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Influence of meteorological variables on the development in plantation of *Tachigali vulgaris* L.G. Silva & H.C. Lima (tachi-branco)

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Abstract. The objective of this work was to evaluate the influence of meteorological variables on height and diameter increment in a Tachigali vulgaris plantation fertilized with NPK. The meteorological data were recorded by the agroclimatological station of Embrapa Amazônia Oriental, located in Igarapé-Açu, in the period from March 2016 to June 2018. The monitoring of the increment rate in height and diameter of the plants was done. The data collected were: monthly temperature, average maximum temperature, average minimum temperature andprecipitation. The maximum quarterly periodic increment in height occurred in the June-September 2017 quarter, while the highest diameter increment occurred in the June-September 2016 quarter. Principal component analysis showed that the first three factors together explained 94% of the total variance of the species' growth, where the unfolding analysis of the first two principal components showed that the variables that contributed most to explain the species' stand development correlated with the climate measures observed in this study, were mean and maximum temperatures and precipitation, followed by height, diameter and minimum temperature. It was concluded that the weather variables positively influenced the increment in height and diameter of plants Tachi, with precipitation being the variable with the greatest contribution to predicting tree growth.

Keywords: rainfall, plant incremente, seasonality, forestry, bioenergy.

STUDY IMPLICATIONS

The global demand for forest products, although with different rates by segment, in general, has consistently grown in recent years, which has increased the demand for raw materials, resulting in an increase in new forest plantations. However, most of the reforestations are implemented in areas of weathered and leached soils, that is, they have low availability of nutrients, which generates variations in productivity, and the implementation of forestry projects may be economically unfeasible in some cases. In this way, understanding forest production in this context is necessary, since it can be expressed as the result of a function that considers the availability of edaphoclimatic resources, the amount of these absorbed by the plant and the efficiency with which it uses them, to fix atmospheric CO_2 and transform it into biomass. The study of growth trends of forest plantations in different meteorological variations is important in the sense of helping decision-making regarding places where there is little knowledge about adaptation and performance of forest species to be planted. Among the reforestation species is *Tachigali vulgaris* L.G.Silva & H.C.Lima (white tachi), considered an Amazonian species, promising for bioenergetic production. So, providing information on its cultivation under a given microclimate becomes necessary for the establishment of this crop in similar regions, which plays an important economic and ecological role for its region of origin.

INTRODUCTION

Seasonality is the first description of the behavior of the system over time. The difference in the seasonal pattern of functioning of a biological system, which can be more or less stable, is due to both biotic factors and environmental impacts. The Amazon is an example of a highly seasonal environment, with its diverse arboreal component (Silva et al., 2017).

Tree growth is defined by the genetic composition of the species and can be influenced by its characteristics, interacting with the environment. Environmental influences include climatic factors (temperature, precipitation, wind, and sun exposure) (Kanieski et al., 2012). In this context, works have been carried out in order to evaluate the influence of meteorological variables on the growth of tropical and subtropical species. Many studies report that the influence of meteorological variables (precipitation and average temperature) on the increment in diameter of some forest species show positive correlations (Soares & Cruz, 2016, Kanieski et al., 2017, De Jesus et al., 2019, Bertolini et al., 2020).

The excess or insufficiency of available water in the soil causes a decrease in the photosynthetic rate reflecting in the decrease of plant growth. The influence of temperature and precipitation on the distribution and growth of forests is demonstrated by the high correlation between these aspects and climate classifications, such as those made by Merriam, Köppen and Thornthwaite (Zanon & Finger, 2010).

The distribution of forest stands is closely related to the microclimatic conditions of a given region. The climatic elements, such as temperature, relative humidity, precipitation, wind and solar exposure, can influence the growth, development and even the survivability of plants (Santos Neto, 2014). In this context, the study of the growth trends of from forest plantations in different types of soil and on the variation of the water regime is important in order to help decision making regarding the places where there is little knowledge about the adaptation and performance of the forest species to be planted (Santos et al., 2017). Although plants adapted to low nutrient availability can develop naturally (Camargo et al., 2004, Rosim et al., 2016), the adoption of management practices and correction of soil fertility in areas cultivated with species of rapid growth in order to raise the productivity of forest sites, or at least maintain it for future rotations (Pinkard, 2003).

Management practices planit and soil must take into account the use of nutrient sources through mineral or organic fertilization (Vogel, 2005, Silva et al., 2021), ensuring that the soil supplies all nutrients in quantities necessary to obtain the desired growth for plants (Forrester et al., 2006, Smethurst, 2010). The elements nitrogen, phosphorus and potassium stand out, which are essential macronutrients for plant development (Zhang et al., 2010, Biagiotti et al., 2017). Where effects of fertilization with these nutrients on both plant growth and leaf chemical content have been extensively studied in forests such as eucalyptus (Graciano et al., 2006, Rosim et al., 2016, Santos et al., 2017). Thus, the objective of this work was to evaluate the influence of meteorological variables on the increment in height and diameter of planting *Tachigali vulgaris* L. G. Silva & H. C. Lima fertilized with NPK.

MATERIAL AND METHODS

Study área: The study was carried out at the Fazenda Escola de Igarapé Açu - FEIGA of the Universidade Federal Rural da Amazônia - UFRA, in the municipality of Igarapé-açu, Pará State, Brazil.

The municipality belongs to the Northeast Paraense mesoregion and the Bragantine microregion. The municipal seat has the geographical coordinates 01°07'33" South latitude and 47°37'27" West Greenwich longitude. The climate of the municipality is Am type by Köppen classification (Costa et al., 2013), with an average temperature around 25°C throughout the year. The annual precipitation of the region is high, reaching 2,853 mm, with a strong concentration in the months from January to June and less rainy from July to December. The predominant soil in the region is yellow Latosol (Rousseau et al., 2014).

Meteorological data

The meteorological data for this study were obtained from the Embrapa Amazônia Oriental agroclimatological station, located in Igarapé-Açu, Pará, Brazil, situated at latitude 01°07'33"S, longitude 47°37'27" W and altitude 45 m, distant 28 km from the study area.

The meteorological data such as air temperature, maximum and minimum temperature, and precipitation were analyzed in the period from March 2016, when planting was performed, until June 2018.

Experimental design and evaluations

A stand of *Tachigali vulgaris* L. G. Silva & H. C. Lima was established in 2016, whit area of 1.44 hectare (14,400 m2), containing 1728 trees, distributed in four plots with a distance of five meters, to facilitate the implantation of future experiments, with the use of fertilizers applied to the soil surface, thus avoiding contamination between treatments by rainfall, with plants spacing 2 × 3 m (plants × rows), as recommended by Sousa et al. (2016). The planting was submitted to different levels of fertilization, which were applied in grams per plant, which constituted the treatments, of two doses of nitrogen-N (0, 26.67 g), two doses of phosphorus-P (0, 19.56 g) and two doses of potassium-K (0, 30 g). The commercial formulations of urea, triple superphosphate and potassium chloride respectively were used, combined according to the fractional factorial 2k, which totals 8 treatments randomly distributed, with 4 plants grouped in the planting plots, whit 4 replications, namely: T0 (control, no fertilization), T1 (30 g of K), T2 (19.56 g of P), T3 (19.56 g of P + 30 g of K), T4 (26.67 g of N), T5 (26.67 g of N + 30 g of K), T6 (26.67 g of N + 19.56 g of P), T7 (26.67 g of N + 19.56 g of P + 30 g of K). Fertilizations were performed in 2016, right after planting and repeated twelve months later in 2017. Being used as a *parameter of* comparison with the climatic data, the average data of growth in height and diameter of all treatments.

To follow the periodicity and the rate of increment in height and diameter of the plants, measurements were made every three months during the 2-year period, corresponding to the months of March 2016 to March 2017 in the first year and from June 2017 to June 2018 in the second year, thus providing a quarterly analysis of the increment in height and diameter of the plants. The diameter evaluations during the two years were divided into two forms of measurement, due to the fact that the plants only presented measurable DBH (diameter at breast height at 1.3 m from the ground) at 15 months of age, which corresponded to the measurement in June 2017.

In the first year, the diameter was measured at the height of the basal diameter (BD), using a digital caliper, as the plant heights were less than 1.3 m. In the second year, the diameter measurement was made at DBH (Diameter at breast height - 1.3 m), using a diametric tape graduated in centimeters. The total height of the plants was measured with a ruler graduated in centimeters. Periodic quarterly increments (IPT) of plant diameter and height were calculated to express the growth of *Tachigali vulgaris* every three months (equation 1).

$$IPT = Y(t + n) - Y_t \quad (1)$$

where: IPT = quarterly periodic increment
Y = considered dimension
t = age
n = time period

Statistical analysis

The data were submitted to the normality test, and subsequent statistical analysis. In order to verify the associations between the growth variables of *Tachigali vulgaris* L. G. Silva & H. C. Lima and the climatic variables, a multivariate statistical analysis of Principal Components – PCA and Pearson's correlation was performed. For that, the software R studio was used.

RESULTS

The average results found for the quarterly periodic increase in height of the forest stand of *Tachigali vulgaris* L. G. Silva & H. C. Lima showed (Table 1 and Figure 1) that the species maintained its growth rate until September 2017 (94.4 cm overall average), when 76.3 mm of rain was recorded, which was reduced in the fol-

Table 1. Periodic quarterly increase in height and diameter of *T. vulgaris* plants subjected to N, P and K fertilization, and the variation during the period of the meteorological variables of temperature (average, maximum and minimum) and precipitation.

Increments / Treatments		2016				2017		2018	
		Mar.-June	June-Sept.	Sept.-Dec.	Dec.-Mar.	June-Sept.	Sept.-Dec.	Dec.-Mar.	Mar.-June
Height (cm)	0	18.7	37.1	23.3	43.8	77.1	44.4	57.7	76.6
	n:26.67	30.8	45.3	34.3	49.9	96.2	61.1	69.2	69
	p:19.56	19.6	42.9	26.8	48	82.3	47.8	66.3	65.7
	k:30	20.4	44.4	35	46.8	92.6	54.2	70.3	82
	n:26.67, p:19.56	30.7	47.5	32.8	53.4	94.6	55.9	75.3	76.4
	n:26.67, k:30	24.5	45.7	38.7	47	103.3	59.7	68.5	60.3
	p:19.56, k:30	21.3	44.9	41.1	52.6	108.1	54.4	80.2	78.8
	n:26.67, p:19.56, k:30	26.4	48.3	32.9	51.5	100.9	54.5	60.9	71.2
	Average treatments	24	44.5	33.1	49.1	94.4	54	68.6	72.5
Diameter (cm)	0	0.36	1.09	0.78	0.82	1.05	0.73	1.2	0.97
	n:26.67	0.6	1.65	0.74	1.27	1.43	1.01	1.15	0.95
	p:19.56	0.38	1.47	0.63	1.01	1.44	0.69	1.04	0.93
	k:30	0.41	1.31	0.76	0.85	1.31	0.83	1.2	1
	n:26.67, p:19.56	0.54	1.71	0.82	1.2	1.45	0.75	1.01	0.9
	n:26.67, k:30	0.58	1.58	0.83	0.84	1.54	0.81	1.2	0.97
	p:19.56, k:30	0.49	1.45	0.89	1.3	1.82	0.86	1.4	1.09
	n:26.67, p:19.56, k:30	0.58	1.47	0.84	1.05	1.33	0.73	0.96	0.81
	Average treatments	0.49	1.47	0.79	1.04	1.42	0.8	1.15	0.95
Meteorological variables	Temperature-T. °C	27.7	27.5	28	27.5	28.7	28.6	27.5	27.3
	T. maximum °C	32.5	33	33.7	32	33.8	34.1	32	31.9
	T. minimum °C	23	22	22.3	23.1	23.6	23.1	22.9	22.8
	Precipitation (mm)	321.2	120.5	78.9	384.7	76.3	32.6	262.5	310.1

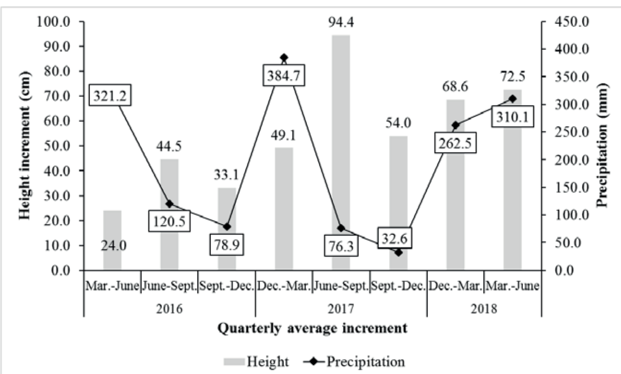

Figure 1. Average quarterly increase in height (cm) of T. vulgaris plants subjected to N, P and K fertilization, and rainfall (mm) during the studied period.

lowing quarter (54.0 cm), which had the lowest rainfall observed during the study, 32.6 mm of rain. The results found indicate that there is a gradual proportionality for the vertical increment of the plants and the precipitation, being able to infer that the planting presented good elasticity regarding the low precipitations, while the temperature was stable over the years, not having great variation (Table 1), keeping within a range of approximately 1°C.

The maximum quarterly periodic increase in height occurred in the quarter from June to September 2017, where treatments with fertilization of nitrogen + potassium, phosphorus + potassium and NPK (nitrogen, phosphorus and potassium) presented values of 103.3, 108.1 and 100.9 cm, respectively (Table 1). And the second largest increase in planting corresponded to the quarter from March to June 2018, where the treatment without fertilization obtained dendrometric accumulation at a height similar to that with the addition of nitrogen plus potassium (76 cm). This growth rate in height is outside the expected patterns, since normally the greatest increases occur in the rainy season, which was not observed in the present study.

Unlike growth in height, the largest increase in diameter occurred in the first year of planting (2016), with 1.47 cm in June-September (Table 1 and Figure 1). The second largest increase (1.42 cm) also occurred in June-September, but in the following year (2017). Pre-

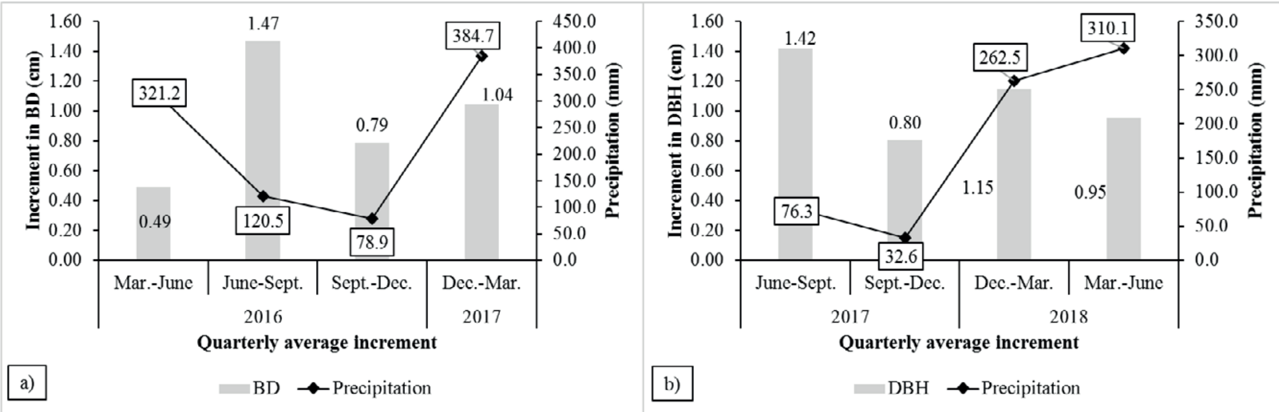

Figure 2. Average increment of basal diameter (BD) (cm), corresponding to the first year of planting (a), diameter at breast height (DBH) (cm), corresponding to the second year of planting (b), and rainfall (mm) during the periods studied.

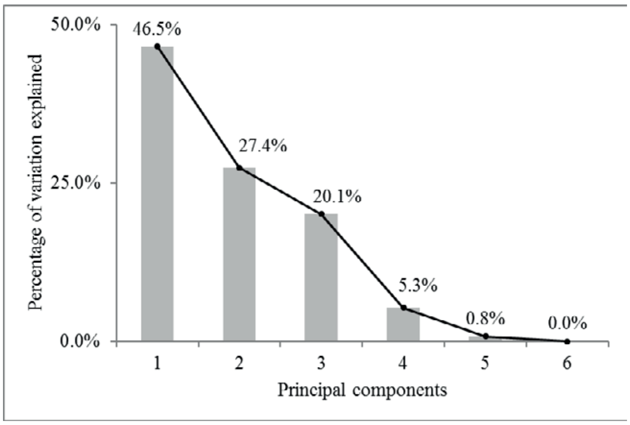

Figure 3. Result of the analysis of principal components of the variables of growth (height and diameter) of *T. vulgaris* plants and meteorological variables (temperature and precipitation).

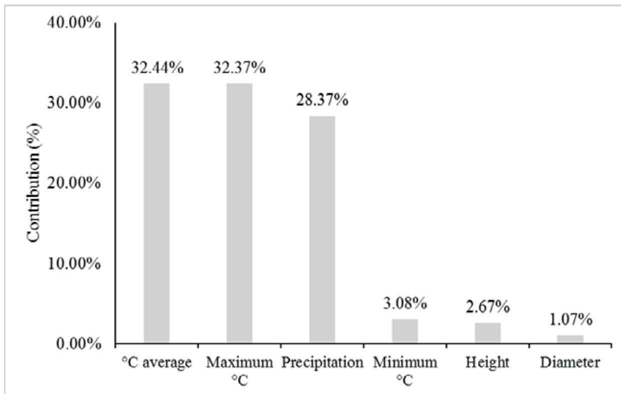

Figure 4. Contribution of the variables of height, diameter, temperature (minimum, average and maximum temperatures) and precipitation, for the first principal component, in a *T. vulgaris* plantation submitted to fertilization with N, P and K.

cipitation in these periods of greatest increase was only 120.5 mm in Jun-Sep 2016 and 76.3 mm in Jun-Sep 2017 (Figure 2).

Among the treatments with the highest mean increments, those with the addition of nitrogen + phosphorus (1.71 cm), nitrogen (1.65 cm) and nitrogen + potassium (1.58 cm) stand out (Table 1).

The reduction in the increase in tree diameter and height in the quarter from December to March 2017, despite the high level of precipitation (384.7 mm), can be partially attributed to the greater number of cloudy days affecting respiration and nutrient translocation. by the roots and photosynthesis, with reflection in the increase of the dendrometric variables.

The principal component analysis showed that the first three factors have eigenvalues, which correspond to 46.5%, 27.4% and 20.1% of the variance (Figure 3), explained by the model's eigenvalues, that is, they explain together 94 % of the total variance of species growth, with a stabilization of the curve after the fourth component. Thus, the first three components were considered, considering that the other components present a low explanation.

The breakdown of the analysis of the first two main components shows that the variables that most contributed to explain the development of the population of the species, correlated with the meteorological variables observed in this study, were the average and maximum temperatures and precipitation (Figure 4), followed by the height, diameter and minimum temperature (Figure 5). For the third main component, only the minimum temperature contributed to explain the data variance (Table 2). This demonstrates that the temperature variation and the amount of rain were the first variables to

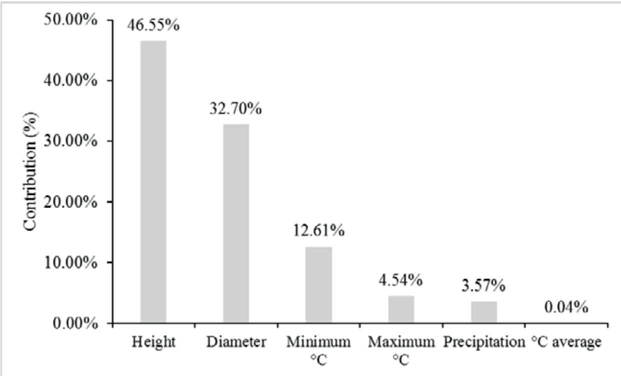

Figure 5. Contribution of height, diameter, temperature (minimum, average and maximum) and precipitation variables to the second principal component in a *T. vulgaris* plantation subjected to N, P and K fertilization.

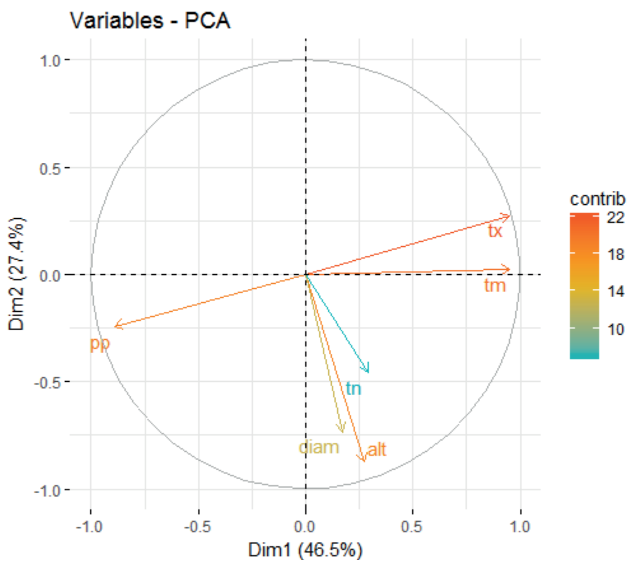

Figure 6. Ordering diagram of the original variables of the six Principal Components, extracteds from the analyzed growth and meteorological variables, in a *T. vulgaris* plantation fertilized with N, P and K.

Table 2. Contribution of growth and meteorological variables to the first three Principal Components extracted, in a *T. vulgaris* plantation fertilized with N, P and K.

Variable	Principal Components		
	1	2	3
Height	2.67%	46.55%	0.63%
Diameter	1.07%	32.70%	25.16%
Average temperature	32.44%	0.04%	7.03%
Maximum temperature	32.37%	4.54%	0.90%
Minimum temperature	3.08%	12.61%	56.74%
Precipitation	28.37%	3.57%	9.53%

predict the development of the plantation, followed by the dendrometric indicators.

In the ordering diagram of the original variables of the six principal components, it can be seen that some dendrometric and climatic variables are superimposed (right side of the circle), which demonstrates that they have similar representation (Figure 6). It can also be observed that the environmental variables are close to the unit circle, denoting a strong relationship with the increase in height and diameter.

Pearson's correlation showed that the variables that most correlated were precipitation with mean and maximum temperatures, with correlation values close to 1 (100%) (Table 3). The height and diameter variables had a low (R=0.3) to moderate (R=0.6) correlation with precipitation. In planting of *Tachigali vulgaris* with spacing (4 × 2 m).

Table 3. Pearson correlation matrix for the growth and meteorological variables studied, in a *T. vulgaris* plantation fertilized with N, P and K.

Variables	Pearson's correlation matrix					
	Height	Diameter	Average T.	Maximum T.	Minimum T.	Precipitation
Height	1					
Diameter	,	1				
Average T.	-	-	1			
Maximum T.	-	-	B	1		
Minimum T.	-	.	.	-	1	
Precipitation	-	.	*	B	-	1

Legend: "-" 0.3, "." 0.6, "," 0.8, "*" 0.95, "B" 1, correlation level.

DISCUSSION

For Brienen et al. (2017), growth can vary intra and interspecifically according to the size class of the trees, in the case of the study they were still in the initial phase of growth, therefore, the association of factors with the climate is important. determinant in the dynamics of growth combined with carbon gain, since larger trees have greater monthly growth, disregarding the point at which age can be limiting (Lyra et al., 2017).

Dias & Marenco (2016) evaluated the effect of rainfall seasonality on tree growth of 28 species in tropical terra firme forest in central Amazonia and concluded that the region's mild dry season is not long enough to deplete soil water, beyond the reach of the root system, which allows trees to grow at constant rates throughout the year. In the present study, the growth also remained constant, not being null during the evaluation period.

As for height, the species showed good elasticity in terms of low precipitation rates. According to (Sette et al. 2010), this result is explained by the availability of water from the rainy season, stored in the deeper layers of the soil.

Physiologically speaking, the assimilation of CO_2 from the atmosphere through foliar photosynthesis depends on temperature limits that allow the work of the enzymes that act in the process, the main one being Rubisco. Excessive temperature limits can not only inhibit Rubisco, but also cause damage to the plant's hydraulic system. This is because temperature is strongly related to vapor pressure deficit (VPD) which, in turn, has been identified as one of the main causes of tree mortality (McDowell and Allen, 2015, McDowell et al., 2018).

In a study to evaluate the growth in trunk diameter of *Eucalyptus grandis* trees and its relationship with climatic variables and mineral fertilization, (Sette et al. 2010) concluded that climatic variables influenced growth rates, where greater rainfall led to reductions in increments. Narducci et al. (2016) evaluated the growth of *Sclerolobium paniculatum* and the relationship between precipitation and diameter increment, in different planting spacings in dystrophic yellow latosol with annual precipitation of 2500 mm, and concluded that the correlation between precipitation and increment in diameter was moderate to strong, which, according to the authors, shows the sensitivity of the growth of this species to the availability of water. However, in the present study this correlation did not occur.

According to Mattos et al. (2015), rainfall from the previous year had a major contribution to the subsequent increase in diameter of Mimosa tenuiflora in seasonally dry tropical forest in Brazil. According to Santos et al. (2017), in places where there is an inventory to support the development and intervene in forest plantations, such as the choice of clones with higher productivity per site, information on rainfall, together with the analysis of growth curves in different types of soils, can help to define the most suitable clone for a given region.

According to Morais et al. (2017), *Tachigali vulgaris* presents strategies to water stress, which is correlated with increased leaf temperature. This promotes the elevation of leaf transpiration rates, serving as a strategy used to reduce leaf temperature, avoiding damages due to the exaggerated heating of the photosynthetic apparatus, since the process of evaporation of the water molecule by the plants causes a substantial loss of heat and constitutes one of the most important means they have to regulate the temperature. This is in agreement with the results found in the present study, where precipitation and maximum and average temperatures strongly influenced the dendrometric increments of *Tachigali vulgaris*. Narducci et al. (2016) also observed a correlation close to 0.6 between precipitation and diameter increment.

Soares and Cruz (2016) evaluated the influence of meteorological variables on the growth in diameter and height of paricá (*Schizolobium parahyba* var. *amazonicum*), using Pearson's correlation analysis, and found positive correlations, showing a directly proportional relationship between the meteorological variables and the increments in diameter and height of the trees of the species. In a study of the relationship of meteorological variables with the growth of planted trees of *Araucaria angustifolia* (Bertol.) Kuntze, it was found that the increase in precipitation positively influences the increase in diameter (Zanon & Finger 2010), which corroborates the results of the present study.

CONCLUSION

Precipitation was the climate variable that most positively influenced the increase in height and diameter of *Tachigali vulgaris* L. G. Silva & H. C. Lima plants,

The plants showed excellent elasticity, especially in periods of low rainfall,

The precipitation and maximum and average temperatures strongly influenced the dendrometric increments of *Tachigali vulgaris*,

In view of the results presented, there is a great possibility of indicating the planting of *Tachigali vulgaris* for regions with climate variations similar to this study.

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