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Articles

Agroclimatic aptitude of *Eucalyptus urophylla* for the Matopiba region

Aptidão Agroclimática do *Eucalyptus urophylla* para a região do Matopiba

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ABSTRACT

This work aimed to identify areas of agroclimatic aptitude for *Eucalyptus urophylla* cultivation in MATOPIBA. The agroclimatic aptitude classes for the species were determined considering the temperature and water needs, being adopted three different values of available water capacity (AWC), using a geographic information system (GIS). The agroclimatic aptitude classes for all AWCs analyzed identified the existence of full cultivation in some regions but with a predominance of restricted areas. The fit zones predominated in the mountainous regions of Bahia, southern Maranhão and northwest of Tocantins. There was a percentage increase in the aptitude area favorable for *E. urophylla* (apt) cultivation, from 7.68% to 29.13%, considering the AWC values of 100 and 220 mm, respectively.

Keywords: Agroclimatic zoning; Hydric balance; Agricultural border

RESUMO

O presente trabalho teve como objetivo identificar áreas de aptidão agroclimática para o cultivo do *Eucalyptus urophylla* no MATOPIBA. As classes de aptidão agroclimática para a espécie foram determinadas considerando as necessidades de temperatura e hídrica, sendo adotadas três diferentes valores de Capacidade de Água Disponível - CAD, utilizando um Sistema de Informações Geográficas - SIG. As classes de aptidão agroclimática para todos os CADs analisados identificaram a existência de pleno cultivo em algumas regiões, porém com predomínio de áreas restritas. As zonas aptas predominaram nas regiões serranas da Bahia, sul do Maranhão e noroeste do Tocantins. Observou-se um incremento percentual da área de aptidão favorável ao cultivo do *E. urophylla* (apta), de 7,68% para 29,13%, considerando os CADs de valores 100 e 220 mm, respectivamente.

Palavras-chave: Zoneamento agroclimático; Balanço hídrico; Fronteira agrícola

1 INTRODUCTION

Brazil is considered a world leader in the use of conventional sources of renewable energy and has an abundance of these natural resources, which include hydraulics, firewood, charcoal, sugarcane biomass, bleach and other primary sources that comprise 45.3% of the internal energy supply, with 8.4% of it represented by firewood and coal (Bondarik; Pilatti; Horst, 2018; BRASIL, 2019).

In the 2021 energy balance referring to the base year 2020, charcoal corresponded to 1.6% of final consumption by source in the country when expressed in equivalent tons of oil. Brazilian annual production of this bioenergy was 6.2 million tons, of which 5.3 million tons are directed to the industrial sector (Ben, 2021).

It is well known that Brazil has a high demand for the exploitation of renewable energy. It is no different in the north of the country (Piacentini, 2016; CETESB, 2016); however, firewood extraction has been carried out inappropriately, affecting the biomes (Gioda, 2019). This occurs due to the lack of technical criteria in the exploitation of that raw material, such as insufficient monitoring, low supervision, and illegal deforestation that has had a significant impact, accelerating the destruction of forests and the ecosystem (Travassos; Souza, 2014; Wilcox-Moore *et al*., 2011; Ndagijimana; Pareyn; Riegelhaulpt, 2015). The author Gioda (2019) also highlights that 97% of the firewood used for energy consumption comes from native forests, and only 3% comes from reforestation.

Therefore, aiming to minimize deforestation, Brazilian forestry has been encouraged, mainly the production and commercialization of eucalyptus wood (*Eucalyptus urophylla*), which is among the most planted in Brazil, with great potential for cultivation in the North and Northeast regions, where forestry plantations are expanding (Scanavaca Junior; Garcia, 2003; Freitas *et al*., 2013). The *Anuário Brasileiro da Silvicultura* [Brazilian Forestry and Timber Yearbook 2016 (2021) cites an increase in the eucalyptus planted area in the states of Bahia, Maranhão, Tocantins, and Piauí, reaching 978,449 hectares, 1.5% more than in the previous one.

However, due to increased eucalyptus cultivation, regardless of the environmental characteristics, the identification of areas for by-the-book implementation of forest species of commercial interest began to be questioned (Martínes *et al*., 2016). Paludzyszyn Filho and Santos (2013) emphasize the importance of knowledge of the planting area, climatic conditions, and species to be cultivated, which can avoid future losses, such as water stress (lack or excess) that can cause reductions in growth, caused by an environment in anaerobic conditions resulting from excess water, under stress conditions.

Forestry producers, therefore, must be aware of the factors above when acquiring new land. This experiment can be considered an important agricultural and environmental planning tool for the federal government and investors, as it aims to support technical and economic decisions regarding eucalyptus cultivation, since investment in eucalyptus forests has increased every year for central Brazil (Brunini; Carvalho, 2018).

Given this context, the objective is to identify areas of climatic aptitude for eucalyptus cultivation in the MATOPIBA region (an acronym that originated from the union between the initials of four states: Maranhão, Tocantins, Piauí, and Bahia), involving water balance analysis associated with the needs of culture and preparation of maps guiding the location of potential areas for culture.

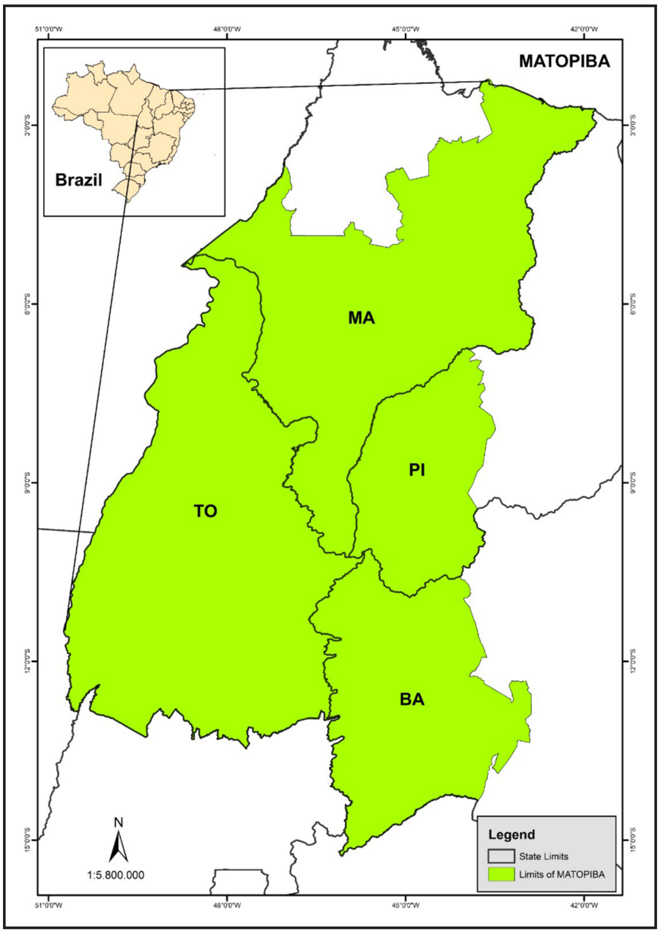
2 MATERIALS AND METHODS

2.1 Characterization of the study area

The study area is the MATOPIBA region, composed of the states of Tocantins (38%), Maranhão (33%), Bahia (18%) and Piauí (11%), which is located in the Northern and Northeastern region of Brazil, with a total area of 73,173,485 ha, containing 337 municipalities and a population of 5,901,789 inhabitants (Miranda; Magalhães; Carvalho, 2015; Brasil, 2015).

The geographical situation of the MATOPIBA region is defined by the following geographical limits: at Latitudes 2°12'30"S, in the extreme north: north of Maranhão/ Atlantic Ocean, 15°16'30"S, in the extreme south: border of the state of Tocantins/ Goiás and at Longitudes 41°48'30"W, in the extreme east: part of the state of Bahia and the state of Piauí and 50°45'10"W, in the extreme west: state of Pará and part of the state of Maranhão. Figure 1 shows the location of the region.

Figure 1 – Location of the MATOPIBA region and its neighbors

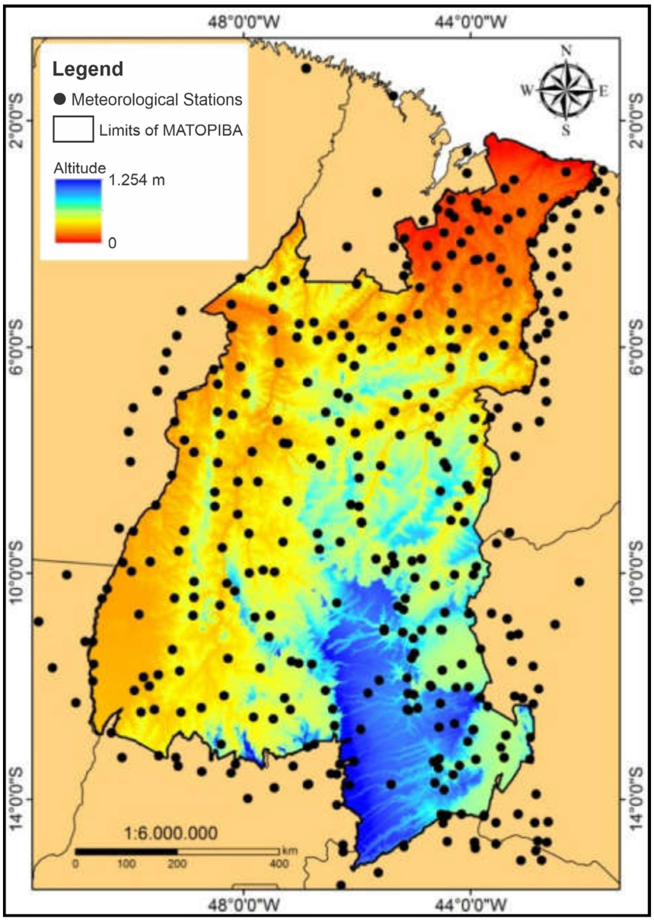


Source: Authors (2020)

This investigation included climatic data from 378 meteorological and rainfall stations in the study area, 110 stations corresponding to the state of Tocantins and surrounding states, organized by Collicchio (2008). Complementary data covering the other states in the MATOPIBA region, considering historical series covering the period from 1982 to 2000, were obtained through the database made available by Embrapa, collected from the Agência Nacional de Águas [National Water Agency] (ANA, 2016), and organized by Souza (2017).

Monthly average temperature data corresponds to 38 meteorological stations organized by Medeiros *et al*. (2005) from INMET, and refer to the *Normais Climatológicas do Brasil* [Climatological Normals of Brazil] (1961 – 1990) (INMET, 1992). Thus, the study area comprises 378 meteorological and rainfall stations, as shown in Figure 2.

Figure 2 – Spatialization of meteorological stations located in the MATOPIBA region



Source: Souza (2017)

The maps containing the average monthly air temperatures were obtained using the model proposed by Santos *et al.* (2015), which uses multiple linear regression to estimate the average monthly air temperature, applied to a digital elevation model

(DEM) of the region, obtained through SRTM (Shuttle Radar Topography Mission) radar data with a resolution of 90m, as shown in the Equation (1) below:

$$T = \beta_0 + \beta_1 Y + \beta_2 X + \beta_3 ALT \quad (1)$$

where: T = air temperature (°C); β_0 = regression constant; Y= Latitude (decimal degrees); X= Longitude (decimal degrees); ALT= altitude (m) and β_1, β_2 and β_3 =regression coefficients for variables Y, X, and ALT.

The program used to calculate the elements of the climatic water balance (CWB) spatially was developed by Victoria (2007). To spatialize the average temperature and precipitation data entered through the spreadsheet in the CWB program, the values were interpolated using the tension spline method.

The CWB program was calculated according to the Thornthwaite and Mather (1955) method, simplified by Pereira, Angelocci and Sentelhas (2002) since the model only requires data on precipitation, average monthly temperature and available water capacity (AWC).

In the climate aptitude zoning for the *E. urophylla*, this study adopted, in the calculation of the climatological water balance, according to Pereira (2005), the methodology adapted by Sperandio *et al.* (2010), considering three different AWCs in the water balance calculation. Thus, we obtained three scenarios for water deficit (period in which precipitation is lower than the evapotranspiration of plants in a given period), being: AWC = 100 mm (low water retention capacity), AWC = 150 mm (medium water retention capacity) and AWC = 220 mm (high water retention capacity).

In this way, for the agroclimatic zoning, we used the same parameters employed by Flores *et al*. (2016), presented in Table 1.

Table 1 – Thermal and water requirements for the species *Eucalyptus urophylla*

Temperature (ºC)	Aptitude classes	Rainfall (mm)	Aptitude classes
< 16	Inapt	< 900	Restricted
16 – 27	Apt	900 - 2,000	Apt
> 27	Inapt	>2,000	Marginal

Source: Flores *et al*. (2016)

Based on Loureiro Júnior *et al.* (2015), among other authors who analyzed eucalyptus productivity in relation to water deficit in different regions of the country, we adapted the parameters (Table 2) of annual water deficit to the species' needs for the present study.

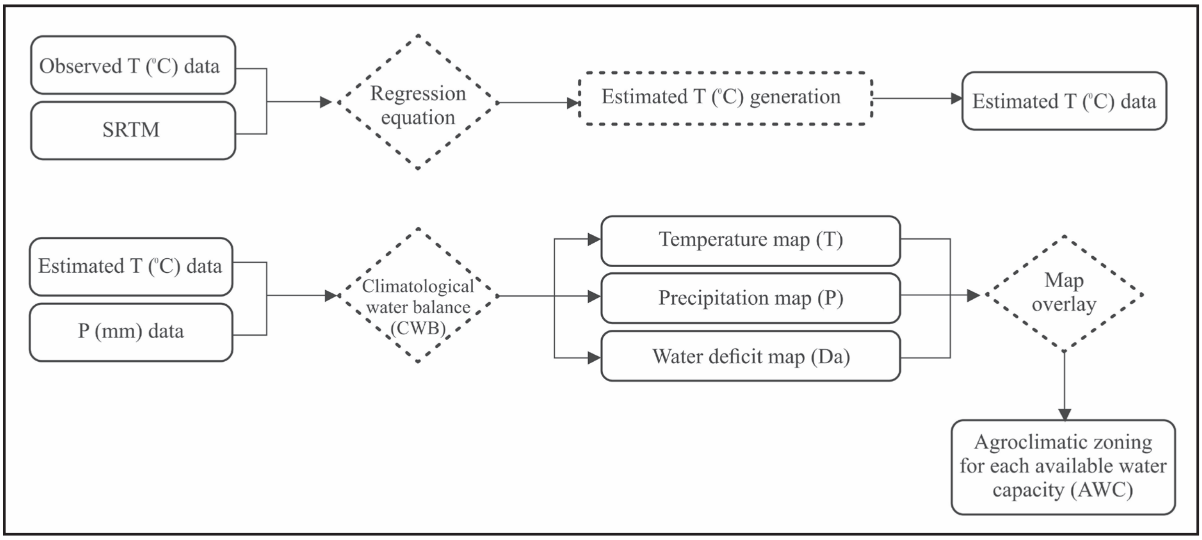
Table 2 – Water requirements based on average crop productivity of the *Eucalyptus*

Productivity potential	Productivity (m^3/ha/year)	Deficit (mm)	Aptitude classes
High	> 35	30 - 250	Apt
Medium	25 – 35	250 - 350	Marginal
Low	< 25	> 350	Restricted

Source: Adapted from Loureiro Junior *et al*. (2015)

From the maps of temperature, average annual precipitation, and annual water deficit, aptitude classes were classified into apt, marginal, restricted, and inapt for cultivation.

Figure 3 – Flowchart of procedures for agroclimate zoning for *Eucalyptus urophylla* crop cultivation in the MATOPIBA region



Source: Authors (2020)

3 RESULTS AND DISCUSSIONS

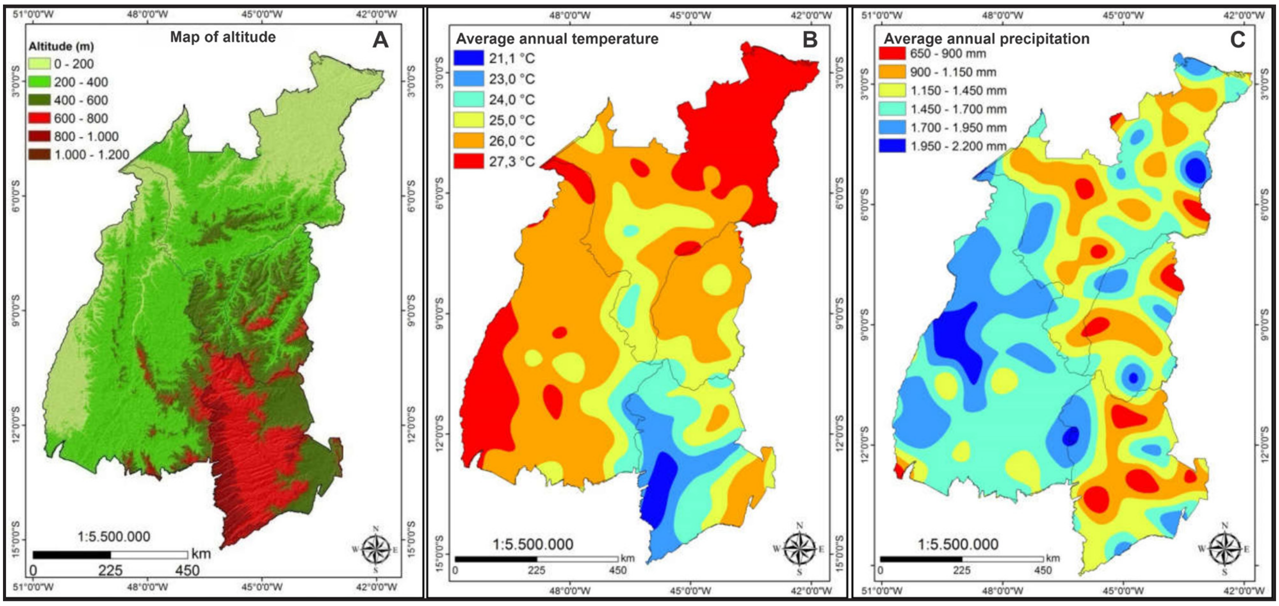
3.1 Current weather conditions

Maps of altitude, average annual temperature, and average annual precipitation in the MATOPIBA region are shown in Figure 4.

From the mosaic of SRTM images, the altitude varies from 1 to 1254 m, predominating areas with heights of up to 600 m (Figure 4A).

The regions with predominant inclined and mountainous areas occur to the south, southeast and east of the MATOPIBA region, more precisely in Bahia. The highest classes of 1,000 to 1,254 m are located to the southwest of the territorial limit of Bahia. The extreme north of Maranhão and the west of Tocantins are regions with lower altitudes and the highest temperatures.

Figure 4 – Altitude classes in meters (A); Average annual temperature in °C (B); Total annual precipitation in mm in the MATOPIBA region (C)



Source: Authors (2020)

Borges, Leite and Leite (2018) report that *E. urophylla* develops best at altitudes ranging from 450 to 1,050 meters, depending on its origin. Figure 4A reveals that the lowest heights (up to 200 m) are generally found in the plain of the Araguaia River (Tocantins) and the northeastern part of MATOPIBA (part of Maranhão). Bôas; Max (2009) state that the *E. urophylla* grows well at low altitudes, with large trees with a straight trunk, reaching up to 50 m in height; at high altitudes, they are small and crooked. The author Marcolini (2015) also highlights that this area is rich in hidric resources and soil with good agricultural aptitude (very deep, porous, and well-permeable soils).

The average annual temperature of the MATOPIBA region determined by the model (Figure 4B) is approximately 24.3°C, varying from 21.1 to 27.3°C, presenting a thermal amplitude close to 6.2°C. According to Sperandio *et al.* (2010), the temperature range is considered ideal for growing *E. urophylla.*

The coastal region of Maranhão and its northeastern region have higher average annual temperatures than the mountainous regions in Bahia, which stands out for its lower average annual temperatures. High temperatures are also found in the southwest and a northern portion of the state of Tocantins.

The predominant temperature in much of the study area ranges from 25 to 27°C, while the lowest temperatures (from 21.1°C) are found in the western region of the state of Bahia.

According to Wilcken *et al*. (2008), Ribeiro (2009) and Flores *et al*. (2016), there would be no restrictions regarding temperature for eucalyptus cultivation in MATOPIBA, except for regions that had an average annual temperature above 27°C, as can be seen in Figure 4B.

As for the average annual precipitation in the MATOPIBA region (Figure 4C), it is approximately 1,425 mm, with an amplitude of 1,550 mm, varying from 650 to 2,200 mm.

We can note that the most significant amounts of rain occur in the western region of Tocantins and a small portion in eastern Maranhão. The lowest precipitation is observed in the southeast regions to the center of the agricultural frontier and the center to the northeast, ranging from 650 to 1,450 in greater proportion in the states of Maranhão, Piauí, and Bahia.

3.2 Climate aptitude classes

The aptitude zones were delimited from the temperature maps, average annual precipitation, and annual water deficit. The definition of eucalyptus cultivation areas in the MATOPIBA region was classified as follows, according to Chart 1.

Chart 1 – Aptitude classes of the Eucalyptus urophylla referring to temperature conditions (T), annual water deficit (AWD) and annual precipitation (Pa)

Conditions			**Aptitude Class**
T(°C) *Inapt* (<16°C or >27°C)	Apt AWD		Inapt*
	Marginal AWD		
	Restricted AWD		
T(°C) *Apt* 16 to 27°C	Apt AWD	900< Pa < 2,000 mm	Apt
	Apt AWD	Pa > 2,000 mm	Apt*
	Apt AWD	Pa < 900 mm	Restricted **
	Marginal AWD	900< Pa < 2,000 mm	Marginal
	Marginal AWD	Pa > 2,000 mm	Marginal*
	Marginal AWD	Pa < 900 mm	Inapt
	Restricted AWD	900< AP < 2,000 mm	Restricted
	Restricted AWD	Pa > 2,000 mm	Restricted *
	Restricted AWD	Pa < 900 mm	Inapt

Source: Authors (2020)

Therefore, Chart 2 presents the description for each aptitude class for the *Eucalyptus urophylla* generated considering the different types of available water capacity - AWC.

Chart 2 – Description of the agroclimatic aptitude classes for the *Eucalyptus urophylla*

Aptitude Class	**Description**
Apt	Favorable thermal and water conditions.
Apt*	Favorable thermal and water conditions, but observing the incidence of diseases.
Marginal	Favorable thermal condition and water restriction. Apt with complementary irrigation.
Marginal*	Favorable thermal condition and water restriction. Apt for supplementary irrigation, but with due regard for the incidence of diseases.

To be continued ...

Chart 2 – Conclusion

Aptitude Class	Description
Restricted	Favorable thermal condition and accentuated water restriction. Apt with full irrigation.
Restricted *	Favorable thermal condition and accentuated water restriction. Apt with full irrigation, but with due regard for the incidence of diseases.
Restricted **	Favorable thermal and water conditions, but with observance of crop productivity due to the low amount of rain in the crop cycle.
Inapt	Favorable thermal condition and accentuated water restriction. Low amount of rain during the crop cycle.
Inapt*	Unfavorable thermal conditions for crop development.

Source: Authors (2020)

Subsequently, the nine agroclimatic aptitude classes (Chart 2) were grouped into just four classes (Chart 3) for better visualization and interpretation of the generated maps.

Chart 3 – Grouping of agroclimatic aptitude classes for the Eucalyptus urophylla

Aptitude Class	Grouped classes
Apt	Apt and Apt* Class
Marginal	Marginal and Marginal* Class
Restricted	Restricted, Restricted* and Restricted** Class
Inapt	Inapt and Inapt* Class

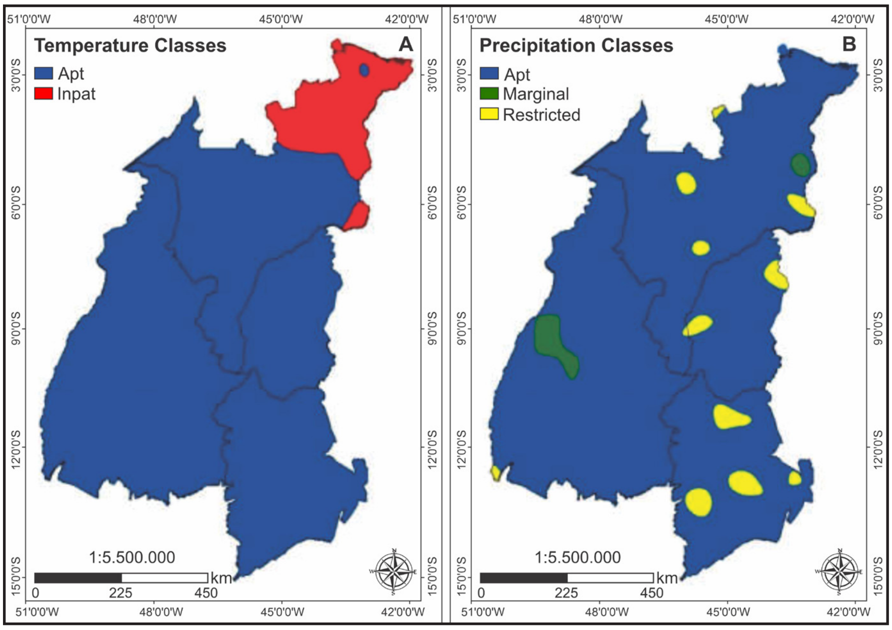
Source: Authors (2020)

3.3 Temperature and Precipitation Classes

The results for the two climate variables demonstrated in Figure 5A and Figure 5B show that, in general, the thermal and precipitation conditions are favorable to the development of the crop, due to the predominance of the “apt” class.

The “inapt” condition in the extreme north of Maranhão in Figure 5A is due to thermal conditions, with temperatures greater than 27°C in the region. Thus, Flores *et al*. (2016) stated that restrictions on cultivation may occur due to high precipitation in some regions of the agricultural frontier, considering that the maximum precipitation for the development of the species *E. urophylla* is 2,000 mm and the minimum is 900 mm.

Figure 5 – Temperature Classes (°C) (A); Precipitation (mm) in the MATOPIBA region (B)

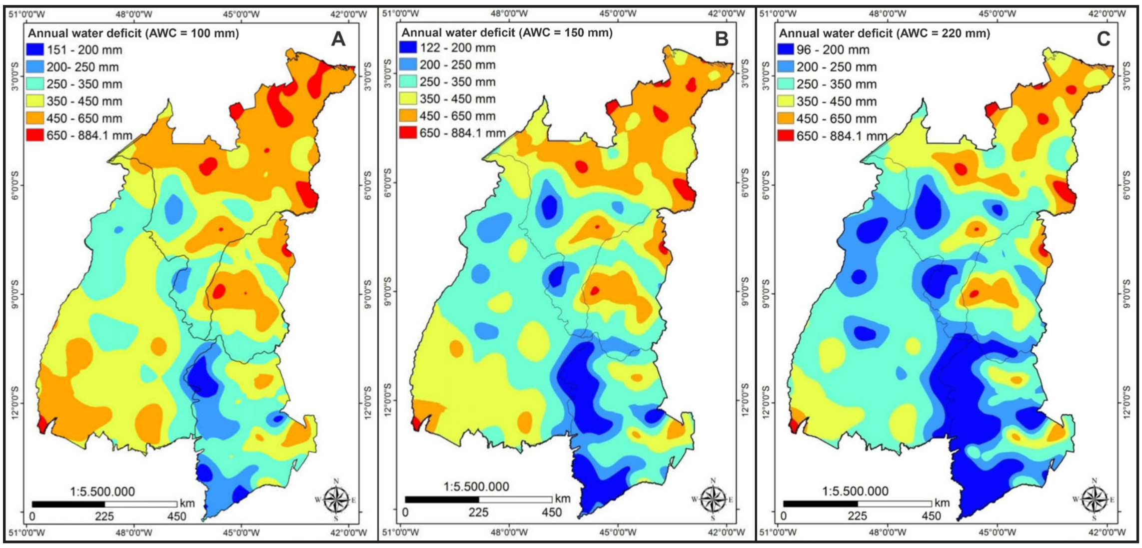


Source: Authors (2020)

3.4 Water deficit classes, considering the different AWCs

The annual water deficit for the different AWCs presented in Figure 6A, Figure 6B, and Figure 6C.

Figure 6 – Annual water deficit for AWC = 100 mm (A); Annual water deficit for AWC = 150 mm (B); Annual water deficit for AWC = 220 mm in the MATOPIBA region (C)



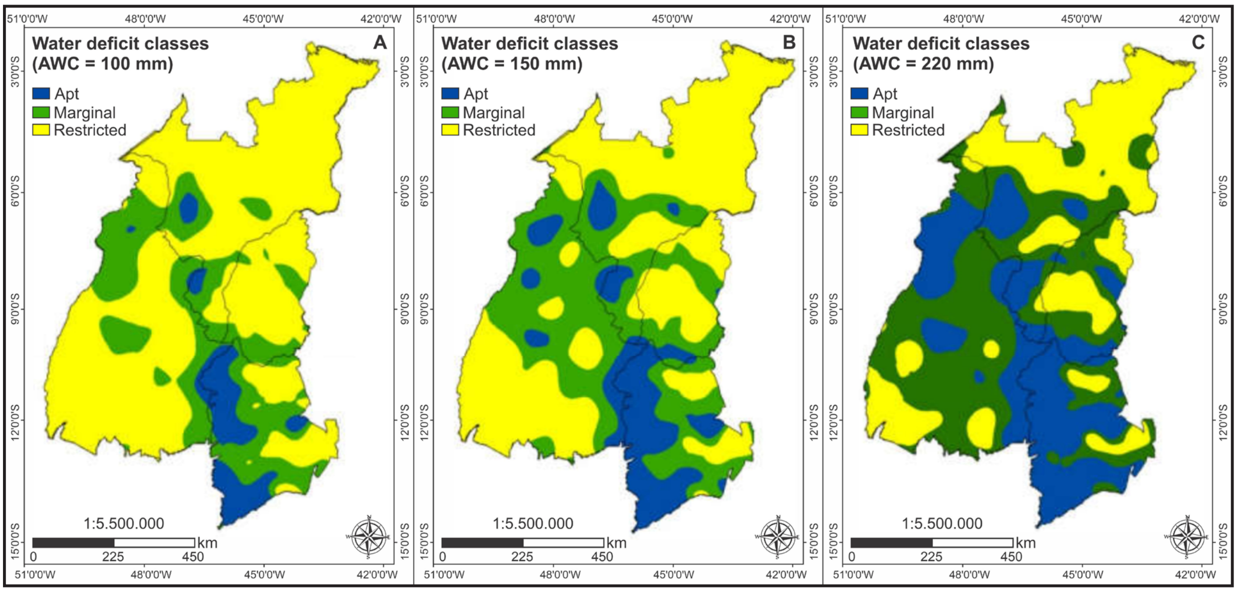
Source: Authors (2020)

The lowest water deficit values for AWC=100mm (Figure 6A) were observed in the southeastern portion of MATOPIBA (western, southern and eastern regions of Bahia) and in some portions to the south of Maranhão, which were at the limit of the favorable aptitude class (30 < Da < 250 mm), i.e., good conditions for eucalyptus cultivation. On the other hand, the greatest water deficits were found in the southwest, east, and south regions of Tocantins, east and west of the state of Piauí, east of Bahia and in the northeast and extreme north of Maranhão.

Figure 6B (AWC = 150mm) shows that an increased proportion of water deficit with a lower value (AWD up to 350 mm) in a transversal strip starting from the southeastern region of Bahia, passing through the center of the study area, and reaching the western and northwestern portion of the state of Tocantins.

The results for the water deficit classes are shown in Figure 7A, Figure 7B, and Figure 7C.

Figure 7 – Annual water deficit classes AWC = 100 mm (A); Annual water deficit classes AWC = 150 mm (B); Annual water deficit classes AWC = 220 mm in the MATOPIBA region (C)



Source: Authors (2020)

Regarding the water deficit aptitude class for AWC = 100 mm, there are three classes: “apt” (30 < AWD < 250), “marginal” (250 < AWD < 350) and “restricted” (AWD > 350). However, as previously noted, the “restricted” class is predominant, representing about 67.12% of the MATOPIBA area (Table 3), and lower productivity or even crop losses may occur in these areas if there is no full irrigation.

Table 3 – Area of water deficit aptitude classes belonging to AWC = 100 mm, 150 mm, and 220 mm

Classes	Area (%)		
	AWC = 100mm	**AWC = 150mm**	**AWC = 220mm**
Apt (30 < AWD < 250 mm)	7.68	15.24	29.55
Marginal (250 < AWD < 350 mm)	25.20	34.03	38.27
Restricted (> 350 mm)	67.12	50.73	32.19
TOTAL	100.00	100.00	100.00

Source: Authors (2020)

AWC = 150 mm (Figure 7B) reveals that the sum of the “apt” (30 < AWD < 250 mm) and “marginal” (250 < AWD < 350 mm) aptitude classes, i.e., which would potentially present high to medium productivity in eucalyptus cultivation, correspond to almost 50% of the MATOPIBA area (Table 3).

The most significant water deficits related to the “restricted” class (AWD > 350 mm), AWC = 150 mm, were observed mainly in the south-southwest regions of Tocantins, in the northwest and extreme north regions of Maranhão and small proportions to the east of Piauí and Bahia. This class covers around 50.73% of the MATOPIBA area.

Loureiro Junior *et al.* (2015) and Custódio *et al.* (2017), related the downward trend in productivity as the annual water deficit increases.

We can see in Figure 7B and Table 4 that there was an increase in the area of the “apt” and “marginal” aptitude classes and a reduction in the “restricted” class area when compared to the use of AWC 100.

The percentage in the “apt” class area increased almost twice, i.e., it leapt from 7.68 to 15.24%, while in the “marginal” class, the area increased from 25.20 to 34.73%.

As for the reduction in the "restricted" class area, we observed that it fell from 67.12 to 50.73% when using AWC 150. These results tend to be more satisfactory for the development of culture in relation to the use of AWC 100.

As for the climatological parameter of water deficit, the classes related to AWC = 220 mm are relatively well distributed, as shown in Figure 7 and Table 3. Water deficit (250 < AWD < 350 mm) largely predominates in the state of Tocantins, reaching the center of Maranhão and the west of Piauí and Bahia.

In summary, the climatological parameters presented for the results for different types of AWCs are shown in Table 4. The annual water deficit for AWC 100 mm in the MATOPIBA region ranged from approximately 151 to 884.1 mm, with a range of 733 mm. The annual water deficit for AWC 150 varied between a minimum of 122 mm and a maximum of 884 mm, with an amplitude of 762 mm, and the annual water deficit varies from 96 to 200 mm and an amplitude of 788 mm.

Table 4 – Observation of climatological parameters for AWC = 100 mm; 150mm, and 220mm

Parameters		Min.	Max.	Medium	Amplitude
Ta (°C)		21.2	27.3	24.3	6.2
AP (mm)		650	2,200	1,425	1,550
AWD (mm)	AWC = 100mm	151	884	517.5	733
	AWC = 150mm	122	884	503	762
	AWC = 220mm	96	884	490	788

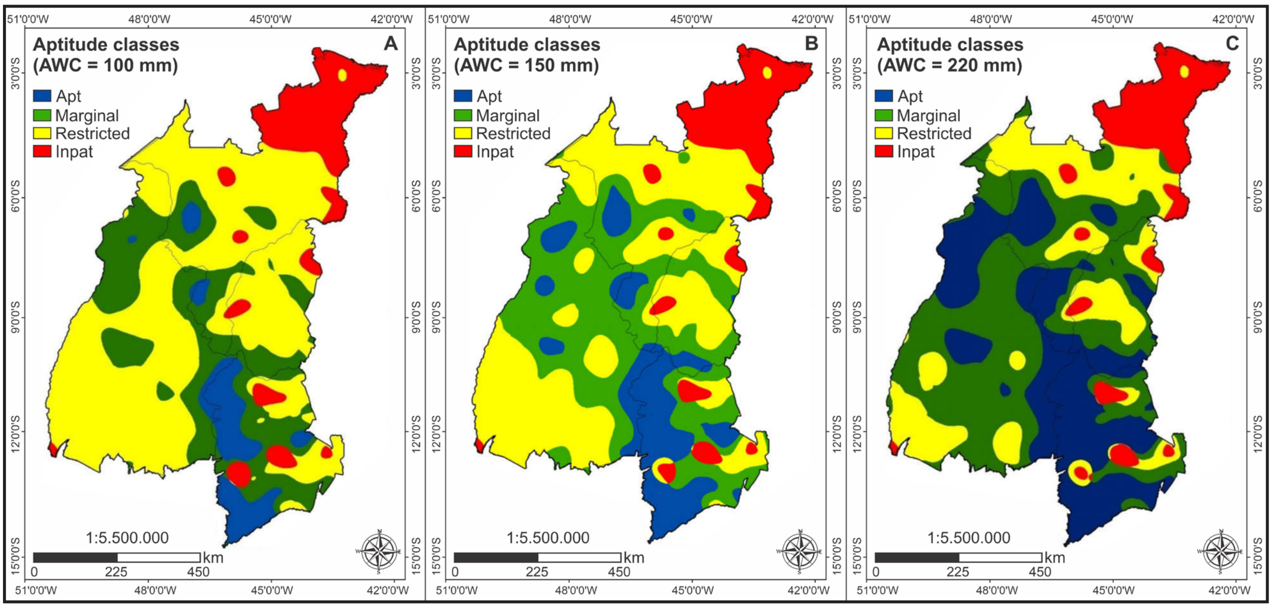
Source: Authors (2020)

3.5 Agroclimatic aptitude for *Eucalyptus urophylla* in the MATOPIBA region

Based on Figure 8, which shows the agroclimatic aptitude for the *Eucalyptus urophylla* in the MATOPIBA region for AWC = 100, 150 and 220 mm, the presence of four aptitude classes is observed, with different extensions.

Figure 8A briefly presents the aptitude classes for cultivating *Eucalyptus urophylla* in the MATOPIBA region for AWC = 150 mm; Table 5 data confirms that the "restricted" class was predominant in the region with 55.06% of the total area.

Figure 8 – Agroclimatic aptitude for *Eucalyptus urophylla* in the MATOPIBA region, for AWC = 100 mm (A); AWC = 150 mm (B) and AWC = 220 mm (C), considering the grouping of aptitude classes



Source: Author (2020)

Table 5 – Area of aptitude classes belonging to AWC = 100 mm, 150 mm, and 220 mm

Classes	Area (%)		
	AWC = 100mm	AWC = 150mm	AWC = 220mm
Apt	7.69	15.00	29.13
Marginal	24.49	33.38	37.14
Restricted	55.06	39.10	21.38
Inapt	12.76	12.52	12.35
Total	100.00	100.00	100.00

Source: Authors (2020)

In short, Figure 8B shows the grouping of aptitude classes on the agricultural border with AWC = 150 mm. Table 5 shows that the classes – marginal (33.38%) and the restricted (39.10%) – stand out in the region. It is worth highlighting the apt class, which increased to 15% with AWC = 100 mm (7.69%).

The "inapt" condition in the extreme north of the state of Maranhão is repeated for the AWC = 150 mm condition, which is due to thermal conditions, with temperatures greater than 27°C in the region.

Attention must be paid to the increase in the marginal aptitude class (250 < AWD < 350 mm) corresponding to 33.38% of the MATOPIBA area. The same occurred with the full aptitude class (30 < AWD < 250 mm), which showed an increase of 7.31%, equivalent to 54,890.58 km² in relation to AWC = 100 mm. Both classes demonstrate ideal thermal conditions for eucalyptus planting; however, the marginal class indicates regions with average productivity.

Finally, Figure 8C shows the aptitude classes in the MATOPIBA region with AWC = 220 mm. In Table 5, the apt, marginal, and restricted classes are well distributed around the border area.

The region with favorable thermal conditions but severe water restrictions refers to the restricted class, found in some portions to the east of the border and others to the southwest and, to a greater extent, to the north; the size of this class reaches 21.38% of the agricultural border.

However, the northern region of MATOPIBA in Maranhão still reproduces the inapt class resulting from temperatures greater than 27 °C, causing restrictions on eucalyptus cultivation.

The apt class refers to the full cultivation of *Eucalyptus urophylla* and high productivity presenting large proportions on the agricultural border, which, finally, increased to 29.13% with AWC = 100 mm (7.69%) and AWC = 150 mm (15%).

In the climate aptitude map for the *Eucalyptus urophylla* presented in Figure 8C, the marginal class stands out, characterized by an area with favorable thermal conditions and water restriction with complementary irrigation corresponding to 37.14% of the MATOPIBA area.

It is essential to highlight that these two classes, apt and marginal, represent 66.27% of the border area and follow ideal conditions for planting with the lowest investment risk.

3 CONCLUSIONS

The results of the present study allowed us to conclude that the studied region presents a predominance of temperature and precipitation aptitude classes favorable to the development of the species *Eucalyptus urophylla.*

However, the estimated water deficit for the different available water capacities (AWC) studied was considered high, thus reducing the possibility of more extensive areas of rainfed cultivation, i.e., without irrigation.

All agroclimatic and environmental aptitude zonings (AWCs 100, 150, and 220 mm) and the existence of "apt" and "marginal" areas in an extensive longitudinal strip (southeastward – northwestward) encompassing the four states support the cultivation of the *E. urophylla.*

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REFERENCES

ANA. Agência Nacional de Águas. Sistema de Informações Hidrológicas. **Software Hidro 1.0.** 2016. Available in: http://hidroweb.ana.gov.br/HidroWeb.asp?TocItem=6010. Accessed in: 23 Mar. 2016.

ANUÁRIO BRASILEIRO DA SILVICULTURA. **Brazilian Forestry and Timber Yearbook 2016** / Letícia Mendes, Michelle Treichel e Romar Rudolfo Beling - Santa Cruz do Sul: Ed. Gazeta Santa Cruz, 2016. 56 p. ISSN 1808-222x. Available in: http://www.abaf.org.br/wp-content/uploads/2016/04/anuario-de-silvicultura-2016.pdf. Accessed in: 27 Apr. 2021.

BEM. Balanço Energético Nacional. Empresa de Pesquisa Energética (Brasil). **Balanço Energético Nacional 2021**: ano base 2020. Ministério de Minas e Energia, 2021.

BÔAS, O. V.; MAX, J. C. M. Crescimento comparativo de espécies de *Eucalyptus* e *Corymbia* no município de Marília, SP. **Revista do Instituto Florestal**, São Paulo, v. 21, n. 1, p. 63-72, jun. 2009.

BONDARIK, R.; PILATTI, L. A.; HORST, D. J. Uma visão geral sobre o potencial de geração de energias renováveis no Brasil. **Interciência**, v. 43, n. 10, p. 680-688, 2018.

BORGES, M. G.; LEITE, M. E.; LEITE, M. R. Mapeamento do eucalipto no estado de Minas Gerais utilizando o sensor Modis. **Espaço Aberto**, v. 8, n. 1, p. 53-70, 2018.

BRASIL. **Balanço energético nacional 2019**. Brasília: Ministério de Minas e Energia/MME. Relatório Síntese: ano base 2018, 303 p. Rio de Janeiro. maio de 2019. Available in: https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-377/topico-494/BEN%202019%20Completo%20WEB.pdf. Accessed in: 27 Apr. 2021.

BRASIL. Decreto nº 8.447 Nº 8.447, de 6 de maio de 2015. Dispõe sobre o Plano de Desenvolvimento Agropecuário do Mapitoba e a criação de seu Comitê Gestor. **Diário Oficial da União Brasília**, DF, 7 mai. 2015.

BRASIL, MAPA - Ministério da Agricultura, Pecuária e Abastecimento. **Projeções do agronegócio Brasil 2019/20 a 2029/30:** projeções de longo prazo. Brasília: MAPA/SPA, 2020. 101p. Available in: https://www.gov.br/agricultura/pt-br/assuntos/politica-agricola/todas-publicacoes-de-politica-agricola/projecoes-do-agronegocio/projecoes-do-agronegocio_2019_20-a-2029_30.pdf. Accessed in: 4 Apr. 2022.

BRUNINI, O.; CARVALHO, J. P. de. **Zoneamento agroambiental para o setor florestal:** zoneamento edafoclimático - orientações técnicas e viabilidade de cultivo. Campinas: Instituto Agronômico, 2018, 39 p; online (Série Tecnologia APTA. Boletim técnico IAC, 218). Available in: http://florestar.org.br/wp-content/uploads/2019/06/btiac218.pdf. Accessed in: 27 Apr. 2021.

CETESB - Companhia Ambiental do Estado de São Paulo. **Biomassa florestal e energias renováveis na Amazônia.** Publicado em: fevereiro de 2016. Available in: https://cetesb.sp.gov.br/biogas/2016/02/01/biomassa-florestal-e-energias-renovaveis-na-amazonia/#:~:text=Na%20regi%C3%A3o%20norte%20do%20pa%C3%ADs,at%C3%A9%2020%20MW)%20e%20res%C3%ADduos. Accessed in: 27 abr. 2021.

COLLICCHIO, E. **Zoneamento edafoclimático e ambiental para a cana-de-açúcar e as implicações das mudanças climáticas no estado do Tocantins.** 2008. 157 p. Tese (Doutorado em Ecologia Aplicada) – Escola Superior de Agricultura Luiz de Queiroz – Universidade de São Paulo. Piracicaba, 2008.

CUSTÓDIO, I. C.; FELÍCIO, R.; NASCENTE, A. C. S.; SANTOS, P. D. F.; DA SILVEIRA, P. S.; MATOS, F. S. Analysis of growth of plants of *Eucalyptus urocam* under water deficit and silicon doses. **Revista Agrotecnologia**, v. 8, n. 2, p. 28-36, 2017.

FLORES, T. B.; ALVARES, C. A.; SOUZA, V. C; STAPE, J. L.; **Eucalyptus no Brasil:** zoneamento climático e guia para identificação. Piracicaba: IPEF, 2016. 448 p.

FREITAS, T. A. S. de; FONSECA, M. D. S.; SOUZA, S. S. M. de; LIMA, T. M.; MENSONÇA, A. V. R.; SANTOS, A. P. dos. **Crescimento e ciclo de produção de mudas de *Eucalyptus* em recipientes**. Embrapa: Pesquisa Florestal Brasileira. 2013. 10 p.

GIODA, A. Características e procedência da lenha usada na cocção no Brasil. **Estudos Avançados**, v. 33, n. 95, p. 133-150, 2019.

INMET, Instituto Nacional de Meteorologia. **Normais Climatológicas do Brasil (1961-1990).** Brasília: INMET. 1992. (Planilha Excel). Available in: www.lce.esalq.usp.br/angelocci/NORMAIS.xls. Accessed in: 12 Nov. 2020.

LOUREIRO JUNIOR, A.; BARBOSA, C. A.; FASOLO, L.; SARTORI, M.; PEDRONI, M. **Aptidão para a silvicultura de eucalipto nas diferentes regiões do estado do Espírito Santo.** Vitória: CEDAGRO - Centro de Desenvolvimento do Agronegócio. 2015. 175 p.

MARCOLINI, M. de P. **Efeito das mudanças climáticas no zoneamento agroclimático para a cultura do eucalipto (*Eucalyptus urograndis*) no estado do Tocantins**. 2015. 100 p. Dissertação (Mestrado em Agroenergia) – Universidade Federal do Tocantins – UFT, Palmas. 2015.

MATOS, F. S.; OLIVEIRA, P. R. C.; ANCIOTTI GIL, J. L. R.; SOUSA, P. V.; GONÇALVES, G. A.; SOUSA, M. P. B. L.; SILVEIRA, P. S.; SILVA, L. M. *Eucalyptus urocan* drought tolerance mechanisms. **African Journal of Agricultural**, v.11, p.1617-1622, 2016.

MEDEIROS, S. de S.; CECÍLIO R. A.; MELO JÚNIOR, J. C. F. de; SILVA JÚNIOR, J. L. C. da. Estimativa e espacialização das temperaturas do ar mínimas, médias e máximas na região Nordeste do Brasil. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.9, n.2, p.247-255, 2005.

MIRANDA, E. E.; MAGALHÃES, L.A.; CARVALHO, C.A. de. **Proposta de delimitação territorial do MATOPIBA**. Campinas: GITE/EMBRAPA, maio 2014.18 p. (Nota Técnica 1). Available in: www.embrapa.br/gite/publicacoes/NT1. Accessed in: 15 Feb. 2016.

NDAGIJIMANA, C.; PAREYN, F. G. C.; RIEGELHAUPT, E. Uso do solo e desmatamento da Caatinga: um estudo de caso na Paraíba e no Ceará–Brasil. **Estatística Florestal da Caatinga**, v. 2, n. 2, p. 18-29, 2015.

PALUDZYSZYN FILHO, E.; SANTOS, P. E. T. dos. **Programa de melhoramento genético de eucalipto da Embrapa Florestas**. Colombo: Embrapa Florestas, 2011. 66 p. (Documentos 214).

PEREIRA, A. R.; ANGELOCCI, L. R.; SENTELHAS, P. C. **Agrometeorologia, fundamentos e aplicações práticas.** Guaíba: Livraria e Editora Agropecuária. 2002. 478p.

PEREIRA, A.R. Simplificando o balanço hídrico de Thornthwaite-Mather. **Bragantia**, Campinas, v.64, n.2, p.311-313, 2005.

PIACENTINI, P. Faltam estratégias no Brasil para gerar energia das marés. **Ciência e Cultura**, v. 68, n. 3, p. 11-13, 2016.

RIBEIRO, C. A. D. **Delimitação de zonas agroclimáticas para cultura do eucalipto no norte do Espírito Santo e sul da Bahia**. 2009. 102p. Dissertação (Programa de Pós-Graduação em Produção Vegetal). Centro de Ciências Agrárias – Universidade Federal do Espírito Santo. Alegre Espírito Santo, 2009.

RUFO, T. F.; SOBRINHO, F. L. A.; ARAÚJO, G. C. C. A região do MATOPIBA: modernização agrícola, dinâmicas e transformações urbanas, em especial os cerrados Piauienses. **Boletim de Geografia**, v. 37, n. 3, p. 244-261, 2019.

RUY, O. F. **Variação da qualidade da madeira em clones de *Eucalyptus urophylla* S. T. Blake da Ilha de Flores, Indonésia**. 1998. 69 p. Dissertação (Mestrado em Ciência e Tecnologia da Madeira) – Escola Superior de Agricultura Luiz de Queiroz, Piracicaba,1998.

SANTOS, A. R. dos; RIBEIRO, C. A. A. S.; SEDIYAMA, G. C., PELUZIO, J. B. E.; PEZZOPANE, J. E. M.; BRAGANÇA, R. **Espacialização de dados meteorológicos no Arc GIS 10.3.** [Recurso eletrônico]. Alegre: CAUFES, 2015. 66 p.

SANTOS, L. C.; CARVALHO, A. M. M. L.; PEREIRA, B. L. C.; OLIVEIRA, A. C.; CARNEIRO, A. de C. O.; TRUGILHO, P. F. Propriedades da madeira e estimativas de massa, carbono e energia de clones de *Eucalyptus* plantados em diferentes locais. **Revista Árvore,** Viçosa-MG, v.36, n. 5, p. 971-980, 2012.

SCANAVACA JUNIOR, L.; GARCIA, J. N. Potencial de melhoramento genético em *Eucalyptus urophylla* procedente da Ilha Flores. **Scientia Forestalis**, Piracicaba, n. 64, p. 23- 32, 2003.

SILVA JÚNIOR, J. L. C. da. **Zoneamento da região sudeste do Brasil, utilizando o índice de temperatura e umidade, para o gado leiteiro**. 2001. 91 p. Dissertação (Mestrado em Meteorologia) – Universidade Federal de Viçosa. Minas Gerais, 2001.

SILVA, M. G. da. **Produtividade, idade e qualidade da madeira de *Eucalyptus* destinada à produção de polpa celulósica branqueada**. 2011, 95 p. Dissertação (Mestrado em Ciência) – Universidade de São Paulo. Escola Superior de Agricultura "Luiz de Queiroz". Piracicaba. 2011.

SOUZA, O. M. M. **Aptidão agroclimática e ambiental do *Eucalyptus urophylla* para a região do MATOPIBA.** 2017. 90 p. Dissertação (Mestrado em Agroenergia) – Universidade Federal do Tocantins. 2017.

SPERANDIO, H. V.; CAMPANHARO, W. A.; CECÍLIO, R. A.; NAPPO, M. E. Zoneamento agroecológico para espécies de eucalipto no estado do Espírito Santo. **Caminhos da Geografia**, Uberlândia, v.11, n.34. p 203-216. 2010.

THORTHWAITE, C.W.; MATHER, J.R. **The water balance**. Publications in Climatology.New Jersey: Drexel Institute of Thechnology, 1955. 104p.

TRAVASSOS, I. S.; SOUZA, B. I. de. Os negócios da lenha: indústria, desmatamento e desertificação no Cariri paraibano. **GEO USP Espaço e Tempo (Online)**, v. 18, n. 2, p. 329-340, 2014.

VICTORIA, D. de C.; SANTIAGO, A.V.; BALLESTER, M.V.R.; PEREIRA, A.R.; VICTORIA, R.L.; RICHEY, J.E. Water balance for the Ji-Paraná river basin, western Amazon, using a simple method through geographical information systems and remote sensing. **Earth Interactions**, Madison, v.11, n.5, p. 1-21, 2007.

WILCKEN, C. F.; LIMA, A. C. V.; DIAS, T. K. R.; MASSON, M. V.; FILHO, P. J. F.; POGETTO, M. H. F. do A. D. **Guia prático de manejo de plantações de eucalipto**. Botucatu: Fundação de Estudos e Pesquisas Agrícolas e Florestais - FEPAF, 2008. 19 p.

WILCOX-MOORE, K.; BRANNSTROM, C.; SORICE, M. G.; KREUTER, U. P. The influence of socioeconomic status and fuelwood access on domestic fuelwood use in the Brazilian Atlantic Forest. **Journal of Latin American Geography**, p. 195-216, 2011.

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