maize;

T3 = subsoiling + without basal dressing + top-dressing + inoculation of microorganisms + consortium with soybean/maize;

T4 = subsoiling + basal dressing + without top-dressing + inoculation of microorganisms + consortium with soybean/maize;

T5 = subsoiling + basal dressing + top-dressing + without inoculation of microorganisms + consortium with soybean/maize;

T6 = without subsoiling + without basal dressing + without top-dressing + without inoculation of microorganisms + without a consortium with soybean or maize.

The subsoiling was conducted, in January 2015, in the planting line of parica plants with a subsoiler implement with a unique stem, regulated to reach the maximum depth of 50 cm. Basal dressing was carried out together with subsoiling, by applying 300 kg ha^{-1} of NPK to the 10-30-10 formula in the planting line, with the aid of the implement coupled to the subsoiler. In the T2 treatment, the basal dressing was carried out simultaneously to the sowing of paricá, in January 2015, with manual application of 0.3 kg plant^{-1} of NPK, in the aforementioned formula.

Concurrently to the planting of paricá, it was manually applied 30 g hole^{-1} of inoculant, distant 10 cm from the hole. The inoculant is a result of the combination of arbuscular mycorrhizal fungi (*Glomus clarum, Glomus intraradices* and *Glomus etunicatum*) associated with nitrogen-fixing bacteria (*Rhizobium* sp). The cultivation and concentration of the inoculant followed the recommendation of [33]. A total of 60 days after planting, manual operations of top-dressing were performed, with the application of 200 g hole^{-1} of ammonium sulfate ($(NH_4)_2$ SO_4), in a lateral hole, distant 20 cm from the principal hole.

Five plots of 400 m^2, each containing 40 trees, were installed for each treatment, being evaluated at 8, 22, 36, 48 and 60 months of age the growth in diameter at breast height (*dbh*) and total height (*th*) and the yield. Measurements of *dbh* and *th* of all trees were performed in each plot at 8, 22 and 36 months of age, as well as survival analysis (%), and estimates were generated for 48 and 60 months for growth trends in *dbh*, *th* and yield.

2.3. Modeling of Growth in Diameter and Height

Growth in diameter and height was projected as a function of age for 48 and 60 months, the latter refers to the age at which paricá trees are usually harvested. It was adjusted the model [45]:

$$Y_2 = Y_1 + exp^{(\beta_0 + \frac{\beta_1}{I_2})} - exp^{(\beta_0 + \frac{\beta_1}{I_1})} + \varepsilon \quad (1)$$

where Y_2 refers to height (m) or diameter (cm) at future age, Y_1 height (m) or diameter (cm) in current age, I_1 current age, in months, I_2 future age, in months, β_0 and β_1 model coefficients, and ε random error. This model was adjusted by the least squares, using Gauss-Newton algorithms through the Stata12® software system [46].

2.4. Sampling and Adjustment of Volumetric Model

At 36 months, the distribution of diameters in classes with amplitude of 2 cm was used to define the sample-trees to be harvested for volume estimation, six sample-trees per class. Total height and diameter with bark were measured in each sample tree, at the heights of 0, 1, 2, 4, 6 m, until the minimum diameter, with bark of 4 cm. The volume of wood with bark of each tree was obtained using the Smalian formula, with previous interpolation in sections of 0,1 [47], with *n* = 100, according to:

$$V = \frac{h}{4^n}\left(\left(\frac{2^{2n+1}+1}{6}\right)g_1 + \left(\frac{2^{2n+1}+1}{6}\right)g_2 + \left(\frac{2^{2n+1}-1}{3}\right)\sqrt{g_1 g_2}\right) \quad (2)$$

where *V* refers to the trunk volume in m^3, *h* trunk length in m, *n* number of linear interpolations, and g_i sectional area $\frac{\pi D_i^2}{40000}$, in m^2.

The Schumacher and Hall [48] model was adjusted:

$$V = \beta_0 dap^{\beta_1} ht^{\beta_2} + \varepsilon \quad (3)$$

where *V* is the volume in m^3, *dap* is the diameter at breast height in cm, *ht* is the total height in m, β_0, β_1 and β_2 are the model parameters, and ε is the random error.

At each age, the volume was obtained by means of the equation adjusted by the volumetric model already mentioned, using the estimated values of *dbh* and *th*. Yield (m^3 ha^{-1}) was calculated by the sum of the volumes of the surviving trees in each plot multiplied by 10,000 (m^2) and divided by the area (400 m^2) of the plot. Graphs were drawn up with the growth curves in *dbh*, *th,* and yield from 8 to 60 months of age.

2.5. Evaluation Criteria of Equations

The following statistics were estimated to evaluate the adjusted equations for *dbh*, *th* and volume:

(a) adjusted coefficient of determination ($\acute{R}^2$) [49]:

$$\acute{R}^2 = QMres/QMtotal \tag{4}$$

where $QMres$ is the residual variance and $QMtotal$ is the corrected total variance.

(b) *Bias* [50]:

$$Bias = \frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)}{n} \tag{5}$$

(c) residual standard error ($S_{y.x\%}$) [51]:

$$S_{y.x\%} = \pm \frac{\sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n-p-1}}}{\overline{y}}.100 \tag{6}$$

where y_i is the observed value for the dependent variable, $\hat{y}_i$ is the estimated value for the dependent variable, $\overline{y}_i$ is the mean of the observed values for the dependent variable, n is the number of observations, p is the number of model coefficients, n is the number of observations of y.

For the equations adjusted for volume, the estimated values were related to the observed and the frequency distributions per class of relative error percentages—RE%.

$$RE = \frac{(\hat{y}_i - y_i)}{y_i}.100 \tag{7}$$

where $\hat{y}_i$ is the estimated value for the dependent variable, and y_i is the observed value for the dependent variable.

2.6. Statistical Analysis

Identity test models [52] were applied to compare the equations adjusted for yield (m^3 ha^{-1}) projected at 60 months of age by the [49] model for each treatment in program Microsoft Office Excel 2021® (Table 3).

Table 3. Analysis of variance for the identity test models aiming to compare [49] model adjusted to different datasets (treatments) *.

FV	GL	SQ	QM	*F*	*p*-Value
Parameters of complete model	p_1	SQParC			
Parameters of reduced model	p_2	SQParR			
Reduction due to H_0	p_1–p_2	$SQRH_0$	$QMRH_0$	$QMRH_0/QMRes$	
Residual	n–p_1	SQRes	QMRes		
Total	n	SQTnc			

* *p*-Value = rejection area of H_0 for F statistical. $QMRH_0/QMRes$ ~ Fα (PC-PR e n-PC g.l.). SQTnc = $Y'\,Y = \sum_{h=1}^{H}\sum_{h=1}^{nH} y_{hi}^2$, with n degrees of freedom, being n_h the number of observations of Y in the dataset of treatment h. SQParC = $\sum_{h=1}^{H}\hat{\beta}'_h X'_h Y_h = \sum_{h=1}^{H}[y'_h y_h - (y_{hi} - \hat{y_{hic}})^2]$, being $\hat{y_{hic}}$ the estimated value of Y for i observation of data set of the treatment h, using the complete model. The number of degrees of freedom is p_1, and is the number of coefficients in the complete model. SQParR = $\sum_{h=1}^{H}\hat{\beta}'_h X'_h Y_h = \sum_{h=1}^{H}[y'_h y_h - (y_{hi} - \hat{y_{hir}})^2]$, being $\hat{y_{hir}}$ he estimated value of Y for i observation of data set of the treatment h, using the reduced model. The number of degrees of freedom is p_2, and is the number of coefficients in the reduced model. $SQRH_0$ = SQParC–SQParcR, with p_1–p_2 degrees of freedom. SQRes = SQTnc–SQParC, with n–p_1 degrees of freedom.

3. Results

The survival rate (%) of plants of paricá at eight months indicated rates between 97 and 99% (Figure 3). The highest survival rate of plant (92%) for the age of 22 months was verified in T2, and the lowest rates in T1 and T6 (79 and 79%, respectively). At 36 months, it was observed reduced survival rates of paricá plants in the treatments. The highest survival rates were found in T2 and T4, and the lowest, in T1 and T5.

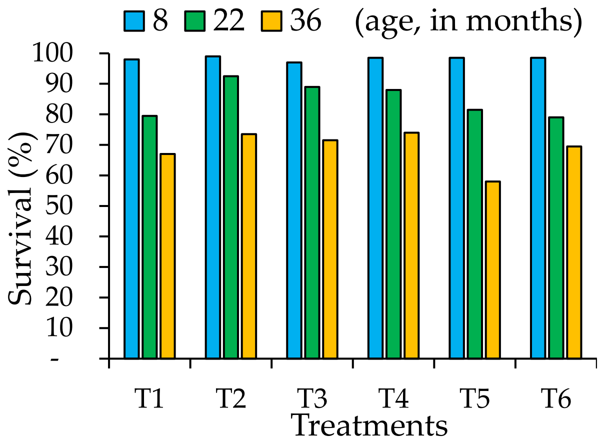


Figure 3. Survival (%) of trees of paricá at 8, 22, and 36 months of age, submitted to soil management practices.

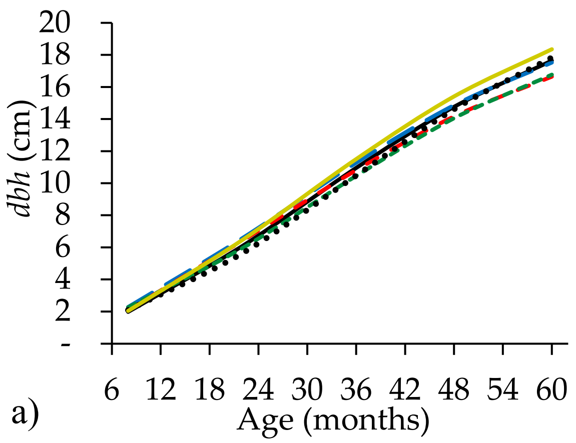
In the six treatments, the equations adjusted for *dbh* and *th* present satisfactory statistics ($\acute{R}^2$, *Bias* e $Sy.x_{\%}$). The best adjustments for *dbh* and *th* were obtained in the treatments T2, T3, and T6, with the highest $\acute{R}^2$ and value lowest rate of *Bias* and $Sy.x_{\%}$, followed by the plants of the treatments T1, T4, and T5. All coefficients of the equations were significant ($p < 0.05$) (Figure 4).

Growth in *dbh* of paricá plants during the consortium period with soybean/maize (18 first months) was higher in T2, compared to the other treatments ($p < 0.05$). The lowest values were observed in plants of the treatments T1 and T5 (Figure 4a). However, with the projection of *dbh* growth in a future age, there was a trend of higher growth for plants of T6 and growth recovery for plants in the treatments T1 and T5, whose growth values were similar to those of the plants in T2. Similar performance was observed for the growth in *th* (Figure 4b).

However, decreased growth trend in *th* in future ages is observed for the T2 plants. Higher values were observed for *dbh*, *th*, and yield, during the consortium period with soybean/maize, with the application of T2. However, the projection of growth in future ages of the plants submitted to T2 shows a trend of early stagnation of growth and lower values of *dbh*, *th* and yield, in comparison to the other treatments, with the exception of plants submitted to T4, which showed the same tendency as the plants in T2. The plants in treatments T1 and T5 presented different behavior from those in T2, with lower growth in *dbh* and *th* and yield, during the consortium period with soybean/maize, and trend of growth recovery in the future ages.

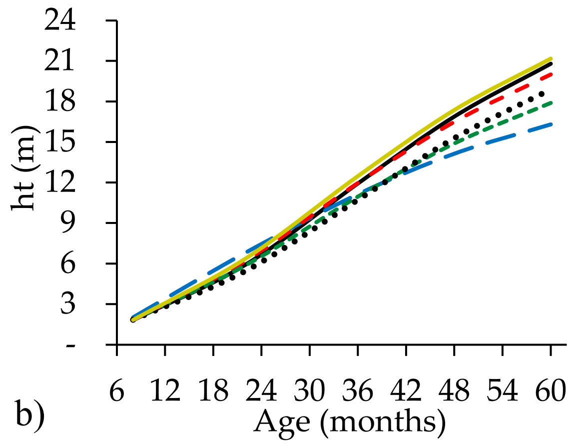
For estimates of volume, we can highlight as more precise adjustments the equations involving the treatments T2, T3 and T4, with higher values of $\acute{R}^2$ and the lowest of *Bias and* $Sy.x_{\%}$, in comparison to the other treatments. All coefficients of the equations were significant ($p < 0.05$) (Figure 4c). For yield of paricá plants during the period of the soybean/maize consortium (Figure 4c), the performance was similar to that observed in plant growth in *dbh* and *th* (Figure 4). In the projection of growth in volume for future ages, there was a trend of higher growth for plants of T6, followed by plants of the treatments T1, T3 and T5. In T2, a greater tendency of plant growth stagnation was observed for future ages.

	β_0	β_1	$\bar{R}^2$	*Bias*	*Sy.x%*
T1	3.3845	-42.8673	0.9793	-1.37×10^{-10}	±1.26
T2	3.3005	-39.6637	0.9832	-0.00001	±1.18
T3	3.2624	-38.7760	0.9787	2.12×10^{-10}	±1.27
T4	3.2543	-42.4173	0.9614	8.06×10^{-8}	±1.65
T5	3.4635	-47.7813	0.9518	-1.14×10^{-10}	±1.79
T6	3.4302	-42.0101	0.9853	-2.34×10^{-6}	±1.13



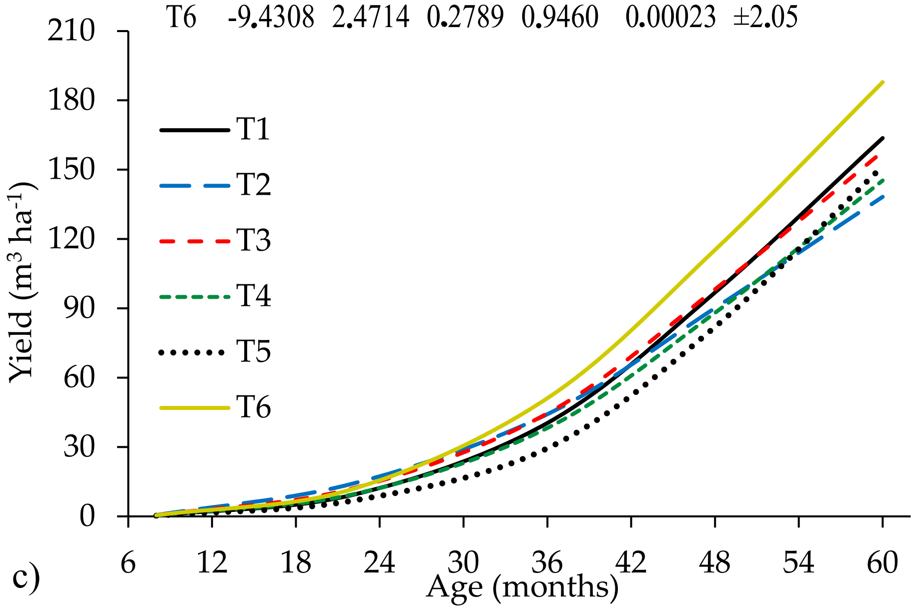
a)

	β_0	β_1	$\bar{R}^2$	*Bias*	*Sy.x%*
T1	3.6940	-50.0081	0.9751	-4.37×10^{-7}	±1.46
T2	3.1887	-34.3250	0.9797	1.50×10^{-6}	±1.30
T3	3.6044	-46.2165	0.9843	6.42×10^{-7}	±1.16
T4	3.4080	-44.0564	0.9636	6.04×10^{-10}	±1.65
T5	3.6140	-51.0451	0.9534	-2.08×10^{-10}	±1.78
T6	3.6967	-47.6076	0.9765	5.58×10^{-7}	±1.52



b)

	β_0	β_1	β_2	$\bar{R}^2$	*Bias*	*Sy.x%*
T1	-9.5456	1.7269	1.0367	0.9876	-0.00004	±0.37
T2	-9.5187	1.4225	1.3444	0.9905	-0.00007	±0.63
T3	-9.3753	1.5760	1.1398	0.9956	0.00015	±1.31
T4	-9.5905	1.3702	1.4067	0.9934	-0.00007	±0.61
T5	-10.0170	1.0260	1.9236	0.9590	-0.00089	±7.99
T6	-9.4308	2.4714	0.2789	0.9460	0.00023	±2.05



c)

Figure 4. Estimates and growth trends in diameter at breast height (*dbh*) (**a**) total height (*th*) (**b**) and Yield (m^3 ha^{-1}) (**c**) of trees of paricá, submitted to soil management practices. β_0, β_1 and β_2 = regression coefficients; $\acute{R}^2$ = adjusted coefficient of determination; *Bias*; $Sy.x_{\%}$ = residual standard error. Trees and species destined for the sale of standing wood by the dbh class center and market value group for the criteria and control treatments, forest management area of Fazenda Shet, Dom Eliseu, State of Pará, Brazil.

Identity test models performed for comparisons, two-to-two, of the equations adjusted for yield (m^3 ha^{-1}) projected at 60 months of age for each treatment, applied to combinations of treatments T1 + T3, T3 + T4 and for all combinations with T5 and T6, indicates differences ($p < 0.05$) between the combined treatments. Therefore, it is appropriate to make the adjustment of the separate volumetric model for the data set of each treatment. On the other hand, the non-significance ($p > 0.05$) to combinations of treatments T1 + T2, T1 + T4, T2 + T3, and T2 + T4 shows that these combined treatments do not differ and that it is more appropriate to use the reduced model (Table 4).

Table 4. *p*-value and F-test (between parenthesis) calculated for comparisons, two-to-two, of the equations adjusted for yield (m^3 ha^{-1}) projected at 60 months of age by [49] model for each treatment.

Treatment *	1	2	3	4	5	6
1		0.0576	**0.0013**	0.2595	**0.0343**	**0.0402**
2	(2.65)		0.5341	0.0801	**0.0498**	**0.0007**
3	**(6.00)**	(0.74)		**0.0017**	**0.0211**	**0.0007**
4	(1.38)	(2.38)	**(5.83)**		**0.0108**	**0.0019**
5	**(3.11)**	**(2.79)**	**(3.53)**	**(4.15)**		**0.0001**
6	**(2.97)**	**(6.71)**	**(6.72)**	**(5.78)**	**(11.77)**	

* *p*-value (≤0.05) in bold.

4. Discussion

Square spatial arrangements (3.5 × 3.5 m) are the most used for monocultures of paricá [6,9–11], and AFS (4 × 4 m, 7 × 7 m and 10 × 10 m) [12,13]. However, in this case study, a rectangular spatial arrangement (5 × 2 m) was used, that is, a greater distance between rows of paricá plants to enable the use of agricultural machinery, and a smaller distance between plants in the planting row to expand the population of parica. Paricá respond to the spacing effect [4,5] and, therefore, in this case study, the relatively smaller spacing (2 m) between plants in the planting line may have anticipated competition between plants up to 22 months of age, since a reduction in the survival rate of plants of all treatments was observed.

Studies presented by [19,53] analyzed the behavior of paricá tree in different spacings and verified higher growth rates in *dbh*, *th* and volume in larger spacing (4 × 3 m and 4 × 4 m), compared to smaller spacings (1.5 × 1.5 m, 3 × 2 m, 3 × 3 m and 4 × 2 m). In the study presented by [54] observed that paricá trees presented larger quadratic diameters for larger spacings, in contrast to the findings for smaller spacings. The author points out that, for the age of 24 months, the diameter of the trees in the smallest spacing did not statistically differ from the larger spacings. Significant influence started at 36 months, due to competition.

The projection of higher growth for T6 may be due to the paricá's ability to develop in low fertility soils and with basic silvicultural practices [8]. The dense arrangement of crops in the AFS may have generated competition between agricultural and arboreal plants, especially in the first years of the AFS. However, plants tend to show growth recovery after intercropping, as shown by [55] in the study in which plants of Tectona grandis (4 × 2 m spatial arrangement) in taungya system with maize, grew less initially, when compared to plants in pure stands, but showed a trend of recovery of growth with the exit of the agricultural component of the system, at 18 months. A study presented by [5] reinforces that paricá cultivated in an AFS with soybean/maize in the initial four years presented production similar to that of paricá in pure stands, from the fifth year.

In the present case study, the plants of paricá in the treatments with lower survival rates presented higher *dbh*, *th*, and yield. It is important to emphasize that, in the cultivation of paricá for the production of veneers and plywood, it is appropriate to conduct the stands in order to obtain trees of larger diameters [3,56]. In studies of [3,57], in which the yield of veneer and plywood production from paricá wood was evaluated, the diameter was the main factor for the yields of high-quality veneers.

However, the decreased survival rate of plants compromises the final productivity of the stands. With the objective of stimulating the maximum growth of the individuals and obtaining superior wood for the industry, it is suggested that thinning be performed or that the spatial arrangement be revised, concomitantly with adequate soil management. Paricá develops under different arrangements and edaphic and climatic conditions [18,58,59]. The study presented by [6], highlights that, with proper management, paricá can present similar or superior growth in AFS, when compared to pure stands.

The present study shows little response of paricá in relation to the soil management practices adopted. Studies performed by [6,8,54] reported that paricá is considered a "rustic" species, for its relatively easy management and its low response to agroforestry combinations [7]. However, the good level of soil fertility (Table 2), a likely consequence of previous crops (Table 1), may explain the absence of responses to soil management practices in the growth and yield of paricá plants in the ages evaluated.

In other studies, the paricá responded to fertilization [20–23], but soil fertility must be analyzed case by case, respecting local particularities, for fertilizer recommendations, since fertilization can be reduced or even unnecessary, according to the supply of nutrients in the soil. Regarding the use of inoculants, their application has been more effective in low fertility soils, since they increase the surface area of the roots and absorption capacity of water and nutrients, which enhances the growth and survival rates of plants [26,59]. When the supply of nutrients in the soil is relatively high, the effect of inoculant on plant growth is little perceived, and application becomes unnecessary [34–36]. In this case study, it is not known whether the use of intercropping with agricultural crops can justify the non-response to fertilization.

Although T6 has not received the evaluated soil management practices, the entire area of this case study was prepared with plowing/harrowing and application of dolomitic limestone (conventional soil management practices for the cultivation of paricá) before applying the treatments (T1–T6), which provided good growing conditions, moreover, the result of the soil analysis carried out before the implementation of the experiment showed good chemical and fertility conditions for the cultivation of parica (Table 2).

It is important to highlight that subsoiling and plowing/harrowing are efficient when carried out in soils with high levels of compaction [60]. Plant roots that grow on soils with compaction problems do not adequately utilize the available nutrients, since the development of new roots that absorb water and nutrients is impaired. In addition, the amount of oxygen in the rhizosphere may hinder metabolic processes [29,31].

Regarding the results of identity test models, it was observed compatibility with the adjustment levels of the equations adjusted for yield (m^3 ha^{-1}) projected at 60 months of age for each treatment, verified in the statistics $\acute{R}^2$, *Bias* and $Sy.x_{\%}$, besides the distribution of RE%. It demonstrates the reliability of test indication for the use or not of the reduced model [61]. The compatibility between the test and the statistics of the adjustments of the volume equations refers to the higher values of $\acute{R}^2$, lower values of *Bias* and $Sy.x_{\%}$ and more homogenous and balanced distribution of RE% observed in the statistics of the treatment T1, T2, T3 and T4, compared to the values found in the statistics of the treatments T5 and T6.

Similarly to other tree species, it is understood that greater success in paricá cultivation is achieved when adequate soil management practices are adopted. This project of sampling and composition of treatments should be improved in future studies, with evaluation of other soil management practices, including treatment without intercropping with soybean/maize, in order to reduce the chances of masking the results of the experiment and providing more conclusions concrete. In this context, new studies should focus on methods of soil preparation, dosages, and times of application of fertilizers and inoculants, in addition to consortia with agricultural or tree crops, also considering local criteria and peculiarities.

5. Conclusions

Soil management practices in agroforestry systems influence the growth and yield of paricá plants. However, there is a tendency for greater growth and yield for plants cultivated in the absence of soil management practices proposed in this case study.

When opting for AFS, paricá intercropped with soybean (first year) and maize (second year), it is recommended for paricá a subsoiling, fertilization, and inoculation of microorganisms.

New spatial arrangements and spacing must be tested for their technical feasibility for use in the intercropping of paricá with agricultural crops and other soil management practices.

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