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Agro-Climate Suitability for Sorghum Cultivation in The State of Pernambuco, Brazil

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ABSTRACT

Sorghum is a tropical strain cultivar, with short cycles and high photosynthetic percentages, requiring a warm climate to express its productivity. The objective of this work is to determine the agroclimatic suitability for the cultivation of sorghum in the state of Pernambuco, Brazil. Rainfall data were provided by the Superintendência do Desenvolvimento do Nordeste (SUDENE) and Agência de Água e Clima de Pernambuco (APAC); and temperature data were originated from the Instituto Nacional de Meteorologia (INMET) for the period 1960-2019. When necessary, the data were estimated by the computational program Estima T.The coefficients of the quadratic function were determined for the mean, maximum, and minimum monthly temperatures as a function of local longitude, latitude, and altitude. Electronic spreadsheets were prepared with monthly and annual data on temperature and precipitation, followed by their filling and consistency analysis. The fluctuations of the twelve points in the evapopluviogram were used, where the indices of vegetation, drought rest, and cold rest were determined. The values of the climatic indexes were analyzed as a function of the classification and climatic suitability. In the Upper Sertão and Sertão regions, the suitability is moderate due to excess water. In the Agreste region, full suitability was obtained with a prolonged rainy season. In the Zona da Mata and Litoral regions, the suitability is full without restrictions.

INTRODUCTION

According to MAPA (2014), sorghum is a cultivar of tropical origin, with xerophilic characteristics, and compliant to dry periods (TABOSA et al., 2002). Sorghum is a plant of the C4 group, which has a high power to accept high levels of solar radiation, in contrast to high photosynthetic indices, reducing the opening of the stomata and consequent loss of water. Thus, light intensity implies greater productivity, whenever other weather conditions are favorable (EMBRAPA, 2012).

Sorghum cultivation needs 300 to 400 mm of rain, regularly distributed throughout its growth and development cycle, to achieve satisfactory productivity. The crop is tolerant to water deficiencies, including periods of short dry spells, being considered resistant to drought. The critical phenological phases of the crop correspond to the seedling and flowering stages, being important in these stages an appropriate water supply to have better yields (Tabosa et al., 2002; EMBRAPA, 2012).

The objective of this study is to determine the climatic suitability for the cultivation of sorghum in the state of Pernambuco, Brazil.

MATERIAL AND METHODS

The State of Pernambuco is located in the center east of the Northeast region of Brazil (Figure 1). It is limited to the north by Paraíba state, to the northwest by Ceará state, to the southeast by Alagoas state and Bahia state to the south, and with Piauí state to the West. In addition, is bathed by the Atlantic Ocean to the east. It occupies an area of 98,937.8 km². The Fernando de Noronha, São Pedro and São Paulo archipelagos are part of its territory (CPRM, 2010).

Being one of the smallest states in Brazil in territorial extension, Pernambuco has a great diversity of landscapes: plateaus, mountains, swamps, semiarid region, and beautiful beaches. The most regular relief is in the coastal plain, and as it moves towards the interior of the state, there are mountain peaks, exceeding 1000 meters in altitude.

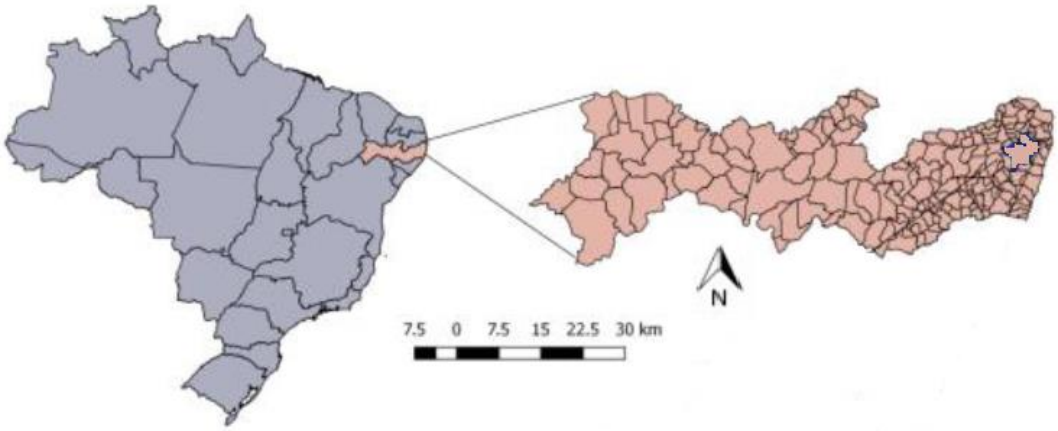

Figure 1. Location of the State of Pernambuco in Brazil.

Source: Medeiros (2021)

The rain provocative and/or inhibiting systems for the studied area which contribute to the pluvial indices are: the vestiges of Frontal Systems; the contributions of the Convergence Zones of the South Atlantic (SACZ); formations of convective clusters and the contribution of Alta da Bolivia; the Intertropical Convergence Zone (ITCZ) contributions from the High-Level Cyclonic Vortexes (HCV); Eastern Wave Disturbances and the Maritime and Terrestrial Breezes; Eastern Waves; and Southeast trade winds (Medeiros, 2016a).

According to the classification criteria of Köppen (1928) and Köppen et al.(1931), three climatic characteristics were identified: "As" type (tropical with dry season) in 108 municipalities; warm semi-arid climate with summer and dry winter rains "Bush" was recorded in 55 municipalities, and type “Am” (Wet. Woodland climate. Driest month with average rainfall below 60 mm and total annual rainfall above 10 times this value) predominating in 20 municipalities. The studies by Alvares et al. (2014) and Medeiros et al. (2018) corroborate the results of this study.

Rainfall data were provided by the Superintendência do Desenvolvimento do Nordeste (SUDENE) and Agência de Água e Clima de Pernambuco (APAC); and temperature data were originated from the Instituto Nacional de Meteorologia (INMET) for the period 1960-2019. When necessary, the data were estimated by the computational program Estima T.

The thermal indices of the meteorological stations of the state, belonging to the Instituto Nacional de Meteorologia (INMET, 2020) were used, and when necessary, estimates were made using the

computer program Estima T (Cavalcanti, Silva, et al., 1994; Cavalcanti et al.,2006). The coefficients of the quadratic function were determined for the mean, maximum, and minimum monthly temperatures as a function of local longitude, latitude, and altitude, according to the methodology presented by Cavalcanti et a*l.*(2006), given by:

$$T = C0 + C1\lambda + C2Ø + C3h + C4\lambda2 + C5Ø2 + C6h2 + C7\lambda Ø + C8\lambda h + C9Øh \qquad 1$$

On what:

C0, C1,....., C9 are the constants;

λ, λ2, λØ, λh is the longitude;

Ø, Ø2, λØ is the latitude;

h, h2, λh, Øh height.

Electronic spreadsheets were prepared with monthly and annual data on temperature and precipitation, followed by their filling and consistency analysis. The computer program Surfer® v.8 was used to make monthly and annual maps for Pernambuco, using the Kriging process. Mean, standard deviation, coefficient of variance, maximum and minimum absolute values were determined. The rainy and dry seasons were defined and the water balance and evapopluviogram graphs were generated (Medeiros, 2016).

For the computation of the Water Balance (WB), it was used the methodology proposed by Thornthwaite (1948) and Thornthwaite et al.(1955), using electronic spreadsheets implemented by Medeiros (2016b). Based on this methodology, the soil water storage capacity (CAD) of 100 mm was used.

The fluctuations of the twelve points in the evapopluviogram were used, where the indices of vegetation (Iv), drought rest (Irs), and cold rest (Irf) were determined, obtained by the following equations described by Medeiros et al. (2014) and Matos, Medeiros, Silva & Santos (2015).

$$I_v = N°P.V$$

$$I_{rs} = N°P.V$$

$$I_{rf} = N°P.V$$

On what:

NºP – number of points on the evapopluviogram of each water sector and thermal range;

V – a value of the Iv, Irs, and If, for each water sector and thermal range.

The values of the climatic indexes were analyzed as a function of the classification and climatic suitability proposed by Ometto (1981), classifying them into full, moderate, restricted and unsuitable. For the validation of the climate suitability of the sorghum crop, the criteria of the methodology of Ometto (1981) and the Brazilian Agricultural Research Corporation (EMBRAPA, 2012) were applied. WB simulations were carried out, which provided the contributions of deficiencies and excess water from planting to harvest, through the worked parameters (Table 1).

Table 1. Criteria used to assess the climate suitability of the sorghum crop.

Climate suitability	EXC (mm)	DEF (mm)	PREC/ETP (mm	PREC (mm)
C_1 – Full without restriction	$0<EXC_j\leq200$	$DEF_j<10$	$PREC_4/ETP_4<1$	$400<PREC\leq500$
C_2 – Full with a prolonged rainy seas	$200<EXC_j\leq300$		$PREC_4/ETP_4\geq1$	$500<PREC\leq600$
C_3 - Moderate by excess water	≥300			≥ 600
C_4 – Moderate by water deficit		$DEF_j<20$	$PREC_4/ETP_4<1$	$280<PREC\leq400$
C_5 – Unsuitable due to severe water deficit		$DEF_j\geq20$		<280

Meaning of abbreviations: EXC = water surplus; DEF = water deficit; PREC/ETP = Precipitation/Evapotranspiration; PREC = Precipitation.

Source: EMBRAPA (2012); Ometto (1981).

RESULTS AND DISCUSSION

Figure 2 shows the annual thermal fluctuations for the state of Pernambuco. It can be seen on the border with the state of Paraíba that the fluctuation in average temperature oscillates between 21.4 °C and 25.8 °C. On the border with Alagoas and Bahia, average temperature fluctuations vary from 22.6

°C to 25.4 °C. In the central region, the variability of average temperatures fluctuates between 20.6 °C and 23.8 °C. In the Sertão region, average temperatures ranged between 22.2 °C and 23.4 °C. In the Zona da Mata and the coastal sector, the average temperature variability ranged from 23.4 °C to 25.8 °C. Studies presented by Medeiros et al.(2014) and Medeiros et al.(2012) corroborate the thermal values obtained for the state of Pernambuco.

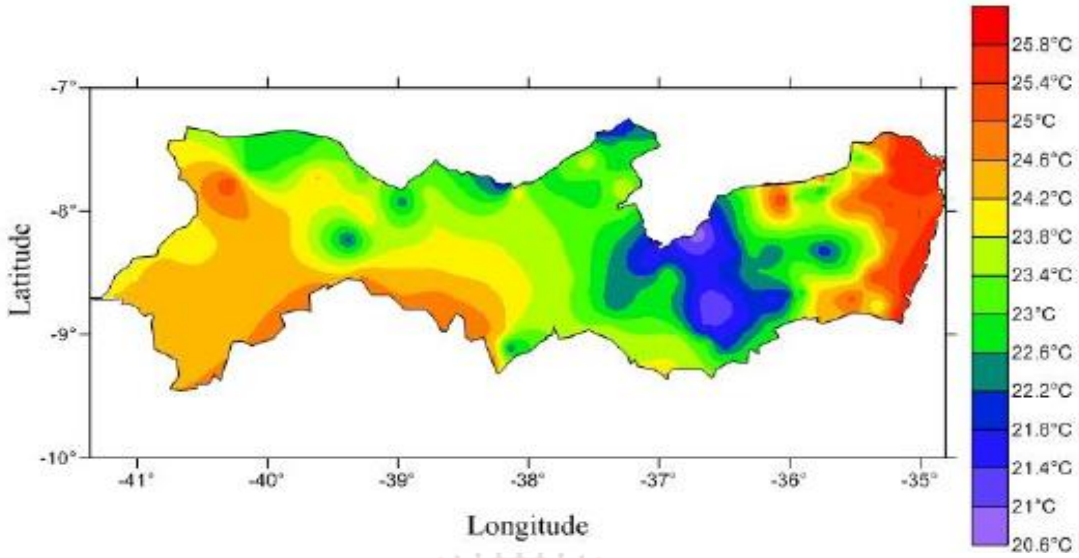

Figure 2. Average annual temperature for the State of Pernambuco, Brazil.

Source: Medeiros (2021).

The distributions of average annual isohyets for the State of Pernambuco (Figure 3) show high spatial variability, with fluctuations ranging between 400 and 2100 mm. In the coastal region and the Mata zone, there were high rainfall rates; in the Upper Sertão and Sertão there were rains in isolated areas of up to 1100 mm, as well as variations from 400 to 900 mm, on the border with the states of Alagoas, Bahia, and Piauí. On the border with Paraíba, rainfall ranges between 400 and 1100 mm; and a small area of 1900 mm in the Agreste region, ranging from 400 to 1100 mm. These variabilities are due to factors acting in the atmosphere such as low intensity of the sun's rays, high cloud cover, fluctuations in the relative humidity of the air, and the oscillation of atmospheric pressure, according to the results of Nobre et al.(1988).

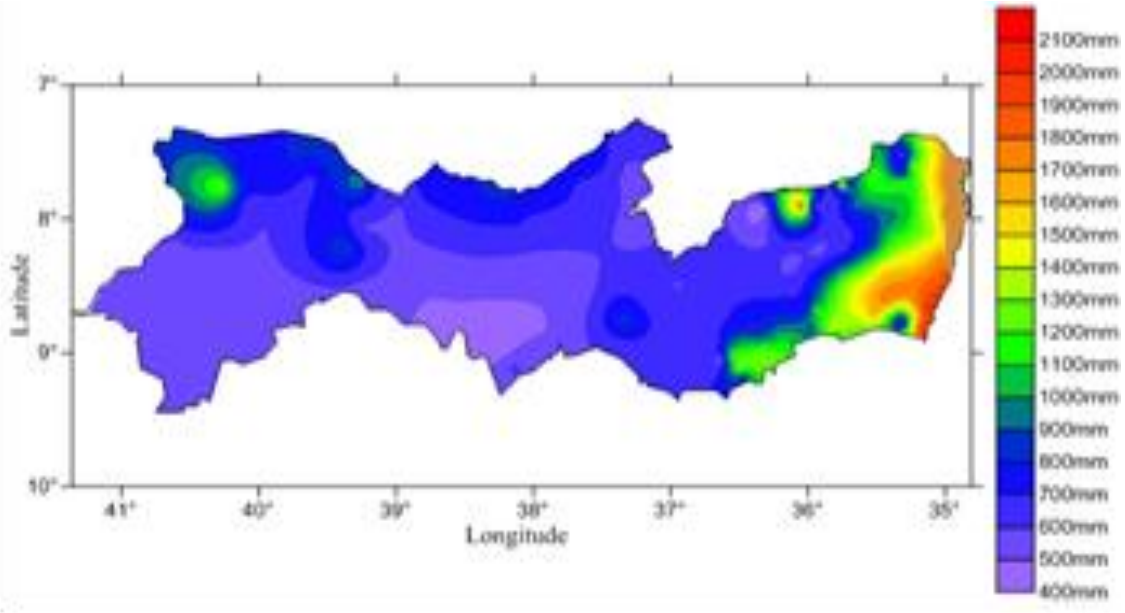

Figure 3. Annual isohyets (mm) for the State of Pernambuco, Brazil.

Source: Medeiros (2021).

Table 2 shows the variability of meteorological factors corresponding to the WB calculations: Temperature (TEM), Precipitation (PREC), Evapotranspiration (ETP), Evaporation (EVR), Surplus (EXC), and Water Deficiency (DEF), monthly for the State of Pernambuco. The annual temperature was 23.7 ºC with fluctuations between 21.5 ºC in July and 25.1 ºC in January. Annual rainfall of 959.9 mm, monthly rainfall ranges from 21.1 mm in October to 135.5 mm in April. The annual evapotranspiration and evaporative indices were 1207.8 and 887.7 mm, respectively. Evapotranspiration was greater than the pluvial index in 20.52% of its annual value. Evaporated 8.13% below the rainfall rate. With an annual water surplus of 320.1 mm recorded between September and February, and a water deficit of 72.2 mm in June and July. These irregular fluctuations in the studied elements are in agreement with studies by Marengo et al. (2011), Marengo et al. (2008), Marengo et al.(2007), Medeiros (2018), IPCC (2014), and IPCC (2007).

Table 2. Temperature (TEM, ºC), Precipitation (PREC, mm), Evapotranspiration (ETP, mm), Evaporation (EVR, mm), Water Surplus (EXC, mm) and Monthly Water Deficiency (DEF, mm) for the balance of the State of Pernambuco, Brazil.

Months	TEM	PREC	ETP	EVR	EXC	DEF
Jan	25,1	56,7	121,7	58,7	63,1	0,0
Feb	25,0	77,2	111,0	77,8	33,2	0,0
Mar	24,8	132,5	118,0	118,0	0,0	0,0
Apr	24,1	135,5	103,1	103,1	0,0	0,0
May	23,1	121,4	93,0	93,0	0,0	0,0
Jun	22,0	121,3	76,8	76,8	0,0	21,2
Jul	21,5	124,9	73,9	73,9	0,0	51,0
Aug	21,7	63,3	76,8	75,9	0,9	0,0
Sep	22,9	40,7	88,8	74,1	14,7	0,0
Out	24,1	21,1	107,5	52,4	55,1	0,0
Nov	24,7	23,8	113,7	37,3	76,4	0,0
Dec	25,0	41,6	123,5	46,8	76,7	0,0
Annual	23,7	959,9	1207,8	887,7	320,1	72,2

Meaning of abbreviations: TEMP = temperature; Prec = Precpitation; ETP = Evapotranspiration; EVR = Evaporation; EXC = Water Surplus; DEF = Water Deficiency.

Source: Medeiros (2021).

Figure 4shows a graphic representation of the climatological water balance for the State of Pernambuco. Water deficit was registered between August and February; the removal of water from the soil predominated between August and December. The replenishment of water in the soil runs from March to June and surplus water in June and July.

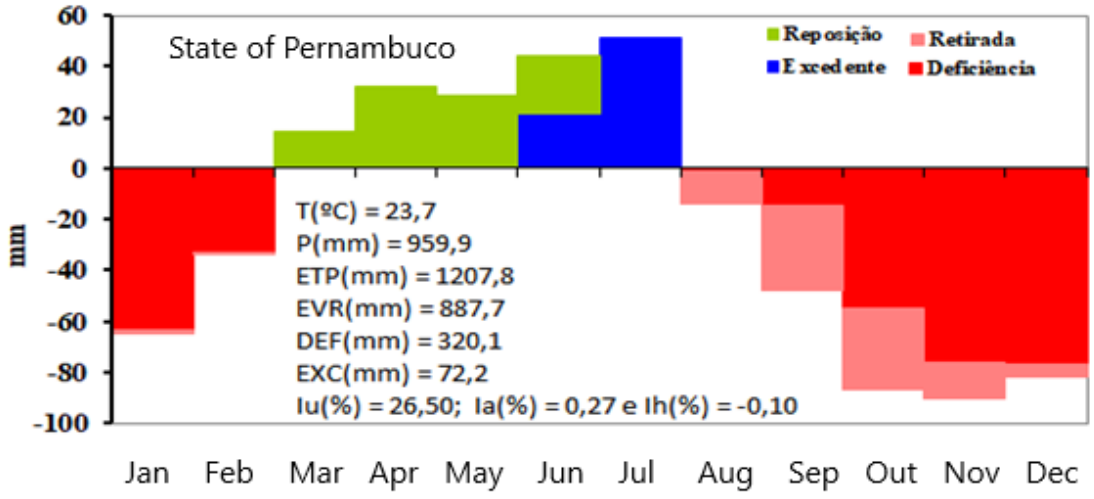

Figure 4. Graphic representation of the climatological water balance in the State of Pernambuco, Brazil.

Source: Medeiros (2021).

The distribution of the water sectors and thermal ranges of the evapopluviogram are shown in Figure 5. The arid climate prevails in one month; the dry climate occurs in three months; the sub-humid climate is registered in two months; the humid climate in three months; the super humid climate was characterized in three months.

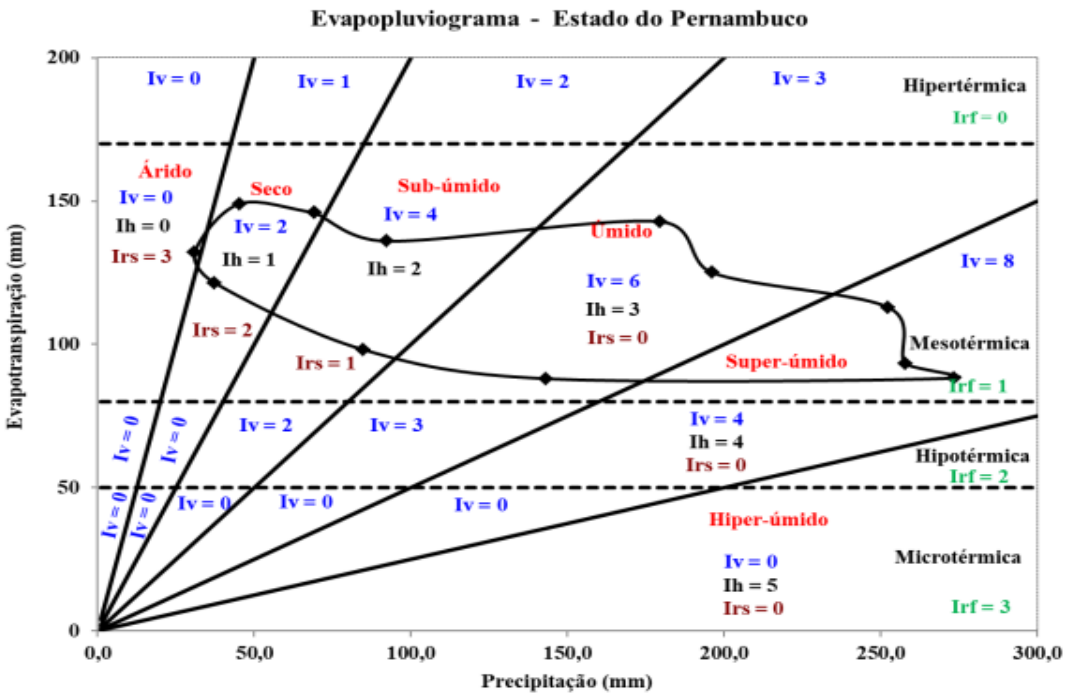

Figure 5. Distribution of water sectors and thermal bands of the evapopluviogram for the State of Pernambuco, Brazil.

Source: Medeiros (2021).

The variability of climate indices and parameters for the State of Pernambuco are shown in Table 3. These indices and parameters were generated from the computation of WB and the evapopluviogram. A study such as that by Medeiros et al.(2013) demonstrates similarities in indexes during several studies carried out for the semiarid region of the Brazilian Northeast.

Table 3. Climatic indexes and parameters for the State of Pernambuco.

Climatic indexes	Ih	Iv	I_{rs}	I_{rf}	Cv (%)	T (ºC)	P (mm)	ETp	DEF	EXC
	28	47	10	6	22,0	23,7	959,4	1207,9	320,1	72,2

Meaning of abbreviations: Ih = Evapluviogram water index; Iv = vegetation indices; Irs = drought rest; Irf = cold rest (Irf); Cv = Concentration of evapotranspiration in the warm season; T = Average air temperature; P = average precipitation; ETP = Potential evapotranspiration; EVR = Evaporation; DEF = Water Deficiency and EXC = Water Surplus.

Source: Medeiros (2021).

Alves (2014) showed that the distribution of evapotranspiration and precipitation in the climate generate the four thermal bands and the six water sectors, being a decisive tool in the characterization of the climate of a given region, providing the choice of the most suitable cultivars for the region, corroborating with the values presented here.

Figure 5 shows the distribution of water surplus in the state of Pernambuco and its climatic suitability for the sorghum crop. Three types of suitability for planting sorghum were recorded in the state.

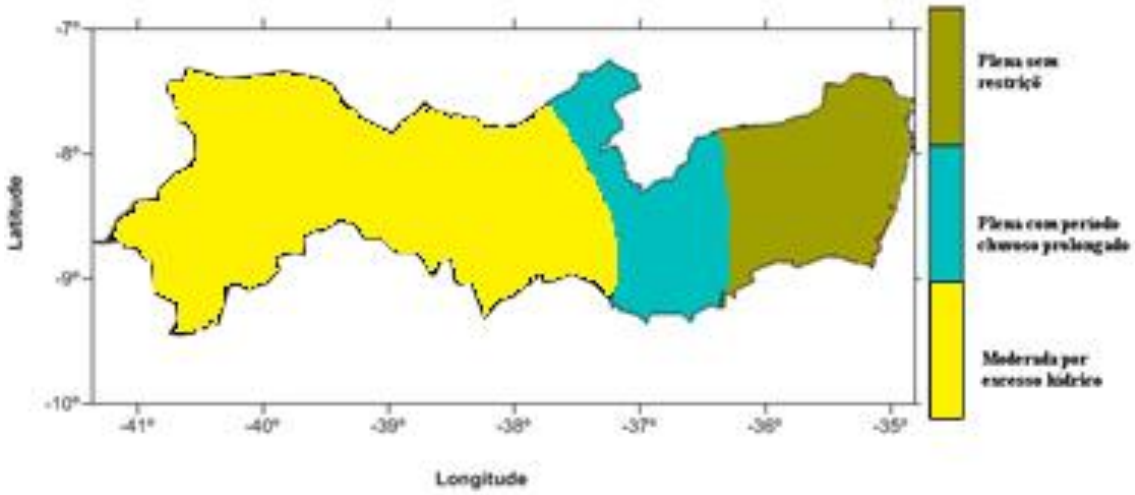

Figure 6. Distribution of water surplus in the state of Pernambuco and its climatic suitability for sorghum crop.

Source: Medeiros (2021).

CONCLUSIONS

In the Upper Sertão and Sertão regions, the suitability is moderate due to excess water. In the Agreste region, full suitability was obtained with a prolonged rainy season. In the Zona da Mata and Litoral regions, the suitability is full without restrictions.

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