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Potentiality of sorghum's climate fitness for the state of Pernambuco, Brazil

Potencialidade da aptidão climática do sorgo para o Estado do Pernambuco, Brasil

Potencialidad de la aptitud climática del sorgo para el estado de Pernambuco, Brasil

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Abstract

Sorghum is a plant of tropical origin, of short days and with high photosynthetic rates, requiring a warm climate in order to express its production potential. The objective is to evaluate the agroclimatic aptitude of the cultivation of sorghum that allows to visualize or identify its productive potential in the state of Pernambuco. The pluviometric data were acquired from the Northeast Development Superintendence and the Pernambuco water and climate agency, the temperature data were from the National Institute of Meteorology and estimated by the estima_T software between the period 1960-2019. In the region of the high sertão and sertão there is moderate fitness due to excess water. In the agreste region full fitness was obtained with prolonged rainy season. In the Zona da Mata and Litoral regions, fitness is unrestricted. The study was carried out using information from the rainy season and without the aid of irrigation, that is, taking into account the rainfed planting.

Keywords: Rain and thermal fluctuations; Surpluses and water deficiencies; Agroclimatic analyzes.

Resumo

O sorgo é uma planta de origem tropical, de dias curtos e com altas taxas fotossintéticas, exigindo, um clima quente para poder expressar seu potencial de produção. Tem-se como objetivo avaliar a aptidão agroclimática do cultivo do sorgo que permita visualizar ou identificar o seu potencial produtivo no estado do Pernambuco. Os dados pluviométricos foram adquiridos da Superintendência do Desenvolvimento do Nordeste e da agência pernambucana de água e clima, os dados de temperatura foram do Instituto Nacional de Meteorologia e estimado pelo software estima_T compreendido entre o período de 1960-2019. Na região do alto sertão e sertão tem-se aptidão moderada por excesso hídrico. Na região do agreste obteve-se aptidão plena com período chuvoso prolongado. Nas regiões da Zona da Mata e Litoral, a aptidão é plena sem restrições. O estudo foi realizado utilizando-se das informações do período chuvoso e sem auxílio da irrigação, ou seja, levando-se em considerações o plantio de sequeiro.

Palavras-chave: Flutuações pluviais e térmicas; Excedentes e deficiências hídricas; Análises agroclimáticas.

Resumen

El sorgo es una planta de origen tropical, de días cortos y con altas tasas fotosintéticas, requiriendo de un clima cálido para poder expresar su potencial productivo. El objetivo es evaluar la aptitud agroclimática del cultivo de sorgo que permita visualizar o identificar su potencial productivo en el estado de Pernambuco. Los datos pluviométricos fueron adquiridos de la Superintendencia de Desarrollo del Nordeste y la agencia de agua y clima de Pernambuco, los datos de temperatura fueron del Instituto Nacional de Meteorología y estimados por el software estima_T entre el período 1960-2019. En la región del sertão alto y sertão hay moderada aptitud física debido al exceso de agua. En la región agreste se obtuvo un estado de plena forma con una temporada de lluvias prolongada. En las regiones de Zona da Mata y Litoral, la aptitud física no está restringida. El estudio se realizó con información de la época de lluvias y sin la ayuda del riego, es decir, teniendo en cuenta la siembra de secano.

Palabras clave: Lluvias y fluctuaciones térmicas; Excedentes y deficiencias hídricas, Análisis agroclimáticos.

1. Introduction

Sorghum is a plant of tropical origin, of short days and with high photosynthetic rates, requiring a warm climate in order to express its production potential, according to the Ministry of Agriculture, Livestock and Supply (MAPA, 2014). In late sowing and in crops after a summer harvest, sorghum productivity is greatly affected by the rainfall regime, solar radiation limitations and is influenced by low temperatures during the end of the cycle (MAPA, 2014). The crop, with xerophilic characteristics, is considered tolerant to dry periods, especially in regions of Northeast Brazil (NEB).

Belonging to the C_4 plant group, sorghum tolerates high levels of solar radiation, responding with high photosynthetic rates, minimizing stoma opening and consequent water loss. In this way, the increase in luminous intensity implies greater productivity, whenever other conditions are favorable according to the Brazilian Agricultural Research Corporation (EMBRAPA, 2012).

Sorghum cultivation requires 300 mm to 400 mm of precipitation, distributed regularly during its growth and development cycle in order to achieve satisfactory productivity. The crop is tolerant to water deficits, including short summer periods, and is considered drought resistant. The critical phenological phases of the crop correspond to the seedling and flowering stages, and it is important in these stages to provide an appropriate water supply for better production (Tabosa et al., 2002; EMBRAPA, 2012).

Medeiros & Duarte (2020) studied climatic factors, water balance and climatic classification for the cultivation of cashew versus sorghum using the method of Thornthwaite and Thorthwaite & Mather (1948, 1955), for the municipality of Recife. They concluded that the classification technique and climatic aptitudes using the water deficiency index for the municipality of Recife did not provide subsidies for high reliability. The determination of the components of the water balance allowed a better understanding of the climatic reality of the studied area, at the same time that it offers conditions of compatibility between the water retained in the soil and the different ways of using it, aiming at minimizing the risks for agriculture and livestock and for populations.

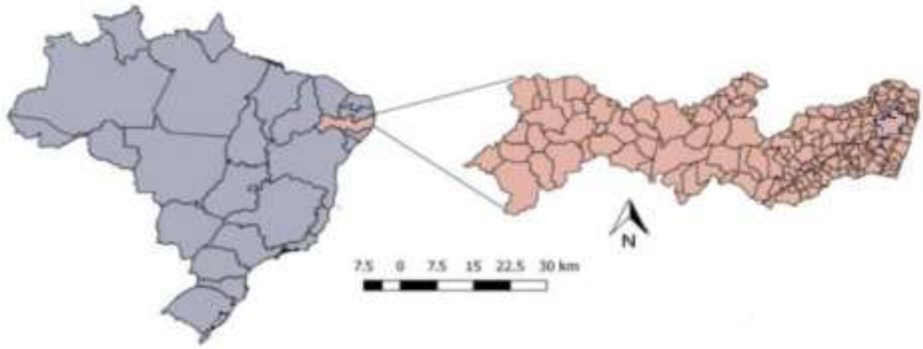
The objective is to evaluate the agroclimatic aptitude of sorghum cultivation that allows to visualize or identify its productive potential in the state of Pernambuco.

2. Methodology

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

One of the smallest Brazilian states in territorial extension, Pernambuco has a great diversity of landscapes: plateaus, mountains, swamps, semiarid and beautiful beaches. The relief is more regular in the coastal plain and, as it moves towards the interior of the state, there are mountain peaks exceeding 1000 meters in altitude. The research used was experimental according to Pereira A.S. et al. (2018), contributing and adding knowledge to the academy and the people involved.

Figure 1 – Position of the State of Pernambuco within the South America region, limited to the north with the state of Paraíba, to the northwest with Ceará, to the southeast with the state of Alagoas, Bahia, to the south, and Piauí, to the west, in addition to being bathed across the Atlantic Ocean in the eastern sector, occupying an area of 98,937.8 km²



Source: Medeiros & Duarte (2020).

The meteorological systems that cause and/or inhibit rainfall for the state of Pernambuco, which contribute with moderate to weak rainfall levels, are the vestiges of Frontal Systems in the southern sector of the state, with less frequency to the contributions of the South Atlantic Convergence Zones (SACZ), in addition to the formation of convective clusters and the contribution of Bolivian High.

The Intertropical Convergence Zone (ZCIT), a disturbance associated with the expansion to the southern hemisphere of the Thermal Equator (zone of rise of the trade winds by thermal convection), causes moderate to heavy rains in almost the entire northern area of the State, followed by contributions from formations of the Cyclonic Vortex in High Levels (CVHL), the Easterly Wave Disturbances and the Sea and Land Breezes, the latter originating in the Atlantic Ocean; as Easterly Waves are common in autumn/winter, aided by southeast trade winds (Medeiros, 2016). (Figure 2).

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Figure 2 – Causing and/or inhibiting meteorological factors in the State of Pernambuco

Source: Medeiros (2016).

According to the classification systems of Köppen (1928), Köppen & Geigom (1931) identified three climatic characteristics: “As” type (tropical with dry season) in 108 municipalities, the hot semi-arid climate “Bsh”, with summer rains and dry winter, was registered in 55 municipalities and the “Am” type predominated in 20 municipalities (Medeiros et al., 2018). The studies by Alvares et al. (2014); Medeiros et al. (2018) corroborate the results presented in this study.

The values of the average air temperature of the meteorological stations of the states belonging to the National Institute of Meteorology (INMET, 2020) were used, and their complementation were estimated by the Estima_T software (Cavalcanti & Silva, 1994; Cavalcanti et al., 2006). Estima_T is a software to make air temperature estimates in the Northeast Region of Brazil. Quadratic function coefficients were determined for average, maximum and minimum monthly temperatures as a function of local coordinates: longitude, latitude and altitude, according to the authors Cavalcanti et al. (2006), given by:

$$T = C_0 + C_1\lambda + C_2Ø + C_3h + C_4\lambda^2 + C_5Ø^2 + C_6h^2 + C_7\lambda Ø + C_8\lambda h + C_9Øh$$

On what:

C_0, C_1, ..., C_9 are the constants;

λ, λ^2, λ Ø, λ h longitude;

Ø, $Ø^2$, λ Ø latitude;

h, h^2, λ h, Ø h height.

The temperature time series was estimated, adding the temperature anomaly of the Tropical Atlantic Ocean (Cavalcanti & Silva, 1994).

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$T_{ij} = T_i + AAT_{ij}$ i= 1,2,3,...,12   j= 1950, 1951, 1952,....2019

On what:

i= 1,2,3,...,12

j= 1950, 1951, 1952, 1953,...,2019.

Electronic spreadsheets were prepared with monthly and annual temperature and precipitation data, with fills the gaps and consistencies. The Surfer 8 software was applied to the statistics using the kriging process, making the referred monthly and annual maps.

The rainfall data was acquired from the Northeast Development Superintendence (SUDENE, 1990) and from the Pernambuco Water and Climate Agency (APAC, 2020), between the years 1960 to 2019. Statistically simplified calculations were used to define mean, standard deviation, coefficient of variance, maximum and minimum absolute values that occurred, rainy and dry periods were also defined. After statistical applications, water balance and evapopluviogram graphs were generated.

The data failures between the 90s can be explained by the exchange of responsibility for collecting rain records from the former (SUDENE, 1990). For this purpose, fault filling, homogenization and consistency were performed in the referred data in order to be able to work and provide reliable information to the general public. The faulty data were filled with data from three neighboring stations, located as close as possible, using the square distance method, where the following form was applied:

$$Px = \frac{1}{3}\left(\frac{Nx}{Na}Pa + \frac{Nx}{Nb}Pb + \frac{Nx}{Nc}Pc\right)$$

On what:

P_x is the rainfall value to be determined;

N_x is the daily precipitation of station x;

NA, NB and NC are, respectively, the daily rainfall observed from neighboring stations A, B and C;

PA, PB and PC are, respectively, the precipitations observed at the moment that the post x failed.

In obtaining the water balance (BH) computation, the method proposed by Thornthwaite (1948); Thornthwaite & Mather (1955) was used, with the preparation of electronic spreadsheets made concrete by Medeiros (2016), which counts the soil water, where precipitation represents the gain and evapotranspiration the loss of soil moisture, being possible to estimate the values of Water Surplus (EXC) and Water Deficiency (DEF). Based on this methodology, it was used the Capacity of Storage of water in the soil (CAD) of 100 mm.

The evapopluviogram is a diagram that is divided into six water sectors, in which the rainfall values correspond to different multiples and submultiples of potential evapotranspiration, and in four other thermal ranges with values corresponding to the thermal limitations and requirements of the crop.

Using the twelve points of the evapopluviogram, the vegetation indices (Iv), dry rest (Irs) and cold rest (Irf), were obtained by the following Equations described by Medeiros et al. (2014); Matos et al. (2015).

$$I_v = N^oP.V$$

$$I_{rs} = N^oP.V$$

$$I_{rf} = N^oP.V$$

On what:

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

V – value of Iv, Irs and Irf, within each water sector and thermal range.

The values of the climatic indexes were analyzed according to the classification and the climatic suitability proposed by Ometto (1981). The values of the climatic indexes were applied in Table 1 to determine the climatic aptitude of the region, classifying the cultures in full, moderate, restricted and inaptitude.

For the assessment of climatic aptitude of the sorghum crop, the criteria were used according to the methodology adapted from Ometto (1981) and the Brazilian Agricultural Research Company (EMBRAPA, 2012), in which water balance simulations were carried out which allowed a view of the influence of deficiency and excess water from planting to harvest, according to the parameters adopted. (Table1).

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Table 1 – Criteria used to assess the climatic suitability of sorghum crops.

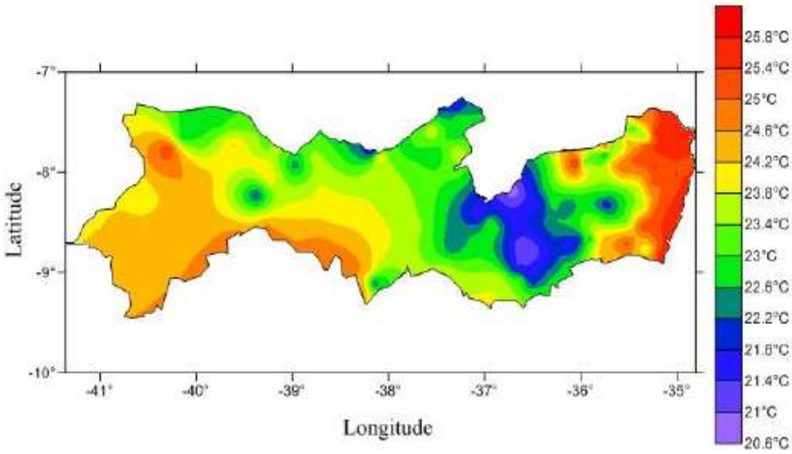
Climatic fitness	EXC(mm)	DEF(mm)	PREC/ETP (mm)	PREC (mm)
C3 – Moderate due to excess water	≥ 300			≥ 600
C2 – Full with prolonged rainy season	$200 < EXC_j \leq 300$		$PREC_4/ETP_4 \geq 1$	$500 < PREC \leq 600$
C1 – Full without restriction	$0 < EXC_j \leq 200$	$DEF_j < 10$	$PREC_4/ETP_4 < 1$	$400 < PREC \leq 500$
C4 – Moderate due to water deficiency		$DEF_j < 20$	$PREC_4/ETP_4 < 1$	$280 < PREC \leq 400$
C5 – Inapt due to severe water deficiency		$DEF_j \geq 20$		< 280

Legend: EXC = Water surplus; DEF = Water deficiency; PREC/ETP = Precipitation/Evapotranspiration; Prec = Precipitation.
Source: Adapted from EMBRAPA (2012).

3. Results and Discussion

Figure 3 shows the average annual temperature distribution for the state of Pernambuco. It is noteworthy that on the border with the state of Paraíba the fluctuation of the average temperature oscillates between 21.4 °C and 25.8 °C. On the border with Alagoas and Bahia, temperature fluctuations vary from 22.6 °C to 25.4 °C. In the central region, the variability of average temperatures varies between 20.6 °C and 23.8 °C. In the sertão region, average temperatures are from 22.2 °C to 23.4 °C. In the Zona da Mata and in the coastal sector, the average temperature variability is from 23.4 °C to 25.8 °C. Studies like that of the authors Medeiros et al. (2014); Medeiros et al. (2012) corroborate the thermal values for the temperature fluctuation in the state of Pernambuco.

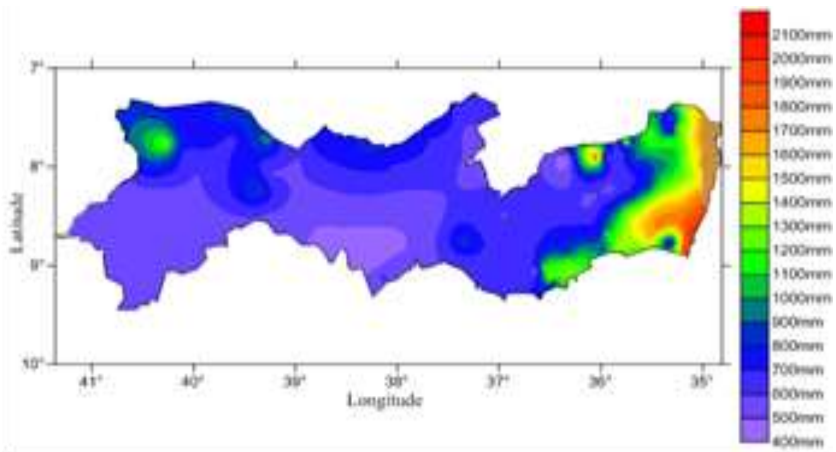
Figure 3 – Average annual temperature for the State of Pernambuco.



Source: Medeiros & Duarte (2020).

Figure 4 illustrates that the distributions of the average annual isoietas for the State of Pernambuco show high spatial variability, with fluctuations varying between 400 mm and 2100 mm. In the coastal region, the Zona da Mata registers high rainfall levels, in the high sertão and sertão there are rains of up to 1100 mm in isolated areas, as well as variations from 400 mm to 900 mm on the border with the states of Alagoas, Bahia and Piauí. On the border with Paraíba, rainfall rates ranging from 400 mm to 1100 mm in a small area of 1900 m². In the Agreste region the variability in the occurrence of rain is from 400 mm to 1100 mm. These variabilities are due to factors acting in the atmosphere, such as low intensity of the solar rays, high cloud cover, fluctuations in the relative humidity of the air and the oscillation of atmospheric pressure according to the results of Nobre & Molion (1988).

Figure 4 – Annual isoietas (mm) for the State of Pernambuco.



Source: Medeiros & Duarte (2020).

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Table 2 shows the variability of the meteorological elements corresponding to the water balance (BH) calculations: Average air temperature, Precipitation, Evapotranspiration, Evaporation, Surplus and Water Deficiency monthly for the State of Pernambuco. The average annual temperature is 23.7 ºC, with fluctuations between 21.5 ºC in July and 25.1 ºC in January. Average annual precipitation of 959.9 mm and its oscillations flowing between 21.1 mm in the month of October to 135.5 mm in the month of April. The annual evapotranpirative and evaporative indices were 1207.8 mm and 887.7 mm, respectively. Evapotranspiration was greater than the rainfall rate by 20.52% of its annual value. Evaporated 8.13% below the rainfall index. With an annual water surplus of 320.1 mm, recorded between the months of September to February, and water deficiencies of 72.2 mm in the months of June and July. These irregular fluctuations in the studied elements are in accordance with the studies by Marengo et al. (2011); Marengo & Camargo (2008); Marengo & Camargo (2007); Medeiros et al. (2018); IPCC (2014); IPCC (2007).

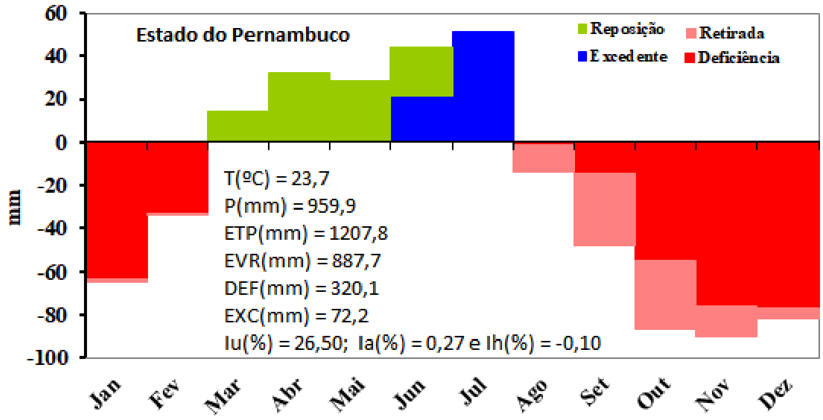
Table 2 – Average air temperature (ºC), Precipitation (mm), Evapotranspiration (mm), Evaporation (mm), Water surplus (mm) and Water deficiency (mm) monthly for the water balance of the State of Pernambuco.

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
Oct	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
Yearly	23.7	959.9	1207.8	887.7	320.1	72.2

Legend: TEM = Average air temperature (°C); PREC = Precipitation; ETP = Evapotranspiration; EVR = Evaporation; EXC = Water surplus and DEF = Water deficiency.
Source: Medeiros & Duarte (2020).

In Figure 5, there is a graphical representation of the climatological water balance for the State of Pernambuco. Water deficiency occurred between August and February; the withdrawal of water in the soil predominated between the months of August to December. The replacement of water in the soil runs from March to June and water surpluses in the months of June and July. It is noteworthy that in the BH graph are the annual fluctuations of the aforementioned climatic elements, aiming at a better understanding or understanding.

Figure 5 – Graphical representation of the climatological water balance for the State of Pernambuco.

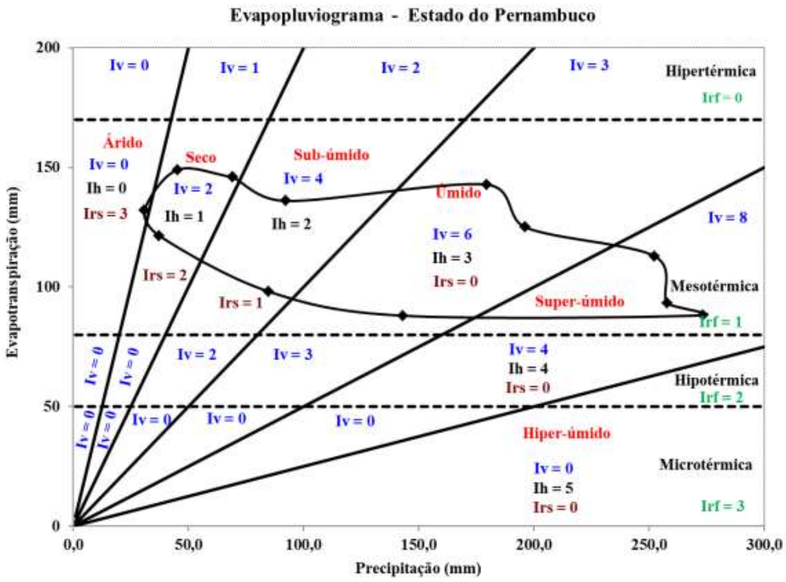


Source: Medeiros & Duarte (2020).

Figure 6 shows the illustration of the evapopluviogram, which is a climate chart adjusted by BH, for the purpose of studying climatic species adapted to the cultivars to which it is intended to be applied, using orthogonal coordinate systems. The diagram is divided into six water sectors, in which the rainfall values correspond to different multiples and submultiples of potential evapotranspiration, and in four other thermal ranges with values corresponding to the thermal limitations and requirements of the crop.

The distribution of the water sectors and thermal ranges of the evapopluviogram had the following behavior for the study period. The arid climate predominates 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 type of super-humid climate is characterized in three months. (Figure 6).

Figure 6 – Distribution of the water sectors and thermal ranges of the evapopluviogram for the State of Pernambuco.



Source: Medeiros & Duarte (2020).

The variability of the climatic indexes and parameters for the State of Pernambuco are shown in Table 3. These indexes and parameters were generated from the BH computer and the evapopluviogram. The meanings of the symbols are available in the legend of Table 3. Studies such as that by Medeiros et al. (2013) demonstrate similarities in indexes with several studies carried out for the Northeastern semi-arid region.

Table 3 – Indexes and climatic parameters for the State of Pernambuco.

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

Legend: Ih = Evapopluviogram water index; Iv = vegetation indexes; Irs = dry rest; Irf = cold rest (Irf); Cv = Evapotranspiration concentration in the hot season; T = Average air temperature; P = average rainfall; ETP = potential evapotranspiration; EVR = Actual evaporation; DEF = Water deficiency and EXC = Water surplus.
Source: Medeiros & Duarte (2020).

Alves (2014), in their studies, showed that the distribution of evapotranspiration and precipitation in the climatogram generates the four thermal ranges and the six water sectors, being a decisive tool in characterizing the climate of a given region for the exploration of the

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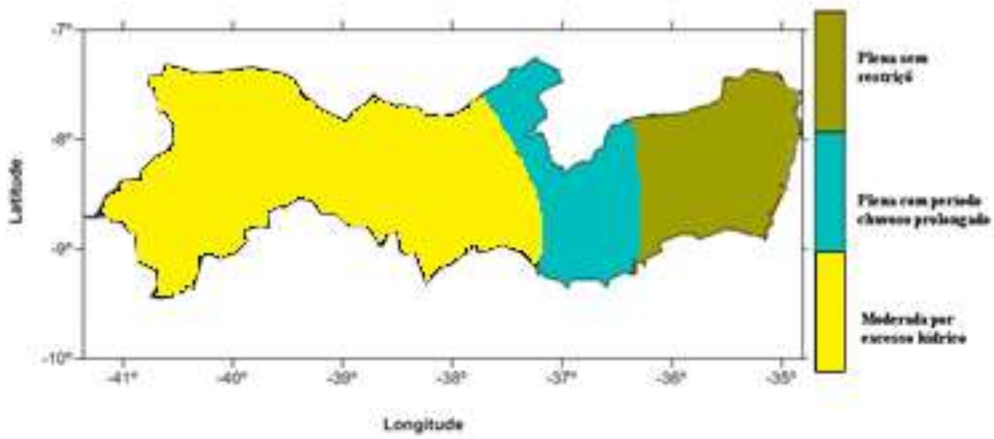
region's own cultivars. These results determined by Alves (2014) corroborate with the discussions in this article.

Figure 7 illustrates the distribution of the water surplus in the state of Pernambuco and its climatic suitability for the cultivation of sorghum. There were three types of aptitudes for planting sorghum in the state. Representing 65% of planting moderated by excess water, 15% of planting with prolonged rainy season and 20% of planting without restrictions, which characterizes a strategy of using the soil in its aptitudes.

Figure 7 – Distribution of the water surplus in the state of Pernambuco and its climatic suitability for the cultivation of sorghum.



Source: Medeiros & Duarte (2020).

4. Final Considerations

In the high sertão region, there is moderate fitness due to excess water, considering its diverse potential and opportunities, which makes it unlimitedly comparable with other regions in other countries. With another vision in the agreste region, full fitness was obtained with prolonged rainy season. In the Zona da Mata and Litoral regions, fitness is full without restrictions.

The study provides a tool for strategic planning and possible governmental actions aimed at the best way to implement the potential of sorghum's climatic aptitude for the state of Pernambuco, Brazil.

For future work, funding is recommended through research promotion agencies involving the contrasts of the high sertão and the agreste, seeking to make the two ecosystems extremely attractive and in full conditions to improve people's lives.

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