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Climatic Regionalization And Rainfed Agricultural Production In The State Of Maranhão, Brazil

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Abstract:
This study had as specific objectives: a) To evaluate whether the climatic regions created for the state present differences in their respective rainfall and air temperature averages, considering the series of rainfall and temperature precipitations observed between the years 1901 to 2020 and b) To evaluate the instability of rainfall and annual air temperatures in Maranhão between the years 1901 to 2020 with unfolding for the 10 climatic sub-regions into which the state was divided; c) to show the aggregate behavior of rainfed crops in these different regions. The data used were collected from NOAA (2022) and IBGE's Municipal Agricultural Surveys (PAM) in several years. Dummy variables were used to test whether the ten climatic regions had different averages of both rainfall distribution and annual temperatures. To assess the adequacy of rice, bean, cassava and maize crop yields to the regions created, the factor analysis method was used to generate weights in which harvested areas, yields, prices and rainfall were aggregated at the level of the 217 municipalities of the state of Maranhão. The results showed that Maranhão has ten regions with rainfall regimes whose annual averages are different. They also showed that the same does not apply to average annual temperatures, which were more homogeneous. As for aggregate agricultural production, it was observed that in five of the ten regions, crop yields show different behavior from the others.

Key Word*: Climatic instability; Rainfed agricultural production; Rural development; Land productivity*

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I. Introduction

Maranhão is geographically positioned between the humid Amazon and the water-stressed Northeast. It presents contrasts in its climatic characteristics: one part is located in the Amazon complex, with a predominantly equatorial climate, which occurs in its westernmost part bordering the state of Pará. The other part of the state is located in the east of the state, in spatial sequence with the state of Piauí. This part of the state has climatic characteristics equivalent to those observed in the semi-arid region, including an abundance of caatinga vegetation, a rainfall regime more concentrated in a few months at the beginning of the year, and with a smaller volume [1].

The state of Maranhão is one of the 9 states of the Northeast, the poorest region of Brazil. It is located in the extreme west of the Northeast of Brazil, bordering to the north with the Atlantic Ocean; to the east and southeast, it shares its limits with the state of Piauí; to the south and southwest, it borders the state of Tocantins, and to the west and northwest, with the state of Pará (Map 1). Its total area is 329,651,496 km², which corresponds to approximately 21.20% of the total area of the Northeast region, having the second longest coastline in the country, with an impressive 640 km. Maranhão is a state rich in natural resources, but has the poorest population in Brazil. It's population of 7,114,598 in 2020 had a GDP per capita of only USD 5,780.06, the lowest among all Brazilian states in that Year [2].

Map 1 –Position of Maranhão State in Brazil

Source: Based on Brazilian Institute of Geography and Statistics (IBGE)

It is largely taken by the tropical climate, with annual rainfall volumes that experienced a maximum in the year 1985, with 2,676.27 millimeters, while in 1983 it obtained the lowest average rainfall with 1,042.81 millimeters. These values gravitated around an average of 1,624.78mm with a coefficient of variation of 17.42% [3].

According to Montebeller (2007)[4], in certain regions of the state the distribution of rainfall is conditioned by static-physiographic aspects such as latitude, distance from the ocean and orographic effects. In addition, the movements of air masses (dynamic factors) that are related to each other, characterize the rainfall rates of a defined region. According to Lemos (2020)[5], in the eastern part of the state of Maranhão there are at least 45 municipalities that have semi-arid characteristics. The Federal Government recognized in 2021 that there are 16 municipalities in that part of the state that can be considered as part of the semi-arid climate in Brazil. This information corroborates to demonstrate the climatic diversity of Maranhão [5,6].

In Maranhão State, agriculture faces a high risk of crop loss due to the instability in the distribution of rainfall in time and space, in addition to the predominance of soils of limited efficiency for crops, due to the high process of devastation of the areas[7,8]. The use of techniques that disregard the specific conditions of each environment is a point that deserves to be highlighted, since it affects more intensely the small and medium rural producers, reducing the productivity of crops and their incomes.

It is understood that agriculture is one of the most relevant parts of the state's production chain, becoming dependent and vulnerable to climatic variability in view of the relationship between man and the environment. It is understood that soil and climate control the development and growth of crops and, therefore, environmental circumstances need to be properly analyzed before carrying out an agricultural activity.

In order to achieve better physical yields from the land and more economic returns, with regard to climate, it is known that each crop demands more favorable means throughout its development, that is, they require certain climatic specifications in their various stages of the production cycle, with a minimally adequate availability of water, also having a dry period in the maturation and harvest cycles. The systematization of information on climatic variables is what will make a certain region be seen as favorable for a particular crop and this also involves the risk of loss of plant production [9,10,11].

The zoning of agricultural production becomes important, considering that one of its essential objectives is the identification, characterization and cartographic and spatial delimitation of regions or "zones" with climate and soil aptitudes that provide the ecophysiological use of a given crop. According to Ramalho Filho and Motta (2010)[12], zoning makes it possible to determine the most feasible time for sowing, or planting in the field, for each of the municipalities and provides components for the implantation and increase of the crop on a sustainable basis in which the most critical stages of the crop have a lower probability of clashing with climatic adversities such as water scarcity, high or low temperature rise.

Thus, this research seeks to understand how rainfall behaved in the state of Maranhão over a longer historical period (1901 to 2020) and how the distribution of these rains impacts the different areas of a heterogeneous state such as Maranhão. To this end, it has as specific objectives: a) To evaluate whether the climatic regions created for the state present differences in their respective rainfall and air temperature averages, considering the series of rainfall and temperature precipitations observed between the years 1901 to 2020 and b) To evaluate the instability of rainfall and annual air temperatures in Maranhão between the years 1901 to 2020 with unfolding for the 10 climatic sub-regions into which the state was divided; c) show the aggregate behavior of rainfed crops in these different regions.

II. Material And Methods

The work uses rainfall and air temperature information released by the National Oceanic and Atmospheric Agency (NOAA)[3], for the periods 1901 to 2020, as well as the Sidra database, made available by the Brazilian Institute of Geography and Statistics (IBGE, various years)[13,14] and in the IBGE Statistical Yearbooks. The period of data availability extends from 1974 to 2020 at the municipal level and at the state level we have the years 1933 to 2020. The crops that make up the series studied are: rice, beans, corn and cassava (IBGE, various years). The units of observations are the 217 municipalities of Maranhão.

The annual rainfall and temperature series covering the period from 1901 to 2020 will serve to make the climatic regionalization of the state. To evaluate the behavior of crops in each of the regions, the following variables are used: Harvested areas (ha), land productivity, which will be treated only as productivity (kg.ha-1), prices (USD.kg-1).

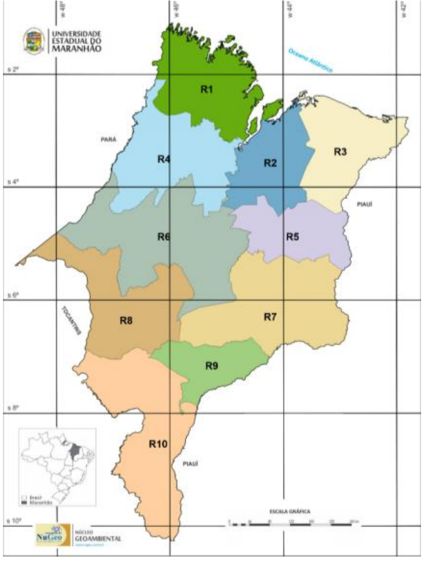
The original work of Menezes (2009)[16], based on twenty years of rainfall observations gathered the 217 municipalities of the state of Maranhão in 10 climatic regions to. In this research, an attempt was made to evaluate whether those regions are maintained based on a series of rainfall precipitations covering the period from 1901 to 2020. According to the regionalization proposal, these areas are composed of municipalities with characteristics of convergent or similar rainfall conditions. Map 1 shows the original regionalization of Menezes (2009)[16], with the following composition. Table 1 shows the designations of each region, as well as the total number of municipalities located in each one. Map 2 illustrates the location of the Regions.

Table 1 - Identification and number of municipalities included in the climate regions created for the State of Maranhão

Regions	Identification	Municipalities
R1	Litoral Ocidental (*Western Coast*)	42
R2	Itapecuru Mirim	25
R3	Baixo Parnaíba (*Lower Parnaiba*)	23
R4	Baixada Maranhense (*Maranhão Lowlands*)	24
R5	Cocais (*Babassu groves*)	18
R6	Alto Mearim e Grajaú (*Upper Mearim and Grajaú*)	24
R7	Chapada do Alto Itapecuru (*Upper Itapecuru Plateau*)	26
R8	Imperatriz	21
R9	Chapada das Mangabeiras (*Mangabeiras Plateau*)	7
R10	Gerais de Balsas (*General of Balsas*)	7
Total	Maranhão State	217

Souce: Menezes, 2009

Map 2 - Spatial distribution of the 10 homogeneous climatic regions over the State of Maranhão



Source: Menezes (2009)

Methodology used to achieve the first specific objective

In order to assess whether the climatic regions created for the state present differences in their respective rainfall averages and air temperatures, considering the series of rainfall precipitation and temperatures observed between the years 1901 and 2020, the model defined in equation (1) is used.

$$Y_{it} = \beta_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 D_6 + \beta_7 D_7 + \beta_8 D_8 + \beta_9 D_9 + \varepsilon_{rt} \quad (1)$$

In this case, the variable Y_{it} can be either the rainfall or the annual temperature of the municipalities. The variables D_r (r = 1, 2, ..., 9) are dummies (binary) that assume the following values:

$D_1 = 1$, in R1, defined as Litoral Ocidental (*Western Coast*), or $D_1 = 0$ in the other regions;

$D_2 = 1$, in R2, defined as Itapecuru Mirim, or $D_2 = 0$ in the other regions;

$D_3 = 1$, in R3, defined as Baixo Parnaíba (*Lower Parnaiba*), or $D_3 = 0$ in the other regions;

$D_4 = 1$, in R4, defined as Baixada Maranhense (*Maranhão Lowlands*), or $D_4 = 0$ in the other regions;

$D_5 = 1$, in R5, defined as Cocais (*Babassu groves*), or $D_5 = 0$ in the other regions;

$D_6 = 1$, in R6, defined as Alto Mearim and Grajaú (*Upper Mearim and Grajaú*), or $D_6 = 0$ in the other regions;

$D_7 = 1$, in R7, defined as Chapada do Alto Itapecuru (*Upper Itapecuru Plateau*), or $D_7 = 0$ in the other regions.

$D_8 = 1$, in R8, defined as Imperatriz, or $D_8 = 0$ in the other regions.

$D_9 = 1$, in R9, defined as Chapada das Mangabeiras (*Mangabeiras Plateau*), or $D_9 = 0$ in the other regions.

When $D_1 = D_2 = D_3 = D_4 = D_5 = D_6 = D_7 = D_8 = D_9 = 0$. the linear coefficient of equation (1) will be the average rainfall of R_{10}, defined as General de Balsas (*General of Balsas*).

If some, or all, of the estimated values of β_r (r = 0, 1, 2. ..., 9) are statistically different from zero, it means that rainfall and temperature have different means when βr is different from zero. The random term ε_{rt}, by assumption, is a white noise. According to Wooldridge (2015)[17] and Gujarati and Porter (2011)[18] under the condition that the assumptions related to the random terms are met, the linear and angular coefficients of equations (1) can be estimated using the Ordinary Least Squares (OLS) method.

Methodology used to achieve the second specific objective

Seeking to evaluate the instability of annual rainfall, as well as the annual air temperatures of Maranhão between the years 1901 and 2020, with unfolding for the 10 climatic sub-regions into which the state was divided. To achieve this goal, the research uses the coefficient of variation (CV). The CV measures a percentage relationship between the standard deviation and an average arithmetic variable. According to Gomes (1985)[19], one can scale CV associated with a random variable according to the amplitudes of the variable in Table 2. Therefore, the closer the CV related to the distribution of a random variable is to zero, the more homogeneous or stable the distribution of studies around the mean will be. Although there is no upper limit, to use CV as a measure of the homogeneity or heterogeneity of the distribution of a random variable, it is necessary to define its minimum critical value.

Table 2 - Classification of coeficiente of variatin (CV) according to its amplitude

Classification of CV	Range CV
Low	CV < 10%
Medium	10% ≤ CV < 20%
High	20% ≤ CV < 30%
Very high	CV ≥ 30%

Source: Gomes, 1985.

Thus, the advantage of using CV in this evaluation model over other measures of variability is that it is independent of the units in which the variables are measured. Thus, it allows the comparison of homogeneities / heterogeneities or stabilities / instabilities between variables measured in different units of measurement [20,21,22,23,24,25].

Methodology used to achieve the third specific objective

In order to assess the association between yields and values per hectare, state and municipal variables related to agricultural production were selected. The data were aggregated using a weighted average. The determination of the weights to be applied in the weighting was conducted using the factor analysis method, with the technique of decomposition into principal components.

According to Fávero et al (2009)[26], factor analysis is an interdependent technique that aims to summarize the relationship between a set of variables in synergy, in order to identify common factors of a phenomenon. The main objective of factor analysis is to simplify or reduce a number "n" of observed variables into a smaller "p" group of unobserved variables (p < n), called factors. Therefore, the interpretation and understanding of the dimensions obtained when performing factor analysis characterize the data in smaller quantities than the amount of original variables. And this is due to the correlation between the variables. In contrast, King (2001)[27] and Hair et al (2005)[28], portray that data reduction can be obtained by calculating the factor scores of each latent dimension and replacing the original variables with these factors that add, in smaller numbers, the information understood in the original variables.

According to Lemos (2015)[29], factor analysis model can be represented as follows in equation (2):

$$X = \alpha f + \varepsilon \tag{2}$$

Where:

$X = (X_1, X_2,..., X_p)^T$ is a transposed vector of observable random variables; $f = (f_1, f_2,..., f_r)^T$ is a transposed vector $r < p$ of unobservable variables, or latent variables, called factors; α is a matrix (p x r) of fixed coefficients called factor loadings; $\varepsilon = (\varepsilon_1, \varepsilon_2, ... , \varepsilon_3)^T$ is a vector of transposed random terms. Usually $E(\varepsilon) = E(f) = 0$. A complementary property related to the factors is that they are orthogonal [30,26,29].

In order to perform factor analysis (FA), it is necessary that the matrix of the original variables is not an identity. Thus, the first step to perform FA is to evaluate the correlations between the variables that make up the secondary diagonals of the correlation matrix. To confirm that the correlation matrix is not an identity, the Bartlett's test of sphericity is used, which has a chi-square distribution. To confirm that the FA can be used, the following procedures are also performed: the Kaiser-Meyer-Olkin (KMO) statistic is calculated, which must have a value between 0.5 and 1.0. The percentage of variance explained by the estimated factor components is also observed, which must be greater than 50%.

When more than one factor is estimated, FA techniques allow orthogonal or oblique rotation of the estimated factors. In this research, we chose to perform orthogonal rotation, using the varimax technique, to generate independent components that thus enable the construction of the productivity index (PI) [26].

Through the FA, linearly independent factor scores (FS) are generated, because the orthogonal rotation was performed, which has mean zero and variance one. Therefore, the FS exhibit positive and negative signs. It is these FS that are used to construct indices, which usually take on positive values. In order to generate positive indices, it is necessary to make a transformation of the EFs so that, without changing the distances between the observed values, they are standardized so that all values are strictly positive or zero. This is achieved by using the transformation shown in equation (3):

$$FE_{ijP} = \frac{(FEt - FEmn)}{(FEmx - FEmn)} \tag{3}$$

So that: FE_{ij}^P= j-th (j = 1,2,...,p) standardized factor score associated with the i-th municipality; FE_{jmax} = maximum value, which should be assumed by the factor score; FE_{jmin} = minimum value associated by the factor score.

For the construction of the productivity index that will capture the synergy between the variables, the geometric mean is used, in which the Productivity Index (PI) is defined using the averages, according to equation (4).

$$\mathrm{PIj} = \sqrt[x]{\prod EF_{Pj}} \tag{4}$$

So that PI_j refers to the composite productivity index associated with the j-th municipality (j = 1, 2, ..., 217) of Maranhão in year t (t = 1974, 1975, ..., 2020). Constructed in this way, the index will be contained between zero and one. To make it easier to understand, the index is converted into percentage values, generating the highest value equal to 100 and the others being molded as shown in equation (5).

$$PI_{j100} = \left(\frac{PI_j}{PI_{jMÁXIMO}}\right) \times 100 \tag{5}$$

III. Results and Discussions

Results found for the first objective

Between the years 1901 and 2020 the average rainfall in the state of Maranhão was 1,624.8mm, with a coefficient of variation of 17.4% which means medium instability, on the scale constructed by Gomes (1985)[19].

To analyze whether the climatic regions created in the research, based on this longer rainfall period (1901 to 2020), for the state of Maranhão, present differences in their respective rainfall averages, tests were performed by applying the linear regression analysis model that was shown in equation (1). Table 3 shows the results found to test the differences between the rainfall and air temperature averages estimated for the ten regions of Maranhão between the years 1901 and 2020.

From the evidence shown in Table 3, it appears that the hypothesis that there are 10 rainfall regions in Maranhão is confirmed. The same cannot be said for average temperatures, where the state is classified into ten regions.

Table 3 - Results found for the test of differences of the average rainfall and temperatures of the regions created in the research in the period 1901 and 2020

	Yearly Rainfall (mm)		Yearly Temperature (ºC)		Regions		
Variables	**Est.**	**Sign.**	**Est.**	**Sign.**	**Regiões**	**Rain. (mm)**	**Temp (ºC)**
D1	679.14	0.000	-0.078	<0.001	R1	$2,075.00^{A}$	27.08^{E}
D2	347.97	<0.001	-0.061	0.012	R2	$1,743.83^{C}$	27.10^{C}
D3	193.85	<0.001	-0.262	<0.001	R3	$1,589.71^{D}$	26.90^{I}
D4	392.23	<0.001	-0.160	<0.001	R4	$1,788.09^{B}$	27.00^{G}
D5	47.90	<0.001	-0.054	0.032	R5	$1,443.76^{G}$	27.10^{E}
D6	55.53	<0.001	0.021	0.390	R6	$1,451.39^{F}$	27.18^{B}
D7	-185.43	<0.001	-0.090	<0.001	R7	$1,210.43^{I}$	27.07^{F}
D8	122.28	<0.001	-0.199	<0.001	R8	$1,518.14^{E}$	26.96^{H}
D9	-194.55	<0.001	0.091	0.003	R9	$1,201.31^{J}$	27.2^{A}
Constante	1,395.86	0.000	27.157	0.000	R10	$1,395.86^{H}$	27.16^{B}

Sources of original data: NOAA, 2022.

Remarks: 1 - The adjusted R^2 for assessing differences in rainfall between regions was 0.391; the adjusted R^2 for assessing differences in temperature between regions was 0.02; 2 - The super-indices placed on the estimated medians of rainfall and temperature denote the following hierarchy: hierarquia: A > B > C > D > E > F > G > H > I > J.

Based on the evidence shown in Table 1, the following hierarchy can be constructed, in descending order, of the average rainfall (Pluv) of the 10 regions that were created in the survey :
Rain^{R1} > Rain^{R4} > Rain^{R2} > Rain^{R3} > Rain^{R8} > Rain^{R6} > Rain^{R5} > Rain^{R10} > Rain^{R7} > Rain^{R9}.

Regarding the estimated average temperatures (Temp) for the regions the hierarchy found is as follows: Temp^{R9} > Temp^{R6} = TempR^{10} > Temp^{R5} > Temp^{R2} > Temp^{R1} > Temp^{R7} > Temp^{R4} > Temp^{R8} > Temp^{R3}.

This evidence confirms that the ten regions tested have different pluviometries, therefore, have different rainfall regimes, and the results found from a larger information base confirm the results found in the research by Menezes (2009)[16] from a smaller series of observations. Regarding the regionalization of temperatures, it was observed that it was possible to prove the existence of nine regions with different temperature averages (Table 3).

Results found for the second objective

The second objective of the research, which sought to assess the levels of instability of rainfall and temperatures using the coefficients of variation, has its results shown in Table 4.

From the evidence shown in Table 2 it appears that the rainfall of the regions presented levels of instability, measured by the CV rescpectives, ranging from 16.72% in R10, therefore classified as medium on the scale proposed by Gomes (1985)[19], to 26.22% in R3, therefore a high instability.

With regard to temperatures, it was observed that the variations are all less than 10% (Low), which shows greater levels of stabilities and similarities between the average temperatures of the climatic regions created in the research (Table 4).

Table 4: Coefficients of variation (CV) of rainfall and temperatures estimated for the ten rainfall regions of Ceará defined in the research.

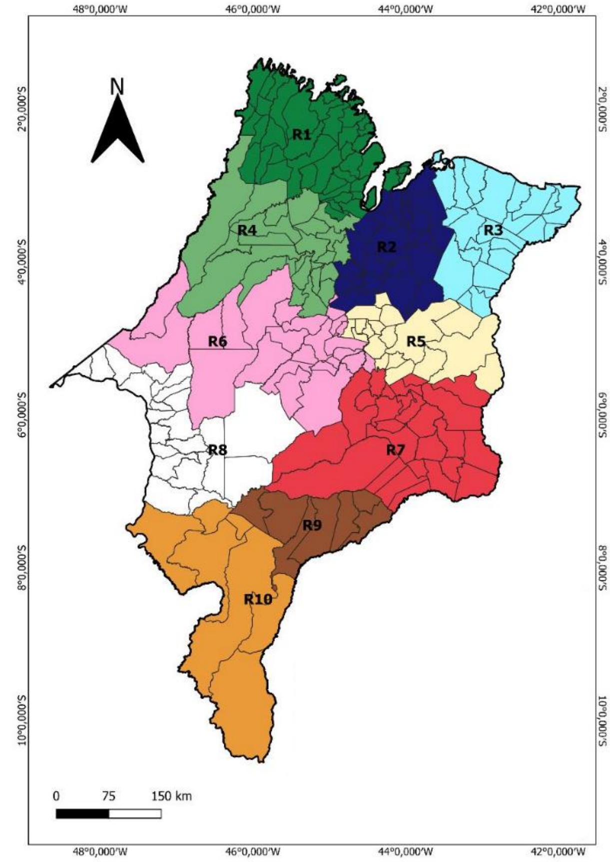
Regions	**Rainfall (CV %)**	**Temperature (CV %)**
R1	19.58	2.44
R2	23.66	2.14

R3	26.22	2.54
R4	18.57	2.18
R5	22.17	2.29
R6	21.46	1.94
R7	23.39	2.28
R8	19.83	2.53
R9	19.81	2.02
R10	16.72	1.94

Sources of original data: NOAA, 2022.

Map 3 illustrates the spatial representation of the distribution of rainfall in each region over a period of 120 years. It is observed that the colors that represent the best averages are: dark green (R1), dark blue (R2), light blue (R3) and light green (R4), with the other colors representing the lowest averages.

Map 3 - Homogeneous Pluviometric Regions in Maranhão



Source: Map based on the information contained in Table 4.

Results found for the third objective

To answer this objective, the Productivity Index (PI) was created using the factor analysis method by the principal component decomposition technique. The results are shown in Table 5. From the evidence shown in this table it appears that the FA was possible to be applied to create the PI, considering that the correlation matrix between the variables is not an identity, as shown by the Chi-Square statistic of the Bartlet test.

The results shown in this table confirm the quality of the estimates, since all communalities were greater than 0.5. The KMO statistic = 0.711, as well as the total variance explained by the three estimated factors (73.98%), suggest the statistical robustness involved in the construction of the four orthogonal factors generated.

Table 5 also shows that the 13 observed variables were reduced to four independent factors, given their orthogonal rotation. Factor 1 had its highest saturations in the prices of rice, beans, cassava and corn. For factor 2 the highest saturations occurred with the harvested areas of the crops. The third factor had the highest loadings with crop yields, while for the fourth factor there was saturation with the rainfall observed for the municipalities of Maranhão in the period studied.

Table 5 - Results found with factor analysis (FA) for the estimation of IPD

Tests for Statistical Robustness in Factor Generation					
Bartlet test	Chi-Square = 4923.467		Degrees of freedom = 78		Sign. =0.000
KMO test =0.711			Explaneid Variance =73.98%		
	Factor loadings				
Variables	Communalities	F1	F2	F3	F4
Rice area	0.884	0.026	**0.939**	0.041	-0.006
Rice yields	0.602	-0.251	0.096	**0.716**	-0.132
Rice price	0.847	**0.884**	0.144	-0.097	-0.190
Bean area	0.736	-0.020	**0.857**	0.019	-0.020
Bean yields	0.759	0.419	-0.182	**0.636**	0.382
Bean price	0.839	**0.838**	0.156	-0.049	-0.332
Cassava Area	0.663	0.451	**0.556**	-0.256	0.292
Cassava yields	0.550	0.090	0.124	**0.715**	0.125
Cassava price	0.705	**0.767**	-0.216	0.076	0.255
Corn area	0.859	0.030	**0.911**	0.151	-0.072
Corn yields	0.692	-0.250	-0.041	**0.722**	-0.326
Corn price	0.890	**0.926**	0.064	-0.128	-0.109
Rainfall	0.591	-0.288	0.012	-0.063	**0.709**

Original data sources: IBGE/PAM (various years) and NOAA (2022).

The following are the results of the tests performed to verify whether the means of the PIs are statistically different between the regions already climatically defined in the survey. These results are shown in Table 4 and Map 4. The adjusted coefficient of multiple determination was 0.181.

According to the evidence shown in Table 6, it appears that the ten (10) regions, that are different from an average rainfall point of view, are reduced to only five in terms of the productivity index (PI). Also according to these results, the ten regions can be hierarchized as follows, taking into account the averages of the estimated PIs for each of them: R1> R4 > R6 > R10 > R2 = R3 = R5 = R7 = R8 = R9.

Table 6 - Results for the test of differences of means of PI by homogeneous rainfall regions, means and coefficients of variation (CV) of the estimated PI for the regions.

Varibles	**Estimate**	**Sign.**	**Region**	**Average PI**	**CV(%)**
D1	**0.109**	**<0.001**	**R1**	**0.527^{A}**	17.48
D2	0.018	0.390	R2	0.436^{E}	15.14
D3	0.028	0.182	R3	0.446^{E}	14.45
D4	**0.079**	**<0.001**	**R4**	**0.496^{B}**	13.51
D5	-0.001	0.979	R5	0.418^{E}	15.76
D6	**0.071**	**<0.001**	**R6**	**0.489^{C}**	23.56
D7	0.010	0.629	R7	0.428^{E}	19.39
D8	0.026	0.209	R8	0.444^{E}	16.68
D9	-0.042	0.112	R9	0.376^{E}	25.90
Constant	**0.418**	**<0.001**	**R10**	**0.418^{D}**	25.14

Original data sources: IBGE/PAM (various years)

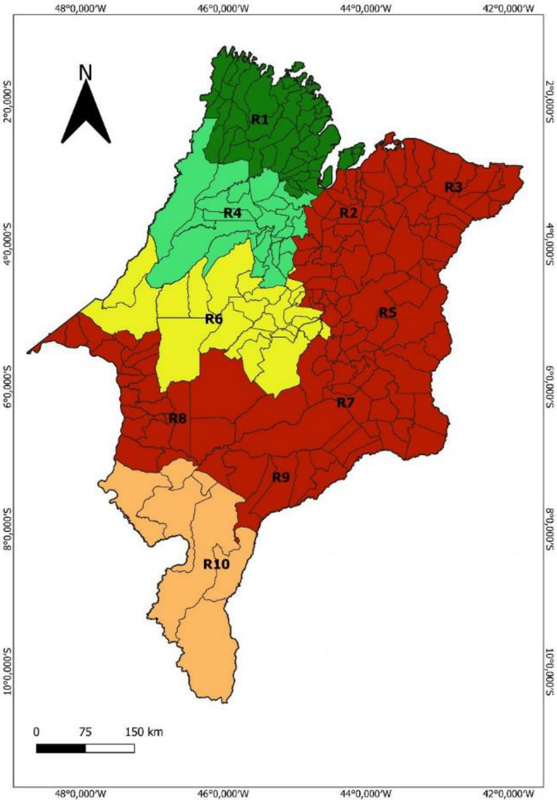
Note, the super-indices placed on the estimated rainfall and temperature averages denote the following hierarchy: A > B > C > D > E

From the evidence shown in Table 1 and Table 4, it appears that the regions with the highest average rainfall R1 (*Western Coast*) and R4 (*Maranhão Lowlands*). also had the highest IP. R6 (*Upper Mearim and Grajaú*) ranks as the sixth best in rainfall and has the third highest PI. These three regions border the state of Pará and have all the characteristics, including landscapes, of the Brazilian Amazon. Regions where food crops studied in the research have an even more relevant participation in the formation of monetary income, in the generation of occupation of the population and in the food security of families. R10 (*General of Balsas*), which has the fourth largest IP, is located in the agricultural frontier known as MATOPIBA (Agreement defining the joint agricultural border involving parts of the states of Maranhão, Tocantins, Piaui and Bahia), where capital-intensive with high productivity crops prevail, especially corn and soybeans, unlike the other regions of Maranhão where family farmers stand out.

On the other hand, R9 (*Mangabeiras Plateau*), which presented the lowest PI, was also the region that had the lowest average rainfall over the period studied. Regions R2 (Itapecuru), R3 (*Lower Parnaiba*), R5 (*Babassu groves*), R7 (*Upper Itapecuru Plateau*) are located in the east of Maranhão, the part that borders the state of Piaui. A very significant part of the municipalities located in these regions has semi-arid characteristics, as demonstrated in the research by Lemos (2020). For these reasons they present low productivities.

From the results shown in Table 4 it is also apparent that the highest instability estimated for PI through the respective CVs was observed in R9 (CV = 25.90), high in the classification of Gomes (1985). This region also presented the lowest mean value for PI (0.376). On the other hand, R1 (*Western Coast*) which presented the highest mean for PI had CV=17.48, classified as medium. The research showed that in 7 of the climatic regions defined in the research prevailed médium levels of instabilities whose CV ranged from 13.51% in R4 (*Maranhão Lowlands*) to 19.39% in R7 (*Upper Itapecuru Plateau*). Map 4 shows how the IP productivity indices are distributed among the 10 climatic regions defined in the survey.

Map 4 - Regionalization of productivity índices



Source: Map based on the information contained in Table 6.

IV. Conclusions

The present study was able to confirm that there are ten different regions in State of Maranhão, from a rainfall point of view. To reach this result, a rainfall series covering the period from 1901 to 2020 was used. The regions have statistically different rainfall averages, but all with medium or high instabilities.

These ten regions are not confirmed with regard to average annual temperatures. In this case only nine regions showed to have different average temperatures. The distributions of these temperatures are very homogeneous over the observed 120 years.

The survey showed that the productivity index (created in the survey) evaluated by the weighted average of harvested areas, land productivities and prices of the main food crops grown in the state (rice, beans, cassava and corn), has divergent averages in only five of the ten regions into which the state was divided in this survey.

It was also observed that the regions with the highest productivity indices (PI) are located on Maranhão's border with the Amazon, where rainfall is higher. On the other hand, the lowest productivity indices (PI) are mostly located on the eastern side of the state, where the municipalities with semi-arid characteristics are located, including in terms of part of the vegetation cover.

Thus, farmers and agents promoting research aimed at technical assistance and rural extension services now have a survey that shows in which parts of the state the crops are most suitable. The results found also serve to review crop planning, in search of understanding why in five of the ten regions studied the results were more promising. This raises the need to promote research that seeks to select cultivars that are suitable for the conditions of the other five regions of the state where productivity rates were lower.

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