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# Influence of meteorological variables on the initial growth of seedlings of native forest species in vegetation restoration plantings

## Influência de variáveis meteorológicas no crescimento inicial de mudas de espécies florestais nativas em plantios de restauração da vegetação

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## Abstract

The importance of forest restoration plantations to restore ecosystems and neutralize greenhouse gases is increasing, especially as a way to combat climate change. Research related to the growth of forest species and the influence of the environment should be considered to determine their potential in neutralizing carbon dioxide. Thus, the objective was to evaluate the growth in diameter at ground level and height of six forest species throughout the first year after planting according to meteorological variables. The experiment was conducted in the Carbon Zero Forest, part of the Open Space for Events on the main *campus* of the Federal University of Viçosa (UFV), Minas Gerais, Brazil. Planting of the 324 seedlings was conducted in December 2019, with 2.0 m x 2.0 m spacing, in a randomized block design. The meteorological characteristics for the year 2020 were obtained through the bulletins of the institution's own automatic station. The current increment in height and diameter was calculated for three-month intervals, per species. The data were subjected to Spearman's non-parametric correlation test. The significant correlations between increments in diameter at ground height and height with climatic variables were weak or moderate. In general, precipitation and maximum absolute temperature positively affected the current increment in height, while global radiation affected them negatively. Precipitation, average temperature and absolute minimum temperature negatively affected the current increment in diameter. The results obtained can help in the elaboration of strategies that promote the restoration of areas according to the adaptability of the species to adverse conditions, aside from potentiating the neutralization of atmospheric carbon dioxide.

**Keywords:** Climate change; Recovery of degraded areas; Neutralization of greenhouse gases.

## Resumo

A importância dos plantios de restauração florestal com o intuito de restaurar os ecossistemas e neutralizar os gases de efeito estufa vem aumentando, principalmente, como forma de enfrentamento às mudanças climáticas. Pesquisas relacionadas ao crescimento de espécies florestais e a influência do ambiente devem ser consideradas para determinação do potencial das mesmas em neutralizar carbono. Dessa forma, o objetivo foi avaliar o crescimento em diâmetro à altura do solo e altura de seis espécies florestais ao longo do primeiro ano pós-plantio em relação às variáveis meteorológicas. O experimento

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foi conduzido no Bosque Carbono Zero, inserido no Espaço Aberto de Eventos do campus-sede da Universidade Federal de Viçosa (UFV), Minas Gerais, Brasil. O plantio das 324 mudas foi realizado em dezembro de 2019, com espaçamento 2,0 m x 2,0 m, em delineamento de blocos casualizados. As características meteorológicas para o ano de 2020 foram obtidas através dos boletins da estação automática da própria instituição. O incremento corrente em altura e em diâmetro foi calculado para intervalos de três meses, por espécie. Os dados foram submetidos ao teste de correlação não paramétrico de Spearman. As correlações significativas entre os incrementos em diâmetro à altura do solo e altura com as variáveis climáticas foram fracas ou moderadas. De maneira geral, a precipitação e a temperatura máxima absoluta afetaram positivamente o incremento corrente em altura, já a radiação global, negativamente. A precipitação, temperatura média e temperatura mínima absoluta afetaram negativamente o incremento corrente em diâmetro. Os resultados obtidos podem ajudar na elaboração de estratégias que promovam a restauração de áreas em função da adaptabilidade das espécies em condições adversas, além de potencializar a neutralização de carbono atmosférico.

**Palavras-chave:** Mudanças climáticas; Recuperação de áreas degradadas; Neutralização de gases de efeito estufa.

## 1. INTRODUCTION

The importance of greenhouse gas neutralization plantations has been increasing, including due to the socio-environmental benefits they can bring (Holl & Aide, 2011). Neutralization through plantations are a potential alternative for mitigating climate change, taking into account the carbon stock of trees in their biomass (Morais Júnior et al., 2019). In addition to the benefits of carbon storage, these plantations can act as a means of forest restoration of degraded areas, increase biodiversity, maintenance of the landscape, among others (Brancalion et al., 2019; Azevedo et al., 2018; Oliveira & Engel, 2017). The demand for knowledge about silvicultural techniques and suitable species for the establishment of plantations grows considerably, with the aim of carrying out plantations adequately and reducing the costs of the process (Brancalion et al., 2019; Crouzeilles et al., 2017).

Growth is a relevant characteristic about species, defined as the increase in their dimensions in a given time, such as in diameter, height, volume or other measurable characteristics, at the individual or forest stand level (Prodan, 1997). Research related to the growth of forest species and the influence of the environment should be considered to determine their potential for restoration and neutralization plantings (Machado et al., 2014; Morais Júnior et al., 2019). The correlation between growth and meteorological conditions has already been proven, with emphasis on studies on precipitation, temperature and availability of water in soils to analyze the variability of growth of species (Kanieski et al., 2017; Martinkoski et al., 2015; Blagitz et al., 2016; Bernert et al., 2020).

Meteorological variables can generate changes over the years in limiting resources such as water, light and nutrients, which directly affect the endogenous metabolism of the plant and interferes with growth (Alves, 2021; Worbes, 1999). The influence of meteorological variables on the initial growth of seedlings can be positive or negative. Low precipitation, for example, is reported as a limiting factor for cambium activity and stem growth in some species, but in other cases, high precipitation can become a hindrance to the initial growth of seedlings (Worbes, 1999).

The relationship between tree growth and environmental factors varies between species, indicating that they have different sensitivities (Shimamoto et al., 2016). The greatest growth of a species in a region depends, among other factors, on its morphological characteristics, the ability to adapt to the environment and the classification of species in terms of their successional strategy (Almeida et al., 2005; Fırıncıoğlu et al., 2010).

Thus, this research aimed to evaluate the growth in diameter at ground level and height of *Anadenanthera colubrina* var. cebil (Griseb). Altschul, *Citharexylum myrianthum* Cham., *Joannesia princeps* Vell., *Peltophorum dubium* (Sprengel) Taubert, *Inga laurina* (SW) Wild and *Libidibia ferrea* var. *leiostachya* (Mart.) during the first year after planting in relation to meteorological variables, temperature, precipitation, relative humidity and radiation.

## 2. MATERIAL AND METHODS

### 2.1 Characterization of the area

The experiment (A1) was conducted in the Bosque Carbono Zero, inserted in the Open Space of Events of the Federal University of Viçosa (UFV), Minas Gerais, Brazil (20º 45’ 35,73” S, 42º 52’ 30,84” O) (Figure 1).

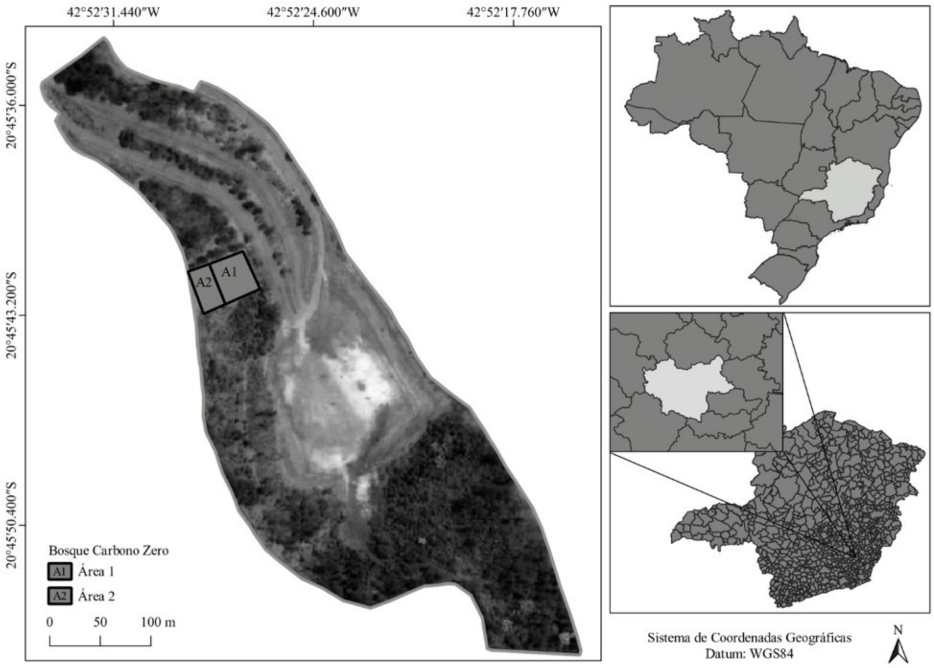


**Figure 1.** Location of the experimental area (A1) in the Carbon Zero Forest.

The site, with an altitude of 697m, is located in the Atlantic Forest biome, regionally characterized as Montane Seasonal Semi-deciduous Forest. The climate is Cwa (Köppen) with hot, rainy summers and cool, dry winters. The meteorological characteristics for the year 2020 were obtained through the bulletins of the institution's own automatic station. The highest accumulated precipitation occurred in January and February, with 495.8 mm and 392.6 mm, respectively. The months of June and July were marked by low rainfall, with values below 5 mm. (Figure 2A). The absolute minimum temperature presented the lowest values in May and August and the absolute maximum in the months of September and October. (Figure 2B). The average temperature varied between 15°C and 25°C, with the lowest averages between the months of May and August (Figure 2B). Relative air humidity had the lowest average in September (Figure 2C), which was also the month with the highest incidence of solar radiation (Figure 2D).

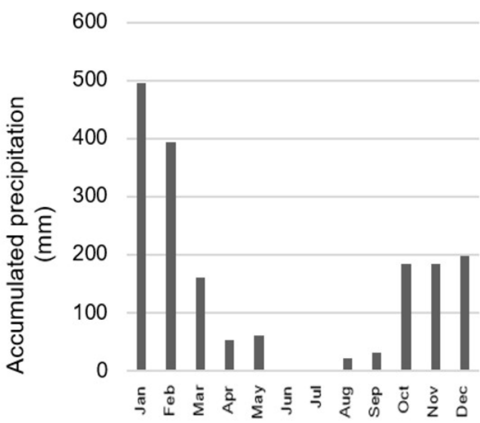


**Figure 2A.** Accumulated precipitation (mm) averages during the year of 2020, in Viçosa, Minas Gerais.

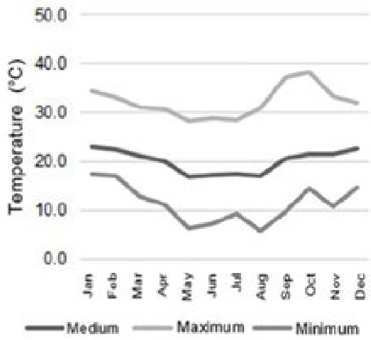


**Figure 2B.** Temperature (ºC), absolute minimum and maximum averages during the year of 2020, in Viçosa, Minas Gerais.

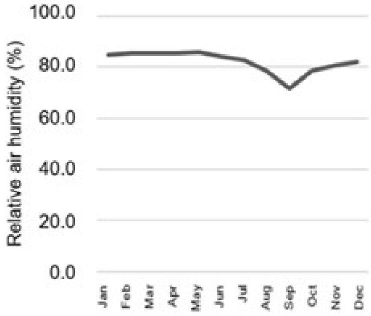


**Figure 2C.** Relative air humidity (%) averages during the year of 2020, in Viçosa, Minas Gerais.

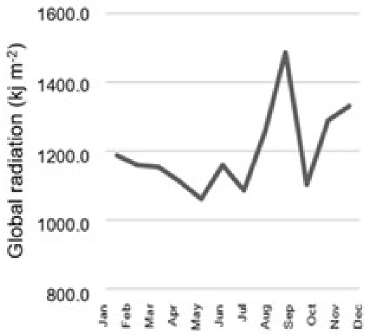


**Figure 2D.** Global radiation (kj $m^{-2}$) averages during the year of 2020, in Viçosa, Minas Gerais.

The local topography is characterized by a pedo-geomorphological gradient with flat tops with access to colluvial slopes, whose predominant soils are dystrophic Latosols abundant in aluminum, and shallow Cambic Latosols and valleys with eutrophic Cambisols (Ferreira Júnior et al., 2012).

## 2.2 Characterization of planting

Three hundred and twenty-four seedlings of six forest species native to the Atlantic Forest; *Anadenanthera colubrina* var. *cebil* (Griseb). Altschul, *Citharexylum myrianthum* Cham., *Joannesia princeps* Vell., *Peltophorum dubium* (Sprengel) Taubert, *Inga laurina* (SW) Wild and *Libidibia ferrea* var. *leiostachya* (Mart.) with 54 individuals each, were planted at 2.0 m x 2.0 m spacing, distributed in 18 rows with pits (30 cm x 30 cm x 30 cm) parallel to the slope of the area. The species are commonly used in flora recomposition projects and deserve attention regarding their behavior and development under such conditions. The cutting of low density crawling vegetation was carried out before and after planting to control weed competition, mainly with brachiaria (*Urocola decumbes* (Stapf) R.D. Webster) favoring the establishment and growth of seedlings.

Liming was done 60 days before planting, with 50g of dolomitic limestone with PRNT 76% mixed into the bottom of the pit. Phosphate fertilization of 300g of simple superphosphate (18%

$P_2O_5$) was also done 30 days before planting. After planting, three surface fertilizations using NPK 20-0-20 were done in January (100g/pit), February (100g/pit), and November (150g/pit) of 2020. There was no need for irrigation, because planting occurred during the rainy season.

The control of leaf-cutting ants with formicide baits (0.3% m/m sulfluramid) was done when active nests were detected. Weed combat was done with a hoe, as needed.

### 2.3 Data Analysis

The height (cm) and diameter at ground level (mm) of each seedling were measured with a tape measure and caliper, respectively. The inventories were made soon after planting and in each quarter of the year. The current increment in height (ICH-cm) and in diameter at ground level (ICD-mm) was calculated in each quarter per species; with ICHij = Hij- H(i-1) j; ICDij = ICDij - ICD(i-1) j, where i = quarter evaluated; j = species.

The meteorological variables temperature, precipitation, relative humidity and radiation collected from the weather station established on the UFV headquarters campus and the information on height and diameter increments were submitted to Spearman's non-parametric correlation test, commonly used for data distributions that do not tend to normality. The alpha (α) adopted was 1%, with the null hypothesis (H0) accepted, when the p-value > α (0.01) with correlation equal to zero and the alternative (Ha), when p-value ≤ α (0.01) with non-zero correlation. Analyzes were performed using the R software.

## 3. RESULTS AND DISCUSSION

The interaction between the current quarterly increment in Height and Diameter at ground level related to the Average, Maximum and Minimum Temperature variables; Precipitation; Radiation, and Relative Humidity are presented in Figures 3A, 3B, 3C and 3D, respectively. The significant correlations between the increments in diameter at ground level and height with the climatic variables were weak or moderate, which may be related to the tropical climate of the study region. The effect of variations in temperature, precipitation, solar radiation, among other climatic variables on the growth rate of trees is more significant in areas with temperate climates (Jacoby, 1989).

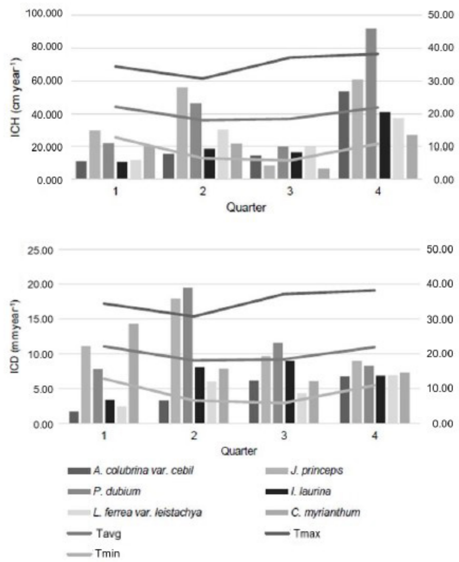


**Figure 3A.** Quarterly current increment in Height (ICH - cm year -1) and Diameter at ground level (ICD - mm year-1) in relation to the variables Average Temperature (T avg - °C), Maximum (Tmax - °C) and Minimum (Absolute Tmin - °C).

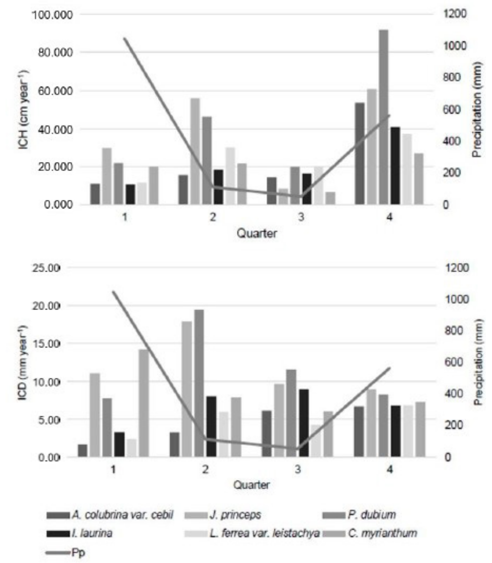


**Figure 3B.** Quarterly current increment in Height (ICH - cm year$^{-1}$) and Diameter at ground level (ICD - mm year$^{-1}$) in relation to the variable Precipitation (Pp - mm).

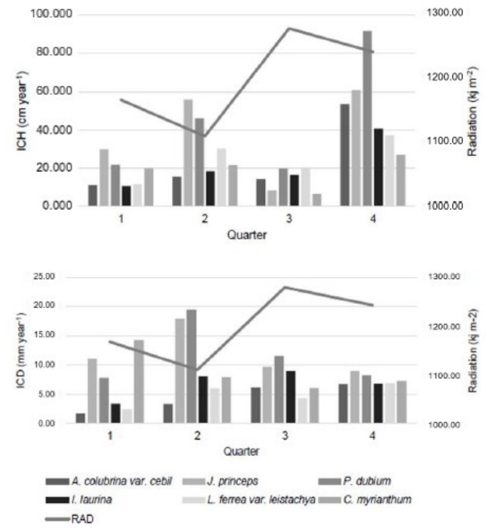


**Figure 3C.** Quarterly current increment in Height (ICH - cm year$^{-1}$) and Diameter at ground level (ICD - mm year$^{-1}$) in relation to the variable Radiation (RAD - Kj$^{-2}$).

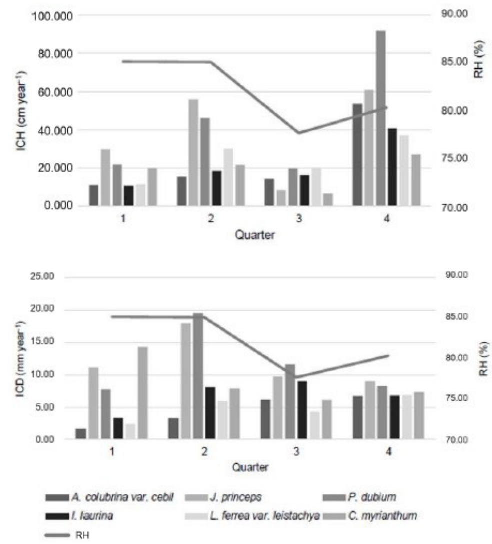


**Figure 3D.** Quarterly current increment in Height (ICH - cm year$^{-1}$) and Diameter at ground level (ICD - mm year$^{-1}$) in relation to the variable Relative Air Humidity (RH - %).

In general, precipitation and absolute maximum temperature positively affected the current height increase, while global radiation negatively affected it (Table 1). Solar radiation and maximum temperature were the climatic variables that most influenced the current increment in individual height of the species studied, but with an interdependence considered weak between the variables.

**Table 1.** Correlation values between the Current Increment in Height (ICH) and in Diameter at Ground level (ICD), and the analyzed climatic variables

| Variable | ICH | ICD |
|---|---|---|
| Pp | 0.128* | -0.126* |
| RAD | -0.106* | -0.048 |
| Tavg | -0.027 | -0.177* |
| Tmax | 0.185* | 0.055 |
| Tmin | 0.128* | -0.126* |
| RH | 0.009 | 0.068 |

*significant correlations, at 1% probability, by Student's test.

Generally for height growth analyses, the quarter with the lowest ICH is between June and August. This behavior is similar in the analysis of increment in diameter at ground level (ICD), but less expressive. Even though this is a study conducted in a tropical climate area, a lower plant development is expected in these months, since the period is marked by water scarcity and milder temperatures, typical of the Cwa (Koppen) climate in winter (Alvares et al., 2013). The differences found in the growth patterns are related to the seasonal conditions to which they are exposed, because the individual trees adapt their growth to withstand the seasonal stress to which they are submitted.

In the fourth quarter (October to December), the highest rates of ICH were observed; a period that coincides with the hottest and rainiest season. In a study related to the periodicity of the growth of tree species, it was concluded that the analyzed species also had a greater development in the months in question (Blagitz et al., 2016). The quarters that had the highest precipitation rates favored height growth, but decreased the diameter increment at the base of the evaluated individuals. Precipitation and, consequently, soil water availability are paramount for the development of tropical forest seedlings, and recurrent periods of drought inhibit growth rates and reduce the response to precipitation (O'Brien et al., 2017; Wang et al., 2019). The variation in precipitation alters the availability of soil water and nutrients and, consequently, the dynamics of the root system, since the roots expand in drier conditions, in search of water (Moran et al., 2019). Other water use strategies besides rooting depth are used by plants, such as deciduousness, tissue water storage, hydraulic architecture, and regulation of stomatal conductance (Comita & Engelbrecht, 2009).

The increase in radiation caused a decrease in ICH in *J. princeps* and *C. myrianthum*, in which the interdependence was considered very weak. For *A. colubrina* var. *cebil*, *I. laurina* and *P. dubium*, on the other hand, the effect of Tmax was the opposite, causing an increase in ICH as it increased. This effect was significant, but with an interdependence considered very weak. The other interdependencies between the climatic variables and the ICH were very weak, with the effect of precipitation and absolute minimum temperature being positive, while the average temperature was negative. The effect of relative humidity was variable, being negative for *A. colubrina* var *cebil*, *I. laurina* and *L. ferrea* var. *leiostachya*, and positive for *J. princeps* and *C. myrianthum.*

The current increment in diameter at ground level was more influenced individually by the analyzed climatic variables, in comparison with ICH. The growth in diameter of trees varies between and within species, and is influenced not only by age, but also by seasons and weather conditions (Higuchi et al., 2003). The peak growth in diameter tends to vary depending on the climatic conditions of each year, and may suffer a reduction due to the decrease or cessation of the cambial activity resulting from the onset of water deficit, in conjunction with the lower temperatures that preceded the onset of winter (Maria, 2002).

Precipitation had a significant and positive effect for the increments only for *C. myrianthum* and, negative for *A. colubrina* var. *cebil*, *P. dubium*, *I. laurina* and *L. ferrea* var. *leiostachya*. The distribution of precipitation is one of the climatic factors that regulate the growth of tree species in tropical forests (Brienen et al., 2011). In these forests, the reduction in cambial activity and consequently in the ICD, is mainly due to the decrease in precipitation (Martinkoski et al., 2015). Good results of survival and development of individuals of *C. myrianthum* in places with high rainfall and good water availability in the soils were obtained by Silveira et al. (2013). According to the authors, these results may have been attributed to the fact that this species preferentially inhabits humid places. Positive effects of precipitation are reported for height and basal diameter growth and total biomass accumulation in forest seedlings (Wang et al., 2019), but this behavior is variable depending on the species. Water is related to growth due to its participation in all physiological and biochemical processes, being the main constituent of plant tissues, responsible for cell turgidity, reactant in hydrolytic processes and acting as a means of dissolving salts and other substances, creating a continuous system for dissolution inside the plant (Campos, 1970).

The maximum and minimum temperature had a significant positive influence on the ICH, while the average and minimum temperature influenced the ICD with a negative effect; that is: the lower the minimum temperature or the quarterly average, the higher the ICD. Temperature is a key determinant of the rate of metabolic processes and therefore has a direct impact on plant growth, influencing photosynthesis and cellular respiration, which can affect the plant's water balance, disrupt enzyme systems, induce water stress and cause loss of turgidity (Landsberg et al., 2011). Daily maximum and minimum temperatures are variables of interest because they can cause damage to plants and interrupt growth temporarily or permanently, and are a significant source of abiotic stress (Landsberg et al., 2011).

The current increment in diameter at ground level was more influenced individually by the analyzed climatic variables, when compared with ICH. Precipitation had a significant and negative effect for *A. colubrina* var. *cebil*, *P. dubium*, *I. laurina* and *L. ferrea* var. *leiostachya*, positive. The interdependence between precipitation and the current increment in diameter of *I. laurina* is moderate, in the other species it was considered weak or very weak. The global radiation and the current increase in diameter at ground height had moderate and negative interdependence with *J. princeps* and *P. dubium*, but with *A. colubrina* var. *leiostachya*, positive.

The interdependence of Tavg was not significant only for *A. colubrina* var. *cebil*. For *C. myrianthum*, the Tavg was moderate and positive, while in the other species it was weak and negative. With the other species, the interaction was moderate and negative. Tmax and Tmin had moderate interaction effects, and Tmax had a positive effect for *A. colubrina* var. *cebil* and negative for *J. princeps* and *P. dubium*. In contrast, the effect of Tmin was positive for *C. myrianthum* and negative for *A. colubrina* var. *cebil* and *P. dubium*.

Thus, in this study, by analyzing only the climatic variable Tmax, it can be inferred that individuals of *A. colubrina* var. *cebil*, *I. laurina* and *P. dubium*, have a good ICH in locations that have high temperatures. However, it is necessary to determine the optimum temperature rates for each species, because rates above optimum lead to increases in photorespiration, which reduces photosynthesis because the enzymes and membranes involved in the photosynthetic process lose their function. The average growth rate of *Ficus insipida* Willd., *Ochroma pyramidale* (Cav. Ex Lam.) Urb and *Calophyllum longifolium* L., which grow in neotropical regions, peaked at temperatures near 30°C and the appearance of the plants was also affected by temperature variation (Slot & Winter, 2017). In general, pioneer species such as *P. dubium* even when in competition with herbaceous plants, grow faster in warmer locations, and thus small increases in temperature and length of the growing season may favor the establishment of forest stands in grasslands (Fridley & Wright, 2018). Temperature extremes are responsible for stress in plants (Maria, 2002). Thus, when analyzing climatic ranges to which species are adapted, it is important to examine their ability to withstand extremes at various stages of growth (Landsberg et al., 2011). High temperatures can reduce the plant's carbon assimilation, due to increased transpiration and the closing of stomata. In contrast, low temperatures damage plant tissue and can impair seedling development, influencing the provision of ecosystem services and even causing seedling death (Tan, 2013; Li et al., 2018). The impact of low temperature is dependent on duration and intensity, and can also be influenced by topography, slope and stand characteristics, such as the degree of canopy closure (Li et al., 2018). The effect can be enhanced in open locations, where a reforestation process is initiated. Seedlings stressed by low temperatures for a short period of time tend to adapt through self-regulation, seeking a new balance to minimize damage and resist cold. However, longer periods alter the physiological functions permanently, for example by damaging cell membranes and promoting electrolyte leakage (Luo et al., 2007; Zhou et al., 2010; Wang et al., 2011).

The global radiation and the current increase in diameter at ground level had moderate and negative interdependence with *J. princeps* and *P. dubium*, but with *A. colubrina* var. *cebil*, it was positive. Relative humidity had no influence on the ICD of *P. dubium* and had a weak positive interaction with *J. princeps* and a negative interaction with *L. ferrea* var. *leiostachya*. The ICDs of *A. colubrina* var. *cebil* and *I. laurina* had moderate and negative interactions with RH, and C. *myrianthum* had positive ones.

The solar radiation indexes contributed negatively to the development of *J. princeps* and *P. dubium*, demonstrating that perhaps these species can have favored growth if planted together with faster growing species, aiming to generate a light shading. Light is one of the climatic variables that has the greatest influence on the development of trees and, like temperature, it can influence many physiological activities that affect plant metabolism (Machado et al., 2014). Photosynthesis, for example, tends to increase with increasing temperature, up to an optimum point, after which it declines for biochemical and hydraulic reasons (Sage & Kubien, 2007; Slot & Winter, 2017). Solar radiation is a key factor for forest productivity, particularly during the rainy season (van de Weg et al., 2014; Banin et al., 2014; Malhi et al., 2017; Fyllas et al., 2017; Uriarte et al., 2018). It is composed of a complex mixture of ultraviolet (UV), visible and infrared wavelengths, and the different wavelengths have different effects on plant growth and development (Verdaguer et al., 2017). Increased radiation can decrease plant height, basal diameter, leaf area index, below and above ground biomass, fruit and stem biomass by 25.6%, 16.4%, 46.4%, 40.9%, 23.3%, 37.5% and 23.8%, respectively, but responses to the effect of increased radiation vary with vegetation types (Fu & Shen, 2017).

## 4. CONCLUSIONS

Precipitation and temperature have an effect on growth in height and diameter at ground level, but with an opposite behavior between the variables, indicating possible strategies for adapting species to adverse conditions.

The effect of meteorological variables varies depending on the species and planting conditions. For solar radiation, its effect on growth must be taken into account in order to minimize the negative effects it can promote, depending on the specific tolerance of each species.

Elucidating the degree to which and how forest species are affected by climate variables is of high importance, especially in the context of current climate change. The results obtained can help in the development of strategies that promote the restoration of areas due to the adaptability of the species to adverse conditions, aside from potentiating the neutralization of atmospheric carbon.

## 5. REFERENCES

Almeida, S. M. Z., Soares, A. M., Castro, E. M. D., Vieira, C. V., & Gajego, E. B. (2005). Alterações morfológicas e alocação de biomassa em plantas jovens de espécies florestais sob diferentes condições de sombreamento. *Ciência Rural*, *35*(1), 62-68. http://dx.doi.org/10.1590/S0103-84782005000100010.

Alvares, C. A., Stape, J. L., Sentelhas, P. C., Moraes Gonçalves, J. L., & Sparovek, G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, *22*(6), 711-728. http://dx.doi.org/10.1127/0941-2948/2013/0507.

Alves, P. B. (2021). *Relação entre atividades de copa e cambial de clones de Eucalyptus spp. em diferentes densidades de plantio* (Masters dissertation). Universidade de São Paulo, Piracicaba.

Azevedo, A. D., Camara, R., Francelino, M. R., Pereira, M. G., & Leles, P. S. S. (2018). Estoque de carbono em áreas de restauração florestal da Mata Atlântica. *Floresta*, *48*(2), 183-194. http://dx.doi.org/10.5380/rf.v48i2.54447.

Banin, L., Lewis, S. L., Lopez-Gonzalez, G., Baker, T. R., Quesada, C. A., Chao, K. J., Burslem, D. F. R. P., Nilus, R., Abu Salim, K., Keeling, H. C., Tan, S., Davies, S. J., Monteagudo Mendoza, A., Vásquez, R., Lloyd, J., Neill, D. A., Pitman, N., & Phillips, O. L. (2014). Tropical forest wood production: a cross-continental comparison. *Journal of Ecology*, *102*(4), 1025-1037. http://dx.doi.org/10.1111/1365-2745.12263.

Bernert, M. R., Jadoski, S. O., Watzlawick, L. F., Lima, V. A., & Zerbieli, L. C. (2020). Influência de variáveis ambientais no incremento radial dos anéis de crescimento de *Pinus taeda* L. *Research Social Development*, *9*(3), e84932472. http://dx.doi.org/10.33448/rsd-v9i3.2472.

Blagitz, M., Botosso, P. C., Bianchini, E., & Medri, M. E. (2016). Growth periodicity of trees species from a seasonal semi-deciduous forest in Southern Brazil. *Scientia Forestalis*, *44*(109), 163-173.

Brancalion, P. H., Niamir, A., Broadbent, E., Crouzeilles, R., Barros, F. S., Almeyda Zambrano, A. M., Baccini, A., Aronson, J., Goetz, S., Reid, J. L., Strassburg, B. B. N., Wilson, S., & Chazdon, R. L. (2019). Global restoration opportunities in tropical rainforest landscapes. *Science Advances*, *5*(7), eaav3223. PMid:31281881. http://dx.doi.org/10.1126/sciadv.aav3223.

Brienen, R. J., Wanek, W., & Hietz, P. (2011). Stable carbon isotopes in tree rings indicate improved water use efficiency and drought responses of a tropical dry forest tree species. *Trees*, *25*(1), 103-113. http://dx.doi.org/10.1007/s00468-010-0474-1.

Campos, J. C. (1970). Principais fatores do meio que afetam o crescimento das árvores. *Floresta*, *2*(3), http://dx.doi.org/10.5380/rf.v2i3.5684.

Comita, L. S., & Engelbrecht, B. M. (2009). Seasonal and spatial variation in water availability drive habitat associations in a tropical forest. *Ecology*, *90*(10), 2755-2765. PMid:19886485. http://dx.doi.org/10.1890/08-1482.1.

Crouzeilles, R., Ferreira, M. S., Chazdon, R. L., Lindenmayer, D. B., Sansevero, J. B., Monteiro, L., Iribarrem, A., Latawiec, A. E., & Strassburg, B. B. N. (2017). Ecological restoration success is higher for natural regeneration than for active restoration in tropical forests. *Science Advances*, *3*(11), e1701345. PMid:29134195. http://dx.doi.org/10.1126/sciadv.1701345.

Ferreira Júnior, W. G., Schaefer, C. E. G. R., & Silva, A. D. (2012). Uma visão pedogeomorfológica sobre as formações florestais da Mata Atlântica. *Ecologia de Florestas Tropicais do Brasil*, *2*, 141-174.

Fırıncıoğlu, H. K., Ünal, S., Erbektaş, E., & Doğruyol, L. (2010). Relationships between seed yield and yield components in common vetch (*Vicia sativa* ssp. *sativa*) populations sown in spring and autumn in central Turkey. *Field Crops Research*, *116*(1-2), 30-37. http://dx.doi.org/10.1016/j.fcr.2009.11.005.

Fridley, J. D., & Wright, J. P. (2018). Temperature accelerates the rate fields become forests. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(18), 4702-4706. PMid:29666251. http://dx.doi.org/10.1073/pnas.1716665115.

Fu, G., & Shen, Z. X. (2017). Effects of enhanced UV-B radiation on plant physiology and growth on the Tibetan Plateau: a meta-analysis. *Acta Physiologiae Plantarum*, *39*(3), 1-9. http://dx.doi.org/10.1007/s11738-017-2387-8.

Fyllas, N. M., Bentley, L. P., Shenkin, A., Asner, G. P., Atkin, O. K., Díaz, S., Enquist, B. J., Farfan-Rios, W., Gloor, E., Guerrieri, R., Huasco, W. H., Ishida, Y., Martin, R. E., Meir, P., Phillips, O., Salinas, N., Silman, M., Weerasinghe, L. K., Zaragoza-Castells, J., & Malhi, Y. (2017). Solar radiation and functional traits explain the decline of forest primary productivity along a tropical elevation gradient. *Ecology Letters*, *20*(6), 730-740. PMid:28464375. http://dx.doi.org/10.1111/ele.12771.

Higuchi, N., Chambers, J. Q., Silva, R. P. D., Miranda, E. V. D., Santos, J. D., Iida, S., Rocha, R. M., Pinto, A. C. M., & Souza, C. A. S. D. (2003). *Uso de bandas metálicas e dendrômetros automáticos para a definição de padrão de crescimento individual das principais espécies arbóreas da floresta primária da região de Manaus, Amazonas, Brasil* (Projeto Jacaranda Fase II: Pesquisas Florestais na Amazônia Central, pp. 55-68). Manaus: INPA.

Holl, K. D., & Aide, T. M. (2011). When and where to actively restore ecosystems? *Forest Ecology and Management*, *261*(10), 1558-1563. http://dx.doi.org/10.1016/j.foreco.2010.07.004.

Jacoby, G. C. (1989). Overview of tree-ring analysis in tropical regions. *IAWA Journal*, *10*(2), 99-108. http://dx.doi.org/10.1163/22941932-90000478.

Kanieski, M. R., Galvão, F., Longhi-Santos, T., Milani, J. E. D. F., & Botosso, P. C. (2017). Parâmetros climáticos e incremento diamétrico de espécies florestais em Floresta Aluvial no Sul do Brasil. *Floresta e Ambiente*, *24*, 24. http://dx.doi.org/10.1590/2179-8087.124814.

Landsberg, J. J., Sands, P. J., Landsberg, J., & Sands, P. (2011). *Physiological ecology of forest production: principles, processes and models* (Vol. 4). London: Elsevier/Academic Press.

Li, X., Wen, Y., Zhang, J., Liu, L., Jin, L., Yan, T., & Wang, Y. (2018). The effect of low-temperature event on the survival and growth of *Juglans mandshurica* seedlings within forest gaps. *Journal of Forestry Research*, *29*(4), 943-951. http://dx.doi.org/10.1007/s11676-017-0520-6.

Luo, Y., Tang, H. & Zhang, Y. (2007). Effect of low temperature stress on activities of SOD and enzymes of ascorbate-glutathione cycle. *Yuan Yi Xue Bao*, *34*(6), 1405.

Machado, S. D. A., Zamin, N. T., Nascimento, R. G. M., & Santos, A. A. P. D. (2014). Efeito de variáveis climáticas no crescimento mensal de *Pinus taeda* e *Araucaria angustifolia* em fase juvenil. *Floresta e Ambiente*, *21*(2), 170-181. http://dx.doi.org/10.4322/floram.2014.015.

Malhi, Y., Girardin, C. A. J., Goldsmith, G. R., Doughty, C. E., Salinas, N., Metcalfe, D. B., Huaraca Huasco, W., Silva-Espejo, J. E., Aguilla-Pasquell, J., Farfán Amézquita, F., Aragão, L. E. O. C., Guerrieri, R., Ishida, F. Y., Bahar, N. H. A., Farfan-Rios, W., Phillips, O. L., Meir, P., & Silman, M. (2017). The variation of productivity and its allocation along a tropical elevation gradient: a whole carbon budget perspective. *The New Phytologist*, *214*(3), 1019-1032. PMid:27768811. http://dx.doi.org/10.1111/nph.14189.

Maria, V. R. B. (2002). *Estudo da periodicidade do crescimento, fenologia e relação com a atividade cambial de espécies arbóreas tropicais de Florestas Estacionais Semideciduais* (Doctoral dissertation). Universidade de São Paulo, Piracicaba. http://dx.doi.org/10.11606/D.11.2002.tde-21082002-141838.

Martinkoski, L., Vogel, G. F., & Jadoski, S. O. (2015). Influência do clima no crescimento diamétrico de *Araucaria angustifolia*: revisão bibliográfica. *Revista Brasileira de Tecnologia Aplicada nas Ciências Agrárias*, *8*(2), 104-111.

Morais Júnior, V. T. M., Jacovine, L. A. G., Torres, C. M. M. E., Alves, E. B. B. M., Paiva, H. N., Alcantara-de la Cruz, R., & Zanuncio, J. C. (2019). Early assessment of tree species with potential for carbon offset plantations in degraded area from the southeastern Brazil. *Ecological Indicators*, *98*, 854-860. http://dx.doi.org/10.1016/j.ecolind.2018.12.004.

Moran, E. V., Das, A. J., Keeley, J. E., & Stephenson, N. L. (2019). Negative impacts of summer heat on Sierra Nevada tree seedlings. *Ecosphere*, *10*(6), e02776. http://dx.doi.org/10.1002/ecs2.2776.

O'Brien, M. J., Ong, R., & Reynolds, G. (2017). Intra-annual plasticity of growth mediates drought resilience over multiple years in tropical seedling communities. *Global Change Biology*, *23*(10), 4235-4244. PMid:28192618. http://dx.doi.org/10.1111/gcb.13658.

Oliveira, R. E., & Engel, V. L. (2017). A restauração florestal na Mata Atlântica: três décadas em revisão. *Revista Ciência, Tecnologia & Ambiente*, *5*(1), 40-48. http://dx.doi.org/10.4322/2359-6643.05101.

Prodan, M. (1997). *Mensura forestal* (No. 1). San José: Agroamerica.

Sage, R. F., & Kubien, D. S. (2007). The temperature response of C3 and C4 photosynthesis. *Plant, Cell & Environment*, *30*(9), 1086-1106. PMid:17661749. http://dx.doi.org/10.1111/j.1365-3040.2007.01682.x.

Shimamoto, C. Y., Botosso, P. C., Amano, E., & Marques, M. C. (2016). Stem growth rhythms in trees of a tropical rainforest in Southern Brazil. *Trees*, *30*(1), 99-111. http://dx.doi.org/10.1007/s00468-015-1279-z.

Silveira, S. B., Neves, E. J. M., Carpanezzi, A. A., & Britez, R. M. (2013). Avaliação silvicultural de *Rapanea ferruginea* e *Citharexylum myrianthum* plantadas em pastagens abandonadas. *Pesquisa Florestal Brasileira*, *33*(73), 99-102. http://dx.doi.org/10.4336/2013.pfb.33.73.410.

Slot, M., & Winter, K. (2017). Photosynthetic acclimation to warming in tropical forest tree seedlings. *Journal of Experimental Botany*, *68*(9), 2275-2284. PMid:28453647. http://dx.doi.org/10.1093/jxb/erx071.

Tan, J. (2013). Physiological and biochemical responses of *Pinus massoniana* superior provenance seedlings under artificial low temperature stress. *Linye Kexue*, *49*(3), 51-55.

Uriarte, M., Muscarella, R., & Zimmerman, J. K. (2018). Environmental heterogeneity and biotic interactions mediate climate impacts on tropical forest regeneration. *Global Change Biology*, *24*(2), e692-e704. PMid:29194879. http://dx.doi.org/10.1111/gcb.14000.

van de Weg, M. J., Meir, P., Williams, M., Girardin, C., Malhi, Y., Silva-Espejo, J., & Grace, J. (2014). Gross primary productivity of a high elevation tropical montane cloud forest. *Ecosystems (New York, N.Y.)*, *17*(5), 751-764. http://dx.doi.org/10.1007/s10021-014-9758-4.

Verdaguer, D., Jansen, M. A., Llorens, L., Morales, L. O., & Neugart, S. (2017). UV-A radiation effects on higher plants: exploring the known unknown. *Plant Science*, *255*, 72-81. PMid:28131343. http://dx.doi.org/10.1016/j.plantsci.2016.11.014.

Wang, J., Hui, D., Lu, H., Wang, F., Liu, N., Sun, Z., & Ren, H. (2019). Main and interactive effects of increased precipitation and nitrogen addition on growth, morphology, and nutrition of *Cinnamomum burmanni* seedlings in a tropical forest. *Global Ecology and Conservation*, *20*, e00734. http://dx.doi.org/10.1016/j.gecco.2019.e00734.

Wang, N., Wu, J., Xia, P., & Su, J. (2011). Physiological responses of *Ilex latifolia* to low temperature and its cold tolerance. *Journal of South China Agricultural University*, *32*(3), 82-86.

Worbes, M. (1999). Annual growth rings, rainfall-dependent growth and long-term growth patterns of tropical trees from the Caparo Forest Reserve in Venezuela. *Journal of Ecology*, *87*(3), 391-403. http://dx.doi.org/10.1046/j.1365-2745.1999.00361.x.

Zhou, Q., Wang, J. Z., & Chen, X. H. (2010). Effect of durative low temperature on morphological and physiological characteristics of cucumber seedling. *Beifang Yuanyi*, *16*, 1-3.

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