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Classification, suitability and zoning of crops in the high course of the Paraíba River Basin – Brazil

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Abstract

Characterization, agroclimatic zoning and crop suitability are important for defining the agricultural potential of a given region or location, defining the planting season and types of crops suitable for the region. Based on the results of the Water Balance and the corresponding evapopluviogram, it was used to carry out the agroclimatic zoning and its aptitudes for crops suitable for planting in the area of the hydrographic basin of the upper course of the Paraíba River. Monthly and annual rainfall data series were used, collected by the Northeast Development Superintendence and provided by the Executive Agency for Water Management of the State of Paraíba. Municipality to municipality). The average air temperature values estimated by the Estima_ T software. The region has an annual water deficit of 794.0 mm, with no storage and excess of water in the soil. The indices of aridity, humidity and water were 65.38; 0.00 and -39.23%, respectively. The climate was classified as Semi-arid, Megathermal, with little or no excess of water and with 29.41% of the potential annual evapotranspiration concentrated in the hottest quarter of the year. There was restricted aptitude for the cultivation of pineapple, cashew, beans and corn; bananas and sugarcane are unsuitable for cultivation, while herbaceous cotton has moderate conditions. To ensure profitable agricultural productivity, the supply of water through irrigation is essential.

Keywords: Irrigation; Agricultural Planning; Water Balance; Climate Variability

1. Introduction

The crops and ranges in which they adapt to the climatic conditions in the upper Parnaiba river basin area provide the development of productive, profitable and socioeconomically viable agriculture for producers, in accordance with the agricultural zoning carried out in the area. In accordance with [2], studies on zoning seek to delimit areas that have productive potential and maintain these potential over time with minimal impact on the environment.

The environment is constituted by a natural set of biotic and abiotic components in constant and complex interactions. In these mutual relationships, the climate acts as a factor in these interactions. The climate of any region, located in the most diverse latitudes of the globe, does not present itself with the same characteristics each year [16].

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[14], demonstrated that the continuous variation of the weather state brings consequent changes to the physical environment in which plant and animal beings develop, making it necessary, therefore, to interpret their effects, the study of meteorological phenomena during the years and its relationship to normal weather conditions.

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 productive potential and greater resistance to water deficit with earlier cycles can reduce the effects determined by the poor distribution of rainfall and the use of inappropriate technologies according to the statement by [15].

The constant changes in the climate are causing an increase in the occurrence of extreme weather events worldwide. In Brazil, these events occur mainly as floods (heavy rains) and prolonged droughts, according to [10]. In the Northeast of Brazil the impacts are greater due to the great rainfall variability in the region. The main systems responsible for the occurrence of precipitation in the NEB are Intertropical Convergence Zone, High Level Cyclonic Vortices, Line of Instability, South Atlantic Convergence Zone, Breezes (Sea and Land) and Wave Disturbances in the Trade Winds [13]. El Niño – Southern Oscillation is another mode of climate variability that influences the occurrence of NEB precipitation.

According to [11], it is extremely necessary to carefully observe the behavior of water deficiency in agricultural planning, in order to obtain a safe and economically viable agriculture. [21] Described that local water and climate conditions are induced into consideration in agroclimatic zoning, aiming at the exploitation of economically profitable crops. [20] Report that the aptitude of a given region is defined based on the association of precipitation, temperature and local altitude, this information is of paramount importance for the development of cultures.

According to [9], in order to obtain information on a region that has a deficiency or excess of water during the year, it is essential to compare two opposite elements of the water balance: precipitation, which increases soil moisture and evapotranspiration, which reduces water soil moisture according to [9]

The evapotranspiration (ETP) is the important parameter to determine the water needs of the plant, because they fundamentally depend on the microclimatic conditions, such as precipitation, wind speed, temperature and relative humidity of the air and solar radiation; from the characteristics of the plants, it is necessary to see the cultivars, vegetative stage, leaf area index, extension and depth of roots and their metabolic activities of the plant; as well as the availability of water in the soil according to the reports by [7].

Therefore, the Thornthwaite climate classification method is widely used, and this function of normal climatological data of temperature, precipitation and potential evapotranspiration (ETp), being efficient to detect small climatic spatial variations when compared to the Köppen classification, according to the authors. [6].

For that, the results of the Water Balance and the corresponding evapopluviogram were taken as a basis, aiming at carrying out the agroclimatic zoning and their aptitudes for crops suitable for planting in the area of the hydrographic basin of the upper course of the Paraíba River.

2. Material and methods

The Paraíba River Basin, with an area of 20,071.83 km^2, between latitudes 6º51'31" and 8º26'21" South and longitudes 34º48'35"; and 37º2'15"; West of Greenwich, it is the second largest in the State of Paraíba, as it covers 38% of its territory, housing 1,828,178 inhabitants that correspond to 52% of its total population. Considered one of the most important basins in the northeastern semi-arid region, it is composed of the Taperoá River sub-basin and regions of the Upper Paraíba River, Middle Paraíba River and Lower Paraíba River. In addition to the high population density, the basin includes the cities of João Pessoa, capital of the state and Campina Grande, its second largest urban center (figure 1) [1].

The basin encompasses, totally or partially, the area of 18 municipalities in Paraíba (Amparo, Barra de São Miguel, Boqueirão, Cabaceiras, Camalaú, Caraúbas, Congo, Coxixola, Monteiro, Ouro Velho, Prata, São Domingos do Cariri, São João do Cariri, São João do Tigre, São Sebastião do Umbuzeiro, Serra Branca, Sumé and Zabelê), distributed between the Western and Eastern Cariri microregions of the State of Paraíba [1].

The basin is formed by regions affected by local, regional and large-scale synoptic events that provoke rain, such as the Intertropical Convergence Zone and the contributions of the High Level Cyclonic Vortex systems when in activity on the NEB, in addition to the effects resulting from the winds. Northeast trade winds in conjunction with the effects of sea breeze, aided by the formation of the Cyclonic Vortices of the South Atlantic; formations of squall lines, the Dipole

Pattern in the Tropical Atlantic Ocean and undulating disturbances in the field of trade winds, providing events of droughts, floods, floods, overflowing rivers, dams, barriers, ponds, lakes and streams. With regard to drainage, most of the flow of rivers at the headwaters of this basin is temporary due to poor rainfall distribution [1].

Source: EASA (2020).

Figure 1 Location of the Paraíba river watershed. In the southwest portion, its Upper course

Monthly and annual rainfall data series collected by the Northeast Development Superintendence (SUDENE 1990) and provided by the Executive Agency for Water Management of the State of Paraíba [1] were used. When using the data, consistency, homogenization and filling of gaps were carried out in each series (city by city).

The adopted methodology used the average air temperature values estimated by the Estima_T software [4; 5]. The empirical model for estimating the air temperature is a quadratic surface for the monthly mean, maximum and minimum temperatures, as a function of the local coordinates: longitude, latitude and altitude, in accordance with the authors [5], given by:

$$T = C0 + C1\lambda + C2\emptyset + C3h + C4\lambda 2 + C5\emptyset 2 + C6h2 + C7\lambda\emptyset + C8\lambda h + C9\emptyset h \ldots\ldots (1)$$

Where:

C0, C1... C9 are the constants;
λ, λ2, λ Ø, λ h longitude;
Ø, Ø2, λ Ø latitude;
h, h2, λ h, Ø h height.

The temperature time series was also used, adding to it the temperature anomaly of the Tropical Atlantic Ocean according to [4].

$$Tij = Ti + AATij \ldots\ldots..(2)$$

Where:

i= 1, 2, 3,...,12
j= 1950, 1951, 1952, 1953,..., 2014.

The calculations of water balances (BH) and climatic indices: Aridity: water and humidity, were checked according to the method of [18; 19] assuming the available water capacity of the soil (CAD) 100 mm.

The monthly reference evapotranspiration values were estimated by the method of [19], according to the methodology presented by [12].

$$Ih = \left(\frac{EXC}{ETP}\right) \times 100$$

$$Ia = \left(\frac{DEF}{ETP}\right) \times 100$$

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

Where:

Ih: water index;
Ia: aridity index;
Iu: moisture content;
EXC: water surplus from BH (mm);
DEF: water deficit from the BH (mm);
ETP: reference or potential evapotranspiration (mm).

The BH calculations were performed using the program developed by [12] taking into account the model by [18; 19]

An evapopluviogram was elaborated, which refers to a climagram adapted to the BH, for the purpose of studying the climatic conditions adjustable to the crops. The climogram consists of the graphic representation of the most relevant meteorological parameters for the plant, 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 submultiples and multiples of the potential evapotranspiration, and into four other thermal bands with values corresponding to the thermal limitations and requirements of the crop.

Based on the results of the BH and the corresponding evapopluviogram, the local agricultural zoning was carried out for crops with full, moderate and unsuitable suitability. Subsequently, in the same evapopluviogram, it was classified by water sectors and thermal bands, together with the vegetation indices: vegetation drought, dry rest and cold rest.

The investigation of the local climate based on indices of aridity (Ia), water (Ih) and humidity (Iu); 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).

From the calculations of the evapopluviogram, the agricultural zoning was carried out, since this information is of fundamental relevance to establish goals and guidelines for the cultures. 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 1 Summary of crop suitability and climatic requirements [14].

Culture	Fitness	Climate Index	Deficiency/Excess
Pineapple	full	→ $-20 \leq I_h < 20$	➡Good hydric and thermal conditions for the development of the culture.
	moderate	→ $I_h > 20$	➡Excessive humidity, harming the vegetative development and fruiting of the crop.
	restricted	→ $-20 \leq I_h < -20$	➡ Water restrictions for crop development.
		→ $-40 \leq I_h < -30$	➡Limitations for pineapple cultivation, due to severe water deficit.
	Disabilit	→ $I_h < -40$	➡Severe water deficiency, not allowing the development of the culture, except through irrigation.

Herbaceous cotton	full moderate restricted Disabilit	→ $30\le I_v<50$, $I_{sv}\le1$ e $I_{rs}\ge4$ → $30<I_v<50$, $I_{sv}>1$ e $I_{rs}\ge4$ → $30<I_v<50$ → $I_{sv}\le1$ 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 fibre 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 Disabilit	→ $I_v>30$, $1<I_{rs}<5$ 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. 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<0 e 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	→ $-20<I_h<0$, DEF>60 mm e	Good hydric and thermal conditions for the cultivation of any varieties.

	moderate restricted Disabilit	T>20ºC → $-40<I_h< -20$, 0<DEF<60 mm e T > 20ºC → $I_h>0$, DEF>100 mm e T<19ºC → $I_h<-40$	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.

Table 2 shows the indicators and their necessary variabilities for the full, restricted and unsuitable suitability of the area under study.

Table 2 Fitness and climatic indicators of the forage cactus Opuntia sp. (Souza et al., 2008)

skills		
Full	**Restricted**	**Disability**
16,1 ≤ Tméd ≤ 25,4	Tméd < 16,1; Tméd > 25,4	-
28,5 ≤ Tmáx ≤ 31,5	Tmáx < 28,5; Tmáx > 31,5	-
8,6 ≤ Tmín ≤ 20,4	Tmín < 8,6; Tmín > 20,4	-
10,0 ≤ AT ≤ 17,2	AT < 10,0; AT > 17,2	-
368,4 ≤ Prec ≤ 812,4	Prec < 368,4; 812,4 < Prec ≤ 1089,9	Prec > 1089,9
-65,6 ≤ Iu ≤ -31,8	-31,8 < Iu ≤ 7,7; Iu < -65,6	Iu > 7,7

Symbols: Tmed - Average temperature; Tmax - Maximum temperature; Tmin - Minimum temperature; AT - Thermal amplitude, Prec - Average annual precipitation; and Iu - Moisture index.

3. Results and discussion

Table 3 Location of the rainfall stations and the municipalities that are allocated to these stations, followed by their local geographic coordinates (latitude, longitude and altitude), followed by the climate classifications according to Thornthwaite and Mather, Köppen for the area under study

Municipalities/Coordinates	Latitude ° ‘S	Longitude ° ‘ O	Altitude metros	Ratings Thornthwaite e Mather				
				Normal	**Rainy**	**Regular**	**Dry**	**Köpper**
Barra de São Miguel	07 45	36 19	486	$C_1A's_2a'$	$C_2C'_1a'$	$C_2B'_2a'$	$C_2E'Ra'$	BSh
Cabaceiras	07 29	36 17	388	$C_1A's_2a'$	$C_2C'_1a'$	$C_2B'_2a'$	$C_2E'Ra'$	BSh
Camalaú	07 53	36 49	521	$C_1A's_2a'$	$C_2D'a'$	$C_2B'_2a'$	$C_2E'Ra'$	BSh
Caraúbas	07 43	36 29	451	$C_1A's_2a'$	$C_2D'a'$	$C_2B'_2a'$	$C_2E'Ra'$	BSh
Congo	07 47	36 39	480	$C_1A's_2a'$	$C_2D'a'$	$C_2B'_2a'$	$C_2E'Ra'$	BSh
Coxixola	07 37	36 36	475	$C_1A's_2a'$	$C_2C'_1a'$	$C_2B'_2a'$	$C_2E'Ra'$	BSh
Monteiro	07 53	37 07	599	$DA's_2Da'$	$C_2D'a'$	$C_2B'_2a'$	$C_2E'Ra'$	BSh
Prata	07 41	37 04	577	$C_1B'_4S_2a'$	$C_2D'Ra'$	$C_2B'_3Ra'$	$C_2E'Ra'$	BSh
São João do Tigre	08 04	36 50	577	$C_1B'_4S_2a'$	$C_2D'Ra'$	$C_2B'_2Ra'$	$C_2E'Ra'$	AS
São José dos Cordeiros	07 23	36 48	527	$C_1B'_4S_2a'$	$C_2D'Ra'$	$C_2B'_2Ra'$	$C_2E'Ra'$	BSh
São Sebastião do Umbuzeiro	08 09	37 00	594	$C_1B'_4S_2a'$	$C_2D'Ra'$	$C_2B'_4Ra'$	$C_2E'Ra'$	BSh
Serra Branca	07 28	36 39	493	$C_1A'S_2a'$	$C_2D'Ra'$	$C_2B'_2Ra'$	$C_2E'Ra'$	BSh

Source: Medeiros (2022).

Table 4 shows the summary of the water balance with the annual values for the municipalities that encompass the studied area.

Table 4 Location of municipalities and indices: humidity, water and aridity, Precipitation, evapotranspiration, evaporation, deficiency and water surplus for the study area

Municipalities/months	IU	IH	IA	PREC	ETP	EVR	DEF	EXC
Barra de São Miguel	63.57	0.64	-0.38	407.6	1165.7	424.6	741.0	0.0
Cabaceiras	72.29	0.72	-0.43	336.4	1197.9	332.0	865.9	0.0
Camalaú	52.54	0.53	-0.32	527.1	1134.2	538.3	595.9	0.0
Caraúbas	66.54	0.67	-0.40	380.7	1162.5	389.0	773.5	0.0
Congo	57.04	0.57	-0.34	478.8	1155.4	496.4	659.0	0.0
Coxixola	58.12	0.58	-0.35	481.0	1166.8	488.7	678.1	0.0
Monteiro	44.26	0.44	-0.27	615.0	1095.2	610.4	484.8	0.0
Prata	39.38	0.39	-0.23	664.3	1110.1	672.9	437.2	2.2
São João do Tigre	53.72	0.54	-0.32	462.7	1038.6	480.7	557.9	0.0
São José dos Cordeiros	49.74	0.50	-0.30	541.3	1120.5	563.2	557.3	0.0
São Sebastião Umbuzeiro	46.91	0.47	-0.28	549.2	1076.5	571.5	505.0	0.0
Serra Branca	54.89	0.55	-0.33	499.2	1144.8	516.4	628.4	0.0

4. Conclusion

The study provides subsidies to aid decision making, through the availability of information on the Climatological Water Balance, climate classification, agroclimatic zoning and crop suitability, favoring an adequate planning of agricultural activities and consequently a reduction of the risks to which this activity is subjected.

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

In the planning of family agriculture where we work with the planting of fencing, this information is extremely necessary, informing the man of the field of how to plant and take advantage of the rainy season.

Pineapple crops are inept; Herbaceous cotton, Sugarcane, Beans, Corn, with moderate suitability and in small areas. Banana, cashew, castor, cassava and sorghum restricted to large areas. Full sisal.

Compliance with ethical standards

Disclosure of conflict of interest

All authors contributed to the development of the article.

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