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Cultural skills for the municipality of Recife - Pernambuco, Brazil

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Abstract

The objective is to characterize the climate and to carry out zoning and agroclimatic aptitude for pineapple, herbaceous cotton, banana, sugarcane, beans, corn, cassava, castor bean, sisal and sorghum crops, pointing out their possible cultivation skills in the city Recife - PE. A historical series of rainfall and mean air temperature was used to calculate climatological water balance, climatic classification, evapopluviogram construction and agroclimatic zoning of the crops. Recife - PE has full aptitude for the cultivations of pineapple, herbaceous cotton, beans, castor bean, cassava and sisal. For the cultivation of cashew, maize, sugarcane and sorghum we contacted moderate aptitude. Only banana cultivation is restricted due to the region having a marked water deficit. The elements temperature, rainfall were determinant for the calculation of the water balance and the definition of the pluviometric scenarios. The study provides support to decision makers by providing information on Climatological Water Balance, climatic classification, agroclimatic zoning and crop aptitude, favoring adequate planning of agricultural activities and consequently reduction of crop risks.

Keywords: Evapotranspiration; Evapopluviograma; Water Deficiencies and Surpluses; Water Storage

1. Introduction

The climatological water balance (BHC) is used to estimate climatic parameters and, based on these, it is possible to identify climatically favorable conditions for the exploitation of a particular local or regional crop, according to the authors [12]. According to [11], the BHC provides assessments of actual evapotranspiration (EVR), water deficit (DEF), water surplus (EXC) and soil water storage (ARM), and can be prepared from daily to monthly scales.

[8a] reports that the studied region has a rainy season corresponding to the months of January to April, with March being the wettest month, with an average monthly total of 240.6 mm, while August has the lowest rate, rainfall 2.7 mm. Rainfall from June to November is characterized as below real evapotranspiration, not being sufficient for rainfed agricultural production and with little contribution to soil water storage, requiring water supply for crops through irrigation.

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The suitability of a given region is defined based on the association of precipitation, temperature and local altitude as stated by [21], this information is of great relevance under the social aspect inherent to the cultures, generating resources for family farming.

The Northeast region of Brazil (NEB) is characterized by the spatial and temporal irregularity of precipitation and the processes of runoff and soil erosion, as well as the high potential for water evaporation due to the enormous availability of solar energy and high temperatures throughout the year. Thus, the NEB region is considered an anomalous region with regard to the spatial and temporal distribution of precipitation throughout the year, as stated by [18]. Hot and humid tropical climates, like ours, seem to be the most unfavorable, and the white man cannot live long in such climates without wearing out his energy and his resistance to disease.

The regional climate variability influences the different socioeconomic, agricultural and agribusiness activities. The climate is constituted by a set of integrated elements, determinant for life, which acquires relevance, in its configuration, being able to facilitate or hinder the establishment of man and the development of his activities in the different regions of the planet. Among the climatic elements, precipitation plays a leading role in the development of human activities, producing results in the economy in accordance with [15].

For [14] states that to ensure productivity in terms of quantity and quality of crops, they state that it is essential to use irrigation systems in regions with severe water deficits, especially when this deficit extends for almost every month of the year.

Water is essential for the development of crops, lack or excess can influence agricultural production in a particular location or region. According to [9b] the water balance technique provides the balance of water available in the soil for the plant, that is, it accounts for the input (precipitation and/or irrigation) and output (potential evapotranspiration), considering a certain water storage capacity by the soil.

Agroclimatological zoning constitutes an important tool in the decision-making process, allowing, from the analysis of local climatic variability and its spatialization, the delimitation of regions with different climatic aptitudes for cultivation. The definition of sowing times adjusted to the probabilistic studies of the temporal distribution of rainfall, as well as the recommendation of cultivars with greater yield potential, greater resistance to water deficit and with earlier cycles can reduce the effects caused by poor distribution of rainfall and by the use of inappropriate technologies according to [16a]. Thus, the investigation of the local climate based on aridity (Ia), water (Ih) and humidity (Iu) indices; favors the study of agroclimatic zoning, determining the aptitude of the exploited crops, based on the evapopluviogram and the calculation of vegetation indices (Iv), dry rest (Irs), cold rest (Irf) and water (Ih).

Thornthwaite's climate classification system (1948) allows to efficiently separate the climates of a region, since the method is very sensitive to the total rainfall, temperature and relief of the studied region, resulting in a greater number of climate types, generating efficient information. Through the normal BH, demonstrating the ability to delimit agroclimatic zones as quoted by [13].

The crops that probably adapt to the climatic conditions for the municipality of Recife - PE will provide its agricultural development, making it profitable and socioeconomically viable, sugar, beans, corn, castor beans, cassava, sisal and sorghum classifying the aptitudes of the most suitable crops for planting in the region and their climate classification.

2. Material and methods

Recife is among the three largest urban agglomerations in the Northeast Region. It occupies a central position, with a distance of around 800 km from the other metropolises, Salvador and Fortaleza, disputing with them the strategic space of influence in the Region. With a territorial area of 330 km^2, Recife is limited to the north by the cities of Olinda and Paulista, to the south by the municipality of Jaboatão dos Guararapes, to the west by São Lourenço da Mata and Camaragibe, and to the east by the Atlantic Ocean. According to data from the 2010 census, the City of Recife has a population of over two million inhabitants [3]. Located at latitude 08º01'S; Longitude 34º51'W, with an average altitude in relation to sea level of 72 meters (Figure 1).

Source: Medeiros (2022).

Figure 1 Location of the city of Recife

The meteorological systems that contribute to the precipitation of the Recife Metropolitan Region are the Frontal Systems, the Eastern Wave Disturbances and the Sea and Land Breezes, the latter being originated in the Atlantic Ocean; East Waves are common in autumn/winter, aided by the southeast trade winds, Waves reach the eastern coast of the Northeast, causing heavy rains, another precipitation inducer is the Intertropical Convergence Zone (CZIT) , disturbance associated with the expansion towards the southern hemisphere of the thermal equator (zone of rise of the trade winds by thermal convection). The CZIT reaches Recife, mainly in autumn, and causes rains with thunderstorms and changes in the direction of the winds from SE to NE, or even calms. The formation of High Level Cyclone Vortex Systems (ASVC) when they form in the months of February to April and with their edges over the NEB, especially above the state of Pernambuco, increases cloud cover and causes moderate to heavy rainfall, in a short period of time, causing damage to communities such as flooding, floods, floods and to the socioeconomic, agricultural, leisure, energy generation and tourism sector in accordance with [9].

The climate of the city of Recife-PE according to [19] is classified as Megathermal Wet Dry for the two periods under study, with sufficient rainfall in all seasons, with associated vegetation as Forest/Atlantic Forest. Thus, the climate type changed from type B_1w_2SA' to $B_3W_2\Gamma A$, resulting in a trend towards a wetter climate, concluding that there were indications of climate change in some elements studied [9].

The method applied was to obtain the climatic water balance proposed by [19; 20], with the elaboration of electronic spreadsheets carried out by [9] that account for soil water, in which precipitation represents gain and evapotranspiration loss of water, soil moisture, and the values corresponding to the Water Surplus (EXC) and Water Deficiency (DEF) can be estimated. Based on this methodology, the available soil water storage capacity (CAD) of 100 mm was estimated. Potential Evapotranspiration (PTE) was obtained according to the Equation described below

$$ETp = Fc \cdot 16 \cdot \left(10\frac{T}{I}\right)^{a}$$

On what:

ETP – Potential annual evapotranspiration in mm.month-1;
Fc – Correction factor, according to Table 1;
T – Monthly average temperature in °C;
I – Annual heat index, corresponding to the sum of the twelve monthly indexes; and
a – Cubic function of the annual heat index given by:

$$a = 6{,}75*10^{-7}*I^{3}-7{,}71*10^{-5}*I^{2}+0{,}01791*I+0{,}492$$

In mm.month^{-1}.

Table 1 Correction Factor (Fc) according to [19] methodology as a function of the months of the year

Fator de Correção											
Jan	Fev	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez
1,80	0,97	1,05	0,99	1,01	0,96	1,00	1,01	1,00	1,06	1,05	1,10

Source: UNESCO (1982).

In the calculation of aridity, humidity and water indices, the following equations were used. Such indices are essential for the climatic characterization of the region according to the method of [19], and in the study of adaptation of cultures to the region - Agricultural Zoning.

$$Ia = 100\frac{\sum D}{\sum ETp}$$

$$Iu = 100\frac{\sum ES}{\sum ETp}$$

$$Ih = Iu - 0{,}6 \cdot Ia$$

On what:

Ia – Aridity index;
Iu – Moisture index;
Ih – Water index;
∑DEF – Sum of annual water deficit;
∑EXC – Sum of annual water excess; and
∑ETp – Sum of potential annual evapotranspiration.

The climatic classification was obtained according to the methodology proposed by [19] using the values of aridity (Ia), humidity (Iu), water (Ih) and (Cv) indices in accordance with the concentration of potential evapotranspiration in the hot season, defined by the three consecutive months of highest temperature of the year.

The concentration of potential evapotranspiration in the warm season was given by Equation 5, which represents the percentage of annual evapotranspiration that occurs in the highest temperature month's j, k, l of the year (warmest quarter).

$$Cv = 100\left(ETp_j + ETp_k + ETp_l\right)/\left(ETp\right)$$

Em que:

Cv – Concentração da evapotranspiração na estação mais quente do ano;
ETp_j – evapotranspiração potencia no mêsj;
ETp_k – evapotranspiração potencial no mês k;
ETp_l – evapotranspiração potencial no mês l;
ETp – evapotranspiração potencial anual.

An evapopluviogram was prepared, which refers to a climogram adapted to the BHC, for the purpose of studying the most suitable climatic conditions for the crops, through the orthogonal coordinate system. As in this case the potential evapotranspiration is plotted as a function of precipitation, thus the evapopluviogram is obtained.

The diagram is divided into six water sectors, in which the precipitation values correspond to different multiples and submultiples of potential evapotranspiration, and into four other thermal bands with values corresponding to the thermal limitations and requirements of the crop. Using the evapopluviogram points, vegetation (Iv), dry rest (Irs), cold rest (Irf) and water (Ih) indices were determined.

Finally, the values of the climatic indexes were applied in Table 2 to determine the climatic suitability of the region, classifying the cultures in full suitability, moderate, restricted and unsuitable.

Table 2 Summary of crop suitability and climatic requirements (Ometto, 1981)

Culture	Fitness	Climate Index	Deficiency/Excess
Pineapple	full moderate restricted Disabilit	→ $-20 \leq I_h < 20$ → $I_h > 20$ → $-20 \leq I_h < -20$ → $-40 \leq I_h < -30$ → $I_h < -40$	Good hydric and thermal conditions for the development of the culture. Excessive humidity, harming the vegetative development and fruiting of the crop. Water restrictions for crop development. Limitations for pineapple cultivation, due to severe water deficit. Severe water deficiency, not allowing the development of the culture, except through irrigation.
Herbaceous cotton	full moderate restricted Disabilit	→ $30 \leq I_v < 50$, $I_{sv} \leq 1$ e $I_{rs} \geq 4$ → $30 < I_v < 50$, $I_{sv} > 1$ e $I_{rs} \geq 4$ → $30 < I_v < 50$ → $I_{sv} \leq 1$ e $I_{rs} < 4$ → $20 < I_v < 30$, $I_{sv} > 1$ e $I > 50$ → $I_v < 20$	Good hydric and thermal conditions for the development of the culture. Normal vegetative period, but with occurrence of drought. Insufficient dry rest for fiber maturation. Short vegetative period with occurrence of drought in it. Excessive humidity for crop development. Occurrence of drought throughout the crop cycle.
Banana	full moderate restricted Disabilit	→ DEF<200 mm → 200<DEF<350 mm → 350<DEF<00 mm → DEF>700 mm	Good water conditions for crop development. Seasonal water insufficiency, prolonging the crop cycle. Marked water deficit, being possible to grow only in floodplains and more humid places. Very severe water deficit. Cultivation only possible through irrigation.
cashew	full moderate restricted Disabilit	→ $I_h > -10$ e DEF<100 mm → $I_h < -10$ e 100<DEF<200 mm → 200<DEF<700 mm → 700<DEF<900 mm → DEF>700 mm	In general, there are no climatic limitations for the crop, especially in hot regions and climates. Normal occurrence of small water deficit. Partial cultivation impaired by water deficiency. Severe water deficit in most soils. Cultivation only through irrigation water supply. Insufficient water supply for the crop.
Sugar cane	full moderate restricted Disabilit	→ $I_h > 0$ e DEF<200 mm → $I_h > 0$ e DEF> 00 mm → $0 > I_h > -10$ → $I_h < -10$	Good water conditions for crop development Occurrence of seasonal drought; recommended cultivation in wet floodplains. Occurrence of intense seasonal drought. Cultivation possible with supplementary irrigation. Very severe water shortage for sugarcane cultivation.
Bean	full moderate restricted	→ $I_v > 30$, $1 < I_{rs} < 5$ DEF>20 mm, T >22ºC → $25 < I_v < 30$ → DEF>20 mm, T>22ºC → $2 < I_v < 25$ → $I_v < 20$ e DEF>20 mm	Better climatic conditions for the development of the culture. Short growing season. Full suitability for early varieties. Severe water deficiency, requiring water supply by irrigation.

	Disabilit		Inappropriate cultivation due to severe water insufficiency. Cultivation possible only with irrigation.
Corn	full moderate restricted Disabilit	→ $40<I_v<60$, DEF>0 e T>9ºC → $30<I_v<40$, DEF<0e EXE<500mm → $I_v<20$ → $I_h>-10$, DEF>100mm e EXC<500 mm	Satisfactory water and thermal conditions for the development of the culture. Small water insufficiency in the vegetative period, with excessive humidity at maturation. Full suitability for early varieties. Severe water deficiency for the development of the culture, or thermal insufficiency.. Very severe water deficit, making corn cultivation unfeasible.
castor bean	full moderate restricted Disabilit	→ $-20<I_h<0$, DEF>60 mm e T>20ºC → $-40<I_h< -20$, 0<DEF<60 mm e T > 20ºC → $I_h>0$, DEF>100 mm e T<19ºC → $I_h<-40$	Good hydric and thermal conditions for the cultivation of any varieties. Small water deficit, except for drought resistant varieties. Areas that are too wet or too dry for the crop. Thermal insufficiency. High water deficits, which jeopardize the development of the culture.
Manioc	full moderate restricted Disabilit	→ $-10<I_h<50$ e T>19ºC → $-35<I_h<-10$ e 17ºC<T<19ºC → $-45<I_h< -35$ → $I_h<-45$ e T<17ºC	Satisfactory climatic conditions for the crop. Small water deficit and thermal limitations for the development of the culture. Severe water deficiency or excess, harming the development or maintenance and harvesting of the crop. Inadequate water and/or thermal conditions for cassava cultivation.
Sisal	full moderate restricted Disabilit	→ $I_h>-10$, DEF>100 mm e EXC<500 mm → $-30<I_v<-10$ e EXC<500 mm → -40<DEF<-30 mm → $I_h<-40$ mm	Good water conditions for crop development. Deficient water supply, harming the development of the culture in some years. Represents excessive humidity in the growing season. Marked water deficiency, harming the vegetative development of the crop. Very severe water deficiency, making the cultivation of sisal unfeasible.
Sorghum	full moderate restricted Disabilit	→ $20<I_v<30$, DEF>200 mm e T>18ºC → $30<I_v<40$ e EXC<00 mm → $40< I_v<60$ → $I_v>60$	Satisfactory water and thermal conditions, both in the rainy season and in the dry season. Due to excess water, affecting production. Restrictions on sorghum cultivation due to its accentuated water excess. Not recommended for sorghum cultivation.

A historical series of 53 years of meteorological data was used for the municipality of Recife - PE, from 1962 to 2015, where these data went through a phase of consistency, filling in gaps and harmonization, later being applied in electronic spreadsheets. The data were kindly acquired from the conventional meteorological station, belonging to the Instituto Nacional de Meteorologia [4].

3. Results and discussion

The variables used to determine the BHC for the period from 1962 to 2015 in the city of Recife - PE are shown in Table 3 and as shown in figure 2, considering the available water storage capacity (CAD) of 100 mm.

The average annual temperature is 25.7 °C, with monthly fluctuations of 24 °C in July and a maximum of 26.9 °C in February. The months of December, January, February and March are the four months of high temperatures of the year, corresponding to the highest rates of potential evapotranspiration.

The range values are in accordance with the cultivar requirements of the region, which presents good physiological development with a temperature ranging from 18 to 34 ºC, temperatures below or above these ranges can harm the development of the reproductive structures of the plants, promoting abortion and fall. of flowers as stated by [7]. [2] also showed in studies on fruit growing in the state of Ceará that temperatures range from 18 to 28 ºC with hot, dry and sub-humid climates, reaffirming the results found in the study.

With irregular rainfall distribution, Recife has an annual average of 1.174.7 mm, with the highest rainfall between the months of February and August, with rainfall between 113.7 and 300.1 mm, which corresponds to the rainy months, The minimum pluviometric indices occur from October to December, with fluctuations from (37.1 to 49.7 mm).

With an annual evapotranspiration rate (ETp) of 1.490.2 mm, with oscillations from 96 to 148.5 mm month-1, the highest evapotranspiration rates occur from September to June. It should be noted that there is a smaller amount of evapotranspired water when compared to the air temperature recorded in the coldest months of the year, July and August. Potential evapotranspiration in the coldest month (June) is only 96 mm month-1, while in the warmest month (February) it is 136.4 mm.

The consumption of how much water is actually being evapotranspired is expressed by the real evapotranspiration (ETr), which behaved differently from the distribution of precipitation (Table 3). These fluctuations occur due to the oscillations between the regional dry and rainy periods. It should also be noted that the oscillations of the factors that provoke and/or inhibit rainfall depend exclusively on large, meso and large-scale phenomena, as well as on the contributions of local effects.

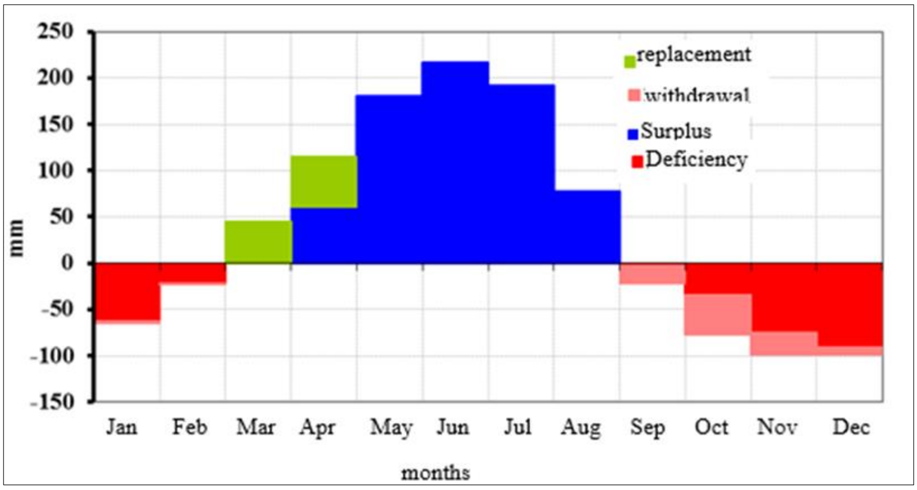
Table 3 Climatological water balance (BHC) for the city of Recife - PE

Meses	T (°C)	P (mm)	ETp (mm)	ETr (mm)	DEF (mm)	EXC (mm)
January	26.7	79.9	144.9	82.3	62.5	0.0
February	26.9	113.7	136.4	114.2	22.2	0.0
March	26.7	191.1	146.6	146.6	0.0	0.0
April	26.2	243.6	129.0	129.0	0.0	61.2
May	25.5	300.1	119.4	119.4	0.0	180.7
June	24.6	318.1	101.3	101.3	0.0	216.7
July	24.0	287.9	96.0	96.0	0.0	191.9
August	24.1	174.8	97.6	97.6	0.0	77.2
September	24.9	85.2	107.3	105.1	2.3	0.0
October	25.7	49.7	127.5	93.0	34.4	0.0
November	26.3	37.1	135.7	60.2	75.5	0.0
December	26.7	49.4	148.5	58.0	90.5	0.0

Symbols: Mean air temperature (T), Rainfall (P), Potential Evapotranspiration (ETp), Actual Evapotranspiration (ETr), Water Deficiency (DEF) and Water Surplus (EXC).; Source: Medeiros (2022).

The behavior of water deficiency must be observed in agricultural planning, aiming at a safe and economically viable agriculture, the use of irrigation systems is recommended. Historical knowledge of climatic conditions is important to plan the crops and the management to be carried out during the crop cycle, carefully observing the variability of precipitation and the intensity of evapotranspiration, which can be avoided, or reduced to a minimum. Maximum, the occurrence of water deficit according to the statement by [7].

Water deficiencies (figure 2) are registered in the months of September to February. There are no water deficits in the months of March to August, the water surpluses occur in the months of April to August, the surpluses are registered between April to August. The withdrawal of water between September and December and the replacement of water between March and April.



Source: Medeiros (2022).

Figure 2 Climatological water balance for Recife – PE

Through the BHC, it was possible to determine the indices of aridity (Ia), humidity (Iu), water (Ih) and Cv, where Cv is the concentration of potential evapotranspiration in the hot season, determined by the three consecutive months of highest temperature in the year (warm quarter). Such indices determine the climatic classification, based on observations and studies carried out in the conditions of the arid Southeast of the United States of America and applied to the rest of the world, proposed by [19].

Table 4 Climatic classification (CC) for Recife - PE

Ia	Iu	Ih	climate type in function of the index water (Ih)	climate type as a function of Potential Evapotranspiration (ETp)	Climate subtype in function of oh and oh	Subtype climate according to of (Cv)
(%)						
0.19	19.28	0.37	B1	W2	S	A

Source: Medeiros (2022).

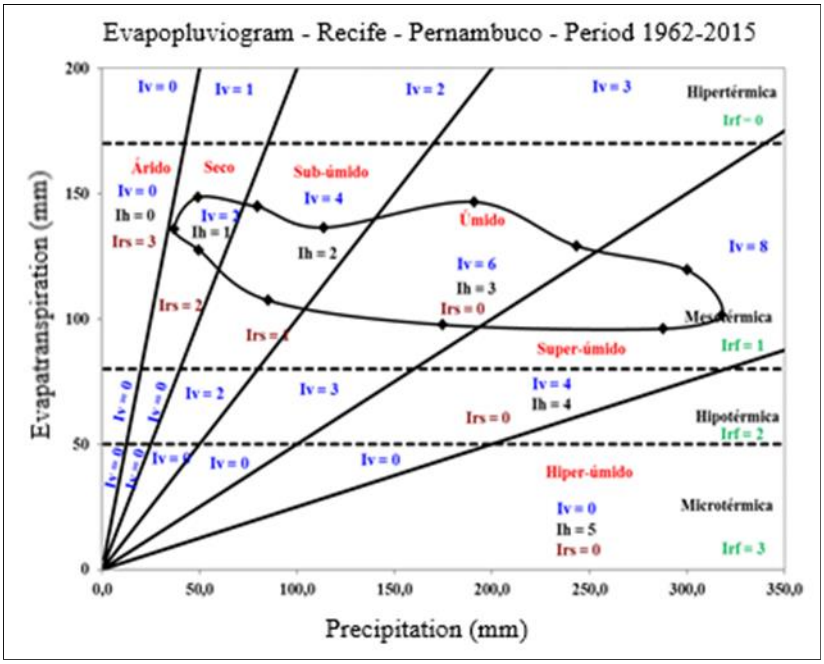
From the results of the BHC and the relationship between evapotranspiration and precipitation, the evapopluviogram Figure 3 was elaborated, in order to carry out the agroclimatic zoning for the crops in the municipality of Recife - PE. According to the authors [1], the distribution of potential evapotranspiration and precipitation in the evapopluviogram, generate the four thermal bands and six water sectors, being an effective tool in characterizing the climate of a given region for crop exploration.

After the calculations of the evapopluviogram and application in tables, the results of the climatic indices are shown in Table 5. These indices are in agreement with several studies carried out for the northeastern semi-arid region, according to [9b].

Table 5 Climatic indexes and parameters for Recife - PE

Climate Index	Ih	Iv	Irs	Irf	Cv	T_a	P	ETp	DEF	EXC
					(%)	(ºC)	(mm)			
Value	30	48	9	3	37.2	25.7	1174.7	1490.2	287.4	727.6

Symbols: Ih - Annual water index derived from the water balance, Iv - Annual vegetative index, Irs - Dry rest index, Irf - Cold rest index, Cv - Concentration of potential evapotranspiration in the warm season, T - Annual mean temperature, P - Rainfall, ETp - Annual Potential Evapotranspiration, DEF - Water Deficiency and EXC - Water Excess; Source: Medeiros (2022).



Source: Medeiros (2022)

Figure 3 Distribution of water sectors and thermal bands of the evapopluviogram Recife – PE

According to [22] the local water and climate conditions are taken into account in the agroclimatic zoning, aiming at the exploitation of economically profitable crops. These are the agroclimatic characteristics of this locality that determine aptitude for the development of cultures.

According to the climatic indexes of Table 5 applied in relation to Table 2, agroclimatic zoning was carried out for some crops for the region, with full, moderate and restricted suitability. The cultures and their physiological activities that adapt to local climatic and water availability were determined for the study area, which are shown in Table 6.

Table 6 Agroclimatic Zoning of some crops for the city of Recife - PE

Culture	**Climate Index**	**Fitness**
Pineapple	$-20 \leq I_h < 20$	full
herbal cotton	$30 \leq I_v < 50$; $I_{sv} \leq 1$ e $I_{rs} \geq 4$	full
Banana	350 <DEF< 700 mm	restricted
Cashew	$I_h < -10$; 200 <DEF< 700 mm	moderate
Sugar cane	$0 > I_h > -10$	moderate
Bean	$I_v > 30$; $1 < I_{rs} < 5$; DEF < 20 mm; $T_a > 22$ ºC	full
Corn	$30 < I_v < 40$; D < 0; EXC < 500 mm	moderate
castor bean	$-20 < I_h < 0$; DEF > 60 mm; T > 20 ºC	full
Cassava	$-10 < I_h < 50$ e $T_a > 19$º C	full
Sisal	$I_h > -10$, DEF > 100 mm, EXC < 500 mm	full
Sorghum	$30 < I_v < 40$, S < 500 mm	moderate

Source: Medeiros (2022).

From the climatic requirements of the crops and based on the ranges of full, moderate, restricted and unsuitability of some crops, and the results of the Ih - Water index, Iv - Vegetation index, Irs - Dry rest index, T - Average temperature, DEF - Water deficiency and EXC - Water excess, it was verified that Recife - PE has full suitability for the cultivation of pineapple, herbaceous cotton, beans, castor bean, cassava and sisal. For the cultivation of cashew, corn, sugarcane and sorghum, moderate suitability was found. Only banana cultivation is restricted due to the region presenting a marked water deficit.

4. Conclusion

The temperature and rainfall elements were decisive for the calculation of water balances and the definition of rainfall scenarios.

The study provides support to decision makers, through the availability of information on the Climatological Water Balance, climate classification, agroclimatic zoning and crop suitability, favoring adequate planning of agricultural activities and consequently reducing the risks of the cultures submitted.

The physiological activities of the crops adapt to the water and climatic availability of the region.

Compliance with ethical standards

Disclosure of conflict of interest

The authors' participation was equal in the development of the article.

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