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AGROCLIMATIC SUITABILITY FOR *Eucalyptus urophylla IN THE* STATE OF TOCANTINS, CONSIDERING DIFFERENT CAPACITIES OF AVAILABLE WATER IN THE SOIL

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ABSTRACT
The objective of this study was to evaluate the agroclimatic suitability of Eucalyptus urophylla in the state of Tocantins, Brazil, considering different capacities of available water in the soil (CAD): 100 mm, 150 mm and 220 mm. The climatological water balance was used by the Thornthwaite-Mather method, with temperature and precipitation data spatialized via Spline interpolation in the ArcGIS 10.1 software. The areas were classified based on the climatic requirements of the species and the annual water deficit values calculated for each CAD in suitability classes: suitable, marginal, restricted and unsuitable. It was observed that, with the increase in the CAD, there was a reduction in the water deficit and expansion of the suitable class, from 0.29% (CAD = 100 mm) to 4.26% (CAD = 220 mm) of the area of the State, concentrated in the North and Northwest regions, where clayey soils predominate. The marginal class was predominant in all conditions, ranging from 53.7% to 50.12% of the territory. The results reinforce the importance of planning based on edaphoclimatic characteristics, especially for regions with sandy soils or low water retention. This agroclimatic zoning can support decisions for the sustainable expansion of E. urophylla cultivation in Tocantins, contributing to efficient forest management and increased productivity in challenging conditions.

Keywords: Water balance, Forest plantation, Geographic information system, Agroclimatic zoning.

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INTRODUCTION

Planted forests play a crucial role as strategic economic activities for the country, offering several benefits. Among them, the reduction of pressure on native forests, the recovery of lands degraded by agriculture, carbon capture, and the preservation of soil and water, among other aspects, stand out (SNIF, 2015). They can be used for both reforestation and energy production. The so-called energy forests are planned with the objective of maximizing biomass production per unit area in a reduced period (INSTITUTO DE ENERGIA E AMBIENTE, 2019).

The growing global demand for wood has been driven by population growth, rising incomes, international cooperation and efforts to mitigate greenhouse gas emissions, which is relevant in relation to the global climate crisis. Projections indicate that the consumption of wood for industrial and energy purposes may grow between 46% and 66% by 2070, compared to 2015, requiring the planting of millions of additional hectares of eucalyptus in the world (NEPAL et al., 2019).

The adoption of products from planted forests for energy purposes, such as those of the *Eucalyptus* genus, offers a sustainable alternative to materials originating from fossil sources. Charcoal, for example, is widely used in the steel industry, while biomass is a viable option for energy generation, replacing both coal and fuel oil (IBÁ, 2017). In this context, *Eucalyptus* is the most commercially prominent exotic forest genus in the country, covering 76% of the total area of planted forests, equivalent to 7.8 million hectares in 2023 (IBÁ, 2024).

Eucalyptus is native to Australia, Tasmania and other islands in Oceania, with more than 700 botanically recognized species (PINTO JÚNIOR; SANTAROSA; GOULART, 2014; THORNHILL et al., 2019). Its characteristics, such as species diversity and climate adaptation, highlight it as an important source of raw material for various industries, including pulp, paper, coal, essential oils, wood, and biofuels (MAGALHÃES et al., 2017; SCANAVACA JÚNIOR; GARCIA, 2023).

Among the most prominent species is *Eucalyptus urophylla*, with good adaptability to different climatic and soil conditions. The species is widely used in reforestation programs due to its resistance to diseases such as eucalyptus canker (*Cryphonectria cubensis*) and rust (*Puccinia psidii*), fast growth and high productive potential (PUPIN et al., 2015).

The expansion of eucalyptus plantations in the country has been observed, where new planting areas are being included in the Midwest, North and Northeast regions,

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reinforcing the need for studies on agroclimatic suitability in these regions. In Tocantins, the planted area of eucalyptus reached 146 thousand hectares in 2017, and in 2023 there was a reduction to 94 thousand hectares, equivalent to 35.6% (IBGE, 2023). The state of Tocantins, although it does not have a steel park, has been a producer of charcoal, and there is a significant opportunity that can be explored with the improvement of the national scenario, especially in relation to the demand and prices of the product. The northern region of the state stands out, as it is favored by the availability of legally regulated land, by the existence of regional eucalyptus plantations, and especially by the proximity of the steel mills in operation in the eastern regions of Pará and southern Maranhão (DUARTE; COLLICCHIO, 2020).

Although eucalyptus adapts well to different environmental conditions, information on the climate and soil is essential to identify the most suitable areas for its cultivation and agricultural mechanization. In this sense, agroclimatic zoning is a strategic tool in the decision-making process, enabling the definition of regions with better climatic aptitude for agricultural and forestry activities (PEREIRA; ANGELOCCI; SENTELHAS, 2002; RIBEIRO, 2009; ARAÚJO; MATRICARDI; NAPPO, 2012; BRUNINI; CARVALHO, 2018). This method contributes to maximizing the return on investments of producers, promoting a more efficient, productive and sustainable forest plantation (HIGA; WREGE, 2009).

The climatological water balance is widely used to assess agricultural suitability, determining the availability of water in the soil based on the available water capacity (CAD). Previous studies indicate that CAD varies between 150 and 300 mm for forest species, depending on the age of the plants and soil conditions (PEREIRA; ANGELOCCI; SENTELHAS, 2002; SOUZA et al., 2006). In the case of *E. urophylla*, understanding the climatic and water limits is essential to define management strategies and expand cultivation to new regions.

In this context, the objective of this work was to develop an agroclimatic zoning for *E. urophylla* in Tocantins, considering different capacities of water available in the soil, in order to guide planning and maximize the productive potential of the species.

METHODOLOGY

The study area of the present work covers the entire State of Tocantins, with an estimated population of 1,577,342 inhabitants (IBGE, 2024), being located in the Northern region of Brazil, with an area of 277,423.627 km². It borders the states of Maranhão to the

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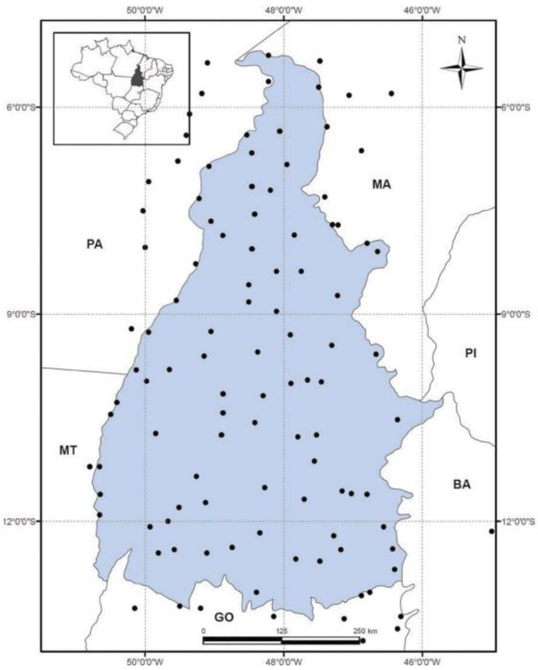
north; Piauí and Bahia to the east; Goiás to the south and Mato Grosso and Pará to the west. To carry out this study, we used the database organized by the team of collaborators of the Laboratory of Agroenergy, Land Use and Environmental Change of the Federal University of Tocantins – UFT/LAMAM, and expanded by the work of Souza et al. (2024), containing the meteorological parameters: precipitation (mm) and air temperature (ºC), with monthly and annual values of 110 meteorological and/or rainfall stations, located in the study area and surrounding regions (Figure 1).

Figure 1 – Location of the State of Tocantins and distribution of meteorological and rainfall stations in the State and its surroundings



The climatological water balance was calculated using the Thorthwaite-Mather method simplified by Pereira (2005), since the model only needs data on precipitation, average monthly temperature and Available Storage Capacity (CAD). The methodology adapted by Sperandio et al. (2010) was used, considering three different values for the available water capacity (CAD): 100 mm (Low water retention capacity), 150 mm (Medium water retention capacity) and 220 mm for high water retention capacity.

According to Sperandio et al. (2010), the general agroclimatic requirements for the species are: a) Average annual air temperature between 19 ºC and 26 ºC; b) Average annual water deficit between 30 and 210 mm; and c) Annual rainfall between 900 mm and 1800 mm.

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According to the methodology recommended by Nappo; Nappo; Paiva (2005) is used by Souza et al. (2015a), Souza et al. (2015b) and Collicchio; Lee; Macolini (2019) for the state of Tocantins, the data were spatialized using the ArcGis 10.1 (ESRI) software, through the Spline interpolation method.

Based on the products generated, the results were classified and the final maps of the agroclimatic suitability zoning were prepared for each of the three CADs, homogeneous suitability zones were generated, classified as: a) Suitable; b) Marginal; c) Restricted and d) Unsuitable for the cultivation of the species, as shown in Table 1.

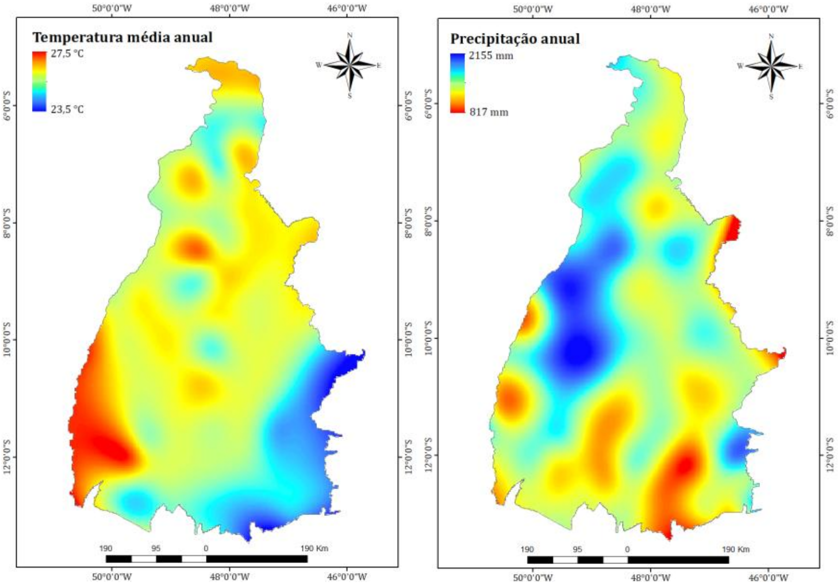
Table 1 – Suitability classes of *E. urophylla* referring to agroclimatic requirements

Aptitude Class	**Conditions**		
	Average annual temperature (T)	**Annual water deficit (AD)**	**Annual Rainfall (P)**
Able	19°C < T < 26°C	30 mm < Da < 210 mm	900 mm < P < 1800 mm
Marginal	It occurred in areas where only one variable (T, Da or P) did not meet the climatic requirements of the species		
Restricted	It occurred in areas where only one variable (T, Da or P) met the climatic requirements of the species		
Unfit	T < 19°C ou T > 26 °C	From < 30 mmouFrom > 210 mm	P < 900 mmouP > 1800 mm

RESULTS AND DISCUSSION

The thematic maps of annual precipitation and average annual temperature in the region of the State of Tocantins are represented in Figure 2. Based on the database of meteorological and/or rainfall stations, it is possible to observe that the average annual temperature of the state of Tocantins varies from 23.5 °C to 27.5 °C, with its highest temperature in the southwest of the state.

Figure 2 – Spatialization of the average annual temperature (°C) and annual precipitation (mm) in the State of Tocantins

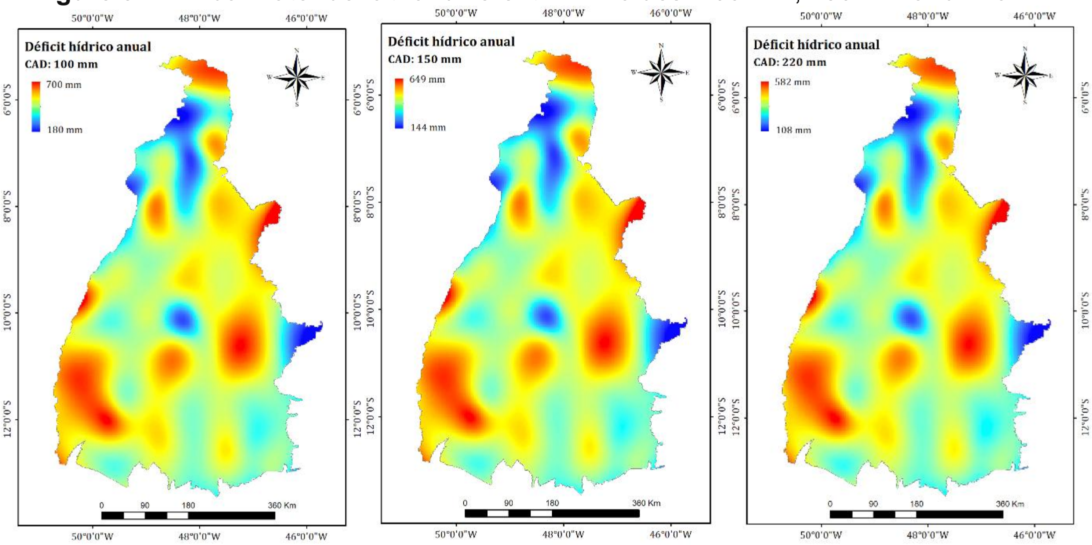


Annual rainfall ranges from 817 mm to 2155 mm, with the highest values in the Midwest and the lowest located in the Southeast region. Despite the existence of regions with more extreme records in terms of temperature and precipitation factors, the state presents a certain homogeneity with a smaller variation of these parameters in the other areas of Tocantins.

It can be seen that the average annual temperature and precipitation indices of Tocantins, in general, are aligned with the agroclimatic requirements of *E. urophylla*.

The annual water deficit for the different types of CAD can be seen in Figure 3. With the increase in CAD, the values of annual water deficit decrease.

Figure 3 – Annual water deficit for different DKA values: 100 mm, 150 mm and 220 mm



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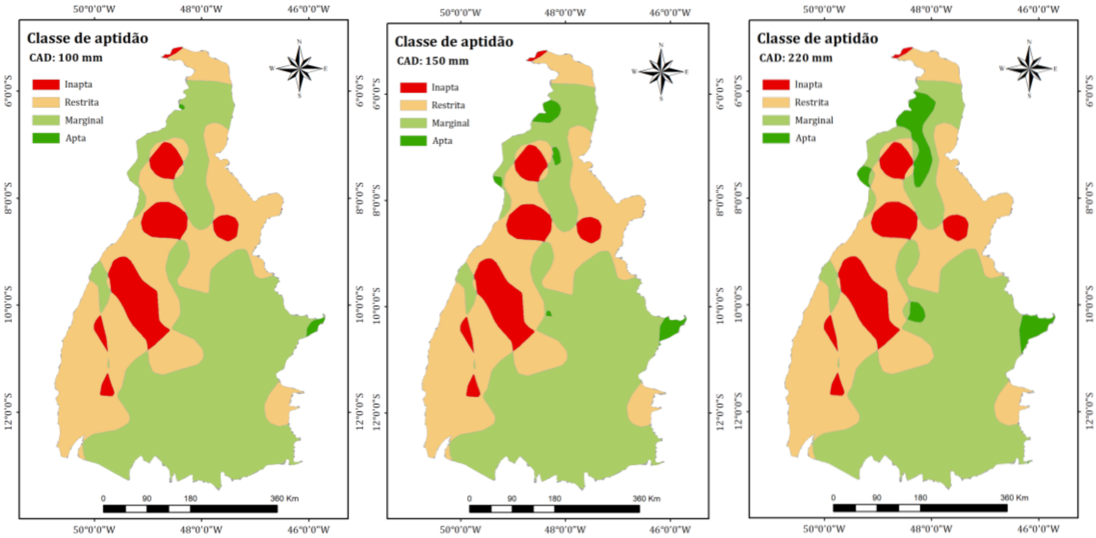
In CAD 100 mm, the maximum water deficit value is 700 mm, while in CAD 220 mm, the maximum value is 582 mm, with a difference of 118 mm from one to the other. Water deficit is directly related to CAD because the greater the soil's capacity to store water, the greater the water availability for plant species and, consequently, the lower the water deficit.

According to the climatic requirements defined by Sperandio et al. (2010), the northwest, part of the east and part of the central part of the state are the ones that presented the lowest values of water deficit for the cultivation of *E. urophylla*.

Compared to the results of Souza et al. (2024), the range of annual water deficit for CAD 100 mm in Tocantins was similar, with regions of higher and lower water deficit consistent, reaching a variation of up to 100 mm in the range. This variation can be explained by the difference in the data used, as Souza et al. (2024) characterized the region with a different number of points (data) in the spatialization. These authors made estimates for the monthly mean temperature, using SRTM (Shuttle Radar Topography Mission) radar data and based on the multiple linear regression equation.

The maps containing the agroclimatic zoning for *E. urophylla in the* State of Tocantins based on the climatic variables and the three different CAD values are presented in Figure 4.

Figure 4 – Agroclimatic suitability of *E. urophylla* for CAD values: 100 mm, 150 mm and 220 mm



The areas in km² and percentages of occupation of the aptitude classes, according to the corresponding CAD, can be seen in Table 1. It can be seen that there was an increase in areas with Apta class from 0.29% (CAD 100 mm) to 4.26% (CAD 220 mm),

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especially in the regions of the State of Tocantins where the water deficit is lower, as shown in Figure 3.

Comparing the three CADs, it is noted that the Unfit and Restricted fitness classes practically did not show variation in their areas (Table 1).

Table 1 – Area (in km² and percentage) occupied in the State of Tocantins by each class of aptitude considering different types of CAD

Fitness classes	CAD 100 mm	CAD 150 mm	CAD 220 mm
Area (km²)			
Suitable	804,16	4.255,64	11.838,98
Marginal	149.323,41	145.897,78	139.384,59
Restricted	102.618,26	102.588,84	101.505,86
Unfit	25.349,26	25.349,26	25.359,09
%			
Suitable	0,29	1,53	4,26
Marginal	53,7	52,46	50,12
Restricted	36,9	36,9	36,5
Unfit	9,12	9,12	9,12

On the other hand, the Marginal class, which was predominant in the region for the three CAD values, showed a greater loss of area as there was an increase in the CAD value, from 53.7% to 50.12% of the total area of the State.

CAD values are associated with soils with certain characteristics. CAD 100 mm is associated with soils with a higher percentage of sand, CAD 150 mm with predominantly loam and silty loam soils, and CAD 220 mm with soils with a predominance of silty clay (KUMAR et al., 2021).

Pintosols and Latosols are considered the predominant soils in the State of Tocantins, occurring in all regions of the State. The Ultisols cover extensions of the northwestern area and also areas not very extensive in the south and west. In the central and southern areas, Cambisols are found and Quartzarenic Neosols are predominantly distributed in the center and east of the State (COLLICCHIO et al., 2022).

In the study by Lopes et al. (2024), which addressed the agroclimatic zoning of *E. urophylla in the* MATOPIBA region using CAD of 100 and 150 mm, a higher percentage of suitable areas in the region was identified, however, most of these areas are not located in the state of Tocantins. Considering the 100 mm CAD, there was a predominance of areas classified as restricted in the state, while with the 150 mm CAD, there was an increase in areas classified as marginal.

As shown in Table 1, the growth of the area of the class considered Apta, is related to the increase of the CAD, it can be noted that for the conditions of precipitation and temperature of the State of Tocantins, the soil characteristic is a fundamental part in determining the value of the water deficit and, consequently, the suitability of cultivation of *E. urophylla* in the State.

The importance of the soil can be observed because in one of the regions where the agroclimatic zoning suitability class was considered suitable, in the north/northwest region of Tocantins, there is a large presence of Ultisol soils that have a predominantly medium to clayey texture, having characteristics compatible with CAD 220 mm, being favorable to the cultivation of the species.

CONCLUSION

Agroclimatic aptitude zoning can support decisions for the sustainable expansion of *E. urophylla* cultivation in Tocantins, contributing to efficient forest management and increased productivity under challenging conditions.

Most of Tocantins has Marginal and Restricted suitability classes, which can hinder the cultivation of this species, especially the lower the value of water capacity available for the region.

It is noteworthy that the results obtained were based on the agroclimatic requirements of the species, without considering the details of the form of cultivation, possible interventions and use of complementary irrigation.

One of the alternatives available to increase the aptitude of the region in the face of the conditions observed in the study refers to soil management so that there is an increase in the water storage capacity in the soil, in addition to the development of studies to adapt the crop to the climatic and soil conditions prevailing in the State of Tocantins.

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