Rainfall instability and per capita production forecast for rainfed food crops in Maranhão State, Brazil

Instabilidade das chuvas e previsão de produção per capita para culturas alimentares de sequeiro no Estado do Maranhão, Brasil

DOI: 10.55905/oelv21n6-053

Recebimento dos originais: 16/05/2023
Aceitação para publicação: 20/06/2023

Erika Costa Sousa
Master's student in Rural Economics
Institution: Universidade Federal do Ceará (UFC)
Address: Av. Mister Hull, 2977, Bloco 826, Campus do Pici, Fortaleza - CE, CEP: 60020-181
E-mail: erikacosta@alu.ufc.br

José de Jesus Sousa Lemos
PhD in Rural Economics from Universidade Federal de Viçosa and Post-Doctorate in Natural Resource and Environmental Economics from Universidade da California, Riverside, California - USA
Institution: Universidade Federal do Ceará (UFC)
Address: Av. Mister Hull, 2977, Bloco 826, Campus do Pici, Fortaleza - CE, CEP: 60020-181
E-mail: lemos@ufc.br

Ronaldo Haroldo Nascimento de Menezes
PhD in Meteorology
Institution: Universidade Estadual do Maranhão (UEMA)
Address: Cidade Universitária Paulo Vi, Av. Lourenço Vieira da Silva, 1000, São Luís - MA
E-mail: ronaldomenezes@professor.uema.br

ABSTRACT
We studied the instability of rainfall, harvested areas and aggregate yields of rice, beans, cassava and corn and made projections of per capita production of these crops between 2022 and 2031. Rainfall in Maranhão between the years 1933 to 2020 was placed into three periods: short, normal and rainy. Agricultural production and population data from IBGE were used. Annual rainfall was collected from the National Oceanic and Atmospheric Administration (NOAA). Variable instabilities were estimated by Coefficients of Variation. ARIMA models were fitted for forecasting. Population forecasts were made using instantaneous geometric rate of population growth in two scenarios. The results showed that it was possible to classify the rainfall in the three

periods with a high level of instability, which manifested itself in harvested areas and yields. The general conclusion of the research is that the per capita production of these crops presented its highest value in 1982, and from that year on it showed a decline, in such a way that the projections made until the year 2031, in different scenarios of population growth in the state, point to decreases in per capita production.

Keywords: dryland farming, food security, family farming.

RESUMO
Estudamos a instabilidade das chuvas, as áreas colhidas e a produtividade agregada de arroz, feijão, mandioca e milho e fizemos projeções da produção per capita dessas culturas entre 2022 e 2031. As chuvas no Maranhão entre os anos de 1933 e 2020 foram divididas em três períodos: curto, normal e chuvoso. Foram usados dados de produção agrícola e população do IBGE. A precipitação anual foi coletada da National Oceanic and Atmospheric Administration (NOAA). As instabilidades das variáveis foram estimadas pelos coeficientes de variação. Os modelos ARIMA foram ajustados para previsão. As previsões de população foram feitas usando a taxa geométrica instantânea de crescimento populacional em dois cenários. Os resultados mostraram que foi possível classificar a precipitação nos três períodos com um alto nível de instabilidade, que se manifestou nas áreas colhidas e nos rendimentos. A conclusão geral da pesquisa é que a produção per capita dessas culturas apresentou seu valor mais alto em 1982 e, a partir desse ano, apresentou um declínio, de modo que as projeções feitas até o ano de 2031, em diferentes cenários de crescimento populacional no estado, apontam para decréscimos na produção per capita.

Palavras-chave: agricultura de sequeiro, segurança alimentar, agricultura familiar.

1 INTRODUCTION

The State of Maranhão is situated in the Northeast, but is not located in the polygon of droughts, presenting a regime of pluviometry and water availability more promising than the other states in the region, however, exhibits irregularities in the spatial and temporal distribution of rainfall, which subjects the local agricultural production to problems, with significant economic and social consequences. This irregularity in rainfall distribution is due to some aspects, such as: geographical position, territorial extension and its physiographic features (Costa, 2016; Menezes, 2009).

Agriculture in Maranhão is characterized by the use of low technological level, although in recent years there have been advances in this aspect in a specific and localized part of the state, which constitutes the agricultural frontier known as MATOPIBA, which brings together areas of the states of Maranhão, Tocantins, Piauí and Bahia. However, the technological advances practiced in that part of the state, are still not within the reach of a large part of the state's farmers, not even in a large part of those who live in that region (Teixeira, 2017).

A characteristic that differentiates Maranhão from the other states of the Northeast is the abundance of water resources, both surface and underground. Besides this, the state also has a differentiated rainfall regime in relation to the other states. However, it has as a common characteristic with these states the instability in the distribution of these rains, which are concentrated in the first months of each year. In the eastern part of the state, there are municipalities that have water difficulties, so much so that studies conducted by UEMA show that at least 45 municipalities in this part of the state have aridity indexes compatible with those that define semi-arid, although SUDENE recognizes only 16 in this condition according to the latest definition of semi-arid (SUDENE, 2021; Lemos, 2022).

The food crops of rice, beans, cassava and corn were chosen for this research because they are mostly cultivated in Maranhão by family farmers and play an important role in food security, in generating employment for rural families and in promoting monetary income for these families. As these crops are mostly cultivated in rainfed areas, they are very affected by both excessive and scant rainfall. According to the 2017 Agricultural Census, the establishments where these crops are grown predominate in the state (IBGE, 2017).

This research seeks to understand how rainfall in the state of Maranhão behaved over a longer historical period (1901 to 2020) and how this rainfall distribution impacted the per capita production of food in the period in which IBGE makes this information available, which covers the period from 1933 to 2021. To this end, it has the following specific objectives: a) To classify the rainfall in Maranhão between 1901 and 2020 in periods of scarcity, normal and rainy; b) to apply this classification for the period 1933 to 2021, years in which information is available about the population and agricultural productions of rice, beans, cassava and corn, which are the rainfed crops studied in the research; c) assess the instabilities associated with rainfall as well as those associated with the aggregate per capita production of rice, beans, cassava and corn in Maranhão between the years 1933 and 2021; d) estimate models to develop the projections of the variables that define the per capita production of rice, beans, cassava and corn between 1933 and 2021.

2 MATERIAL AND METHODS

To classify the rainfall occurring in Maranhão, as well as its instability, rainfall information released by the National Oceanic and Atmospheric Agency (NOAA) was used, in the period from 1933 to 2020. To assess the variables that define the per capita production of rice, beans, cassava and corn the information was collected from the Sidra data bank, from the IBGE Statistical Yearbooks for the period 1933 to 2021, years that this information is available at the state level at the time of the research. The variables used in the search are: $X_{1t} =$ annual rainfall in milímetres; X_{2t} annual rice production (kg); X_{3t} = annual bean production; X_{4t}= annual cassava production (kg); X_{5t} = annual cassava production (kg); X_{6t} = annual rice harvested área (ha); X_{7t} = annual bean harvested área (ha); X_{8t} = annual cassava harvested área (ha); X_{9t} = annual corn harvested área (ha); X_{10t} = annual rice productivy (kg.ha^{-1}); X_{11t} = annual bean productivy (kg.ha^{-1}); X_{12t} = annual cassava productivy (kg.ha^{-1}); X_{13t} = annual corn productivy (kg.ha^{-1}); X_{14t} = annual population (persons).

2.1 METHODOLOGY USED TO CLASSIFY THE RAINFALL IN MARANHÃO BETWEEN 1901 AND 2020

As there is no definition in the literature about the lower and upper limits of the different rainfall periods, in this research we chose to use the classification made in the research of Lemos & Bezerra (2019) for the state of Ceará, defined as follows : 1 - shortfall period in which rainfall is lower than the average minus half a standard deviation; 2 - wet period, in which rainfall is higher than the average plus half a standard deviation; 3 - normal period in which rainfall falls between these two extremes.

To confirm that the periods defined in this classification are statistically different, it was utilized dummies variables by using equation (1)..

$$Y_t = \beta_0 + \beta_1 D_1 + \beta_2 D_2 + \mu_t \quad (1)$$

In equation (1): D1 = 1 in normal years and D1 = 0 in shortfall and rainy years. D2 = 1 in rainy years and D2 = 0 in the other periods (shortage and normal). Thus, D1 = D2 = 0 in shortfall years.

Note that in equation (1) the variable (Y_t) is the annual rainfall occurring in year t (t = 1901, 1902, ..., 2020). If parameter (β_0) is statistically different from zero and D1 = D2 = 0, it is the linear coefficient that will estimate the average rainfall of the shortfall periods. If the estimated parameter (β_1) is statistically different from zero, it expresses that the average rainfall in the normal period differs from the averages of the other periods. The angular coefficient (β_2) being statistically different from zero, will indicate that the average rainfall in the years of the rainy periods is different from those analyzed in the other periods.

The random term (μ_t) is assumed to have zero mean, constant variance and is not auto-correlated ("white noise"). According to Gujarati and Porter (2011) and Wooldridge (2015) the parameters of equation (1) can be estimated using the Ordinary Least Squares (OLS) technique.

2.2 METHODOLOGY USED TO MEASURE RAINFALL INSTABILITIES

The coefficient of variation (CV) is used to measure the stability/unstability associated with rainfall observed between the years 1933 and 2020, as well as the variables that define the per capita productions of the crops studied. By definition, the CV measures the percentage ratio between the standard deviation and the mean of a random variable.

The CV is widely used as a measure of homogeneity/heterogeneity or, what comes to be the same thing, stability/unstability of a random variable by researchers in different fields such as finance, climatology, engineering, risk sensitivity; variability and in agricultural experimentation. An advantage associated with CV is that it allows comparison between variables of different nature and measurement (Garcia, 1989; Gomes, 1985; Nayry and Rao, 2003; Santos and Dias, 2021).

The closer the CV value related to the distribution of a random variable is to zero, the more homogeneous or more stable is the distribution of observed values around the mean. Although there is no upper limit, it is necessary to establish critical values for the CV amplitudes in order to use this measure as an indicator of homogeneity or heterogeneity of the distribution of a random variable. Gomes (1985), established ranges and defined them for the use of CV as an indicator of stability/unstability in scientific studies. These definitions are as follows: 1 - Low if the CV value is less than 10%; 2 - medium if the CV value varies between 10% and 20%; 3 - high if the CV magnitude ranges between 20% and 30%; 4 - very high, if the CV value is greater than 30%% (Gomes, 1985)

The use of the coefficient of variation (CV) allows you to compare stability or instability of variables measured in different units. (Allison, 1978; Santos and Dias, 2021, Garcia, 1989; O'reilly; Caldwell; Barnet, 1989; Wiersema, Bantel, 1993; Punt, 2003; FAO, 2014).

2.3 PREDICTION MODELS FOR THE VARIABLES THAT DEFINE THE PRODUCTIONS STUDIED

Given the productivity (R_{it}) in year "t" of a crop "i" in the state of Maranhão; its harvested area (A_{it}) also in year "t"; its produced quantity (Q_{it}); and being (P_t) the population of the state in year "t", then the following equation is defined:

$$Q_{it} = R_{it}.A_{it} \tag{2}$$

The annual per capita production of this crop (PP_{it}) in the state is defined as follows:

$$PP_{it} = R_{it}.A_{it}/ P_t \tag{3}$$

Calculating the natural logarithm of equation (3), and doing the partial derivatives with respect to time (T) gives the following relation:

$$d[\log(PP_{it})]/dT = d[\log(R_t)]/dT + d[\log(A_t)]/dT - d[\log(P_t)]/dT \quad (4)$$

Farmers are able to define the areas they will plant, which is based in those that they have. But they will not know which areas they will harvest, because they will depend on several external factors. In rainfed crops, as the ones studied in this research, the stability/unstability of the rainfall will have a great influence on the areas that will be harvested, which, in general, are smaller than the planted areas.

Farmers also define the technological procedures they will use to obtain better results. In general, they do not have access to purchased external inputs, such as fertilizers, soil correctives, and pesticides, because they do not have the resources to do so. Moreover, even if they have partial or full access to these inputs, the productivity that they will be able to obtain will also depend on the stability or instability of rainfall.

This paper aggregates the productivity and harvested areas of rice, beans, cassava and corn, to estimate the aggregated annual production of these crops in Maranhão between the years 1933 and 2020. Thus, the research works with two time series that define the annual physical production of crops: productivity and harvested area, which will be generically called Yt. It also uses the time series of the annual population (P_t) of Maranhão. To make the projections of productivity and harvested areas aggregated for rice, beans, cassava and corn, the numerator of equation (3), the research uses the model of Box, Jenkins (1976).

2.3.1 Model used to make projections of aggregate crop yields

The predicted value (Y^P) of a random variable Yt, for the same period "t", will differ from its observed value due to the occurrence of random factors (ξt), which can be caused by exogenous factors or variables. This information can be summarized by Equation (5):

$$Y_t - Y^P = \xi_t\text{; or, similarly, } Y_t = Y^P + \xi_t \quad (5)$$

For this study, the random variable (Y_t) must be stationary and the random error term (ε_t) is calculated from the difference between the observed values (Y_t) and the predicted values (Y^P) for the same year "t". It is for these variables that forecasts will be created in this study using the Box and Jenkins model. The formulations proposed by Box, Jenkins (1976) - ARIMA (Auto Regressive Integrated Moving Average) - are mathematical structures that aim to capture the behavior of a random variable that has values distributed over time series. It is considered that the time series Yt can be represented as follows:

$$Y_t = \mu + \sum \psi_{k.} u_{t-k} = \mu + \psi(B).u_t \quad (6)$$

Where the linear filter ψ is defined as:

$$\psi(B) = \theta(B)/\phi(B) \quad (7)$$

The terms in equation (7) are defined by the following polynomials:

$$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \ldots. - \theta_q B^q \; and \; \phi(B) = 1 - \phi_1 B - \phi_2 B_2 - \ldots - \phi_p B^p$$

By defining $\tilde{Y}_t = Y_t - \mu_t$, wher $\tilde{Y}_t$ is the expected value of Y_t, the following transformation can be obtained:

$$\phi(B)\tilde{Y}_t = \theta(B)u_t \quad (8)$$

In equation (8), u_t is a white noise in general Gaussian. To do so, it must meet the following conditions: i) $E(u_t) = 0$; ii) $E(u_t^2) = \sigma(u_t)^2 < \infty$ and iii) $E(u_t, u_{t+k}) = 0$, to $k = \pm 1, \pm 2, ..$(Box, Jenkins, 1976; Cochrane, 1997 ; Nascimento Camelo et al, 2018; Wooldridge, 2015 ; Box *et al* 2015).

According to Box, Jenkins (1976), equation (9) is called ARMA(p,q) and can be rewritten as follows:

$\tilde{Y}_t = \theta(B)\phi^{-1}.(B)u_t$

The types of Box and Jenkins models are: i) Moving average (MA) models: these are those in which $\phi(B) = 1$ and are called MA(q). ii) Autoregressive models (AR) are those in which $\theta(B) = 1$ and are called AR(p). These models are so called because Yt, at time t, is a function of the values of this variable at times prior to t. iii) Autoregressive moving average (ARMA) models: these are those that have one part (AR) and one part MA and have the notation ARMA(p,q).

Before applying the ARMA model, it is necessary to assess whether the series under analysis are stationary. This is done by looking at the graph of the series and analyzing the autocorrelation and partial autocorrelation functions (Makridakis et al, 1998). Another way to check if the series is stationary is to estimate the first order AR model on the original series and test if the coefficient ϕ is smaller than 1. A stochastic process $Y_t = \psi(B)u_t$ is stationary if: $\psi(B) = \Sigma_{k=0}^{\infty}\psi_k(B)^k$ converges to $|B| < 1$.

If the time series under study is not stationary, it must be transformed to become stationary. The autocorrelation function between the residuals is estimated. If the autocorrelation function stabilizes with the first difference, it can be assured that the series has become stationary. Otherwise, the second, third or more differences are performed to search for stationarity. In general, series need at most three lags to become stationary. In this case, the model is called an autoregressive, integrated moving average (ARIMA) model. "I" is the number of lags needed to make the series stationary (Morretin, Toloi, 1987; Kwiatkowski et al., 1992; Makridakis et al., 1998; Li et al., 2019).

2.3.2 Model adopted to make the projection of population growth

To project the sizes of the annual populations that are likely to be in Maranhão between the years 2022 and 2030, the population growth rate was estimated. According to the Ministry of Health, this rate can be conceptualized as follows "Percentage of average annual increment of the population residing in a given geographic space, in the period considered" (BRASIL, 2018). According to this document, this rate indicates the pace of population growth and is influenced by the dynamics of birth, mortality, and migration. A limitation of the procedure is that its use to make projections of populations distant from the last Demographic Census may not capture relevant changes in changes in the dynamics of demography.

The population growth rate (r) can be estimated assuming linear growth rate (LGR), with constant evolution over time. Taking a discrete interval between two points in time: "t" and "0". If the measurement is made between the populations of two years, with P_0 being the population in the initial year, and P_t being the population in the final period. In this case, the population growth rate is calculated as follows (Tavares; Pereira Neto, 2020).

$$r = (P_t - P_0)/(t - t_0) \quad (9)$$

This growth rate can be estimated by the geometric method, in which case we have the instantaneous geometric growth rate or IGGR (Wooldridge, 2015). The equation for defining the discrete IGGR (r) for two consecutive periods is given by the equation:

$$r = (P_t / P_0)^{1/t} - 1 \quad (10)$$

When we have a continuous variable, observed in an annualized form, as is the case of the population of Maranhão for the period from 1933 to 2020, we use the equation defined below. Given a variable (Yt) observed annually in a continuous manner for N years, the instantaneous TGC is estimated as follows:

$$\log Y_t = \beta_0 + \beta_1 T + \upsilon_t \quad (11)$$

In equation (11), the coefficient β_0 is the log-linear parameter that measures the value of Y_t when T = 0. The β_1 coefficient, being statistically different from zero, measures the instantaneous geometric growth rate (IGGR) of Y_t; the random term υt, by hypothesis, has zero mean, constant variance and is not autoregressive along the series studied (Hill et all, 2003 ; Wooldridge, 2015).

Thus, due to possible changes in the dynamics of population growth over a period of 88 years (1933 to 2021), caused by factors such as migrations, changes in birth rates and mortality rates, two simulations were performed for the state's population growth, one covering the entire period and another estimating the growth rate for the years after the 2000 Demographic Census. Therefore, between 2000 and 2021, two census periods occurred, and the populations made available by IBGE take these two periods into consideration.

3 RESULTS AND DISCUSSION

3.1 CLASSIFICATION OF RAINFALL PRECIPITATION IN MARANHÃO BETWEEN THE YEARS 1933 AND 2020

The results found in the definition of the periods in which this research classified the annual rainfall observed in Maranhão between 1933 and 2020 are presented in Table 1. From the evidence shown in Table 4, it appears that the historical average rainfall observed for Maranhão in these 88 years of observations was 1,629.69 mm. Around this average precipitation oscillated from 1,042.81 mm in 1983 to 2,676.27 mm in 1985. The coefficient of variation estimated for the whole period was 18.34%, considered as average in the scale proposed by Gomes (1985).

Table 1 – Ranges of rainfall periods, number of years of occurrence, averages and coefficients of variation (CV) of the periods.

Periods	Range (mm)	Number of years	Average (mm)	CV (%)
Total	-	88	1,629.69	18.34
Shortfall	Rainfall < 1,480.28	24	1,280.40	8.53
Normality	1,480.28 > Rainfall < 1,779.10	37	1,608.40	5.45
Rainy	Rainfall > 1,779.10	27	1.969.32	10.72

Source of the original data: NOAA (2022).

We observed 24 years (27.3%) with periods classified as shortfall, in which the maximum annual rainfall was 1480.28 mm, with an annual average of 1,280.40 mm; 57 years (42.0%) considered as normal periods, in which rainfall ranged between 1. 480.28

mm and 1,779.10 mm, with an average of 1,608.40 mm; and 33 years (30.7%) classified as rainy periods, in which rainfall was greater than 1,773.71 mm, with an annual average of 1967.50 mm. It is also observed that the rainfall instability was considered average (18.34%) and that the largest of them occurred during the rainy periods (Table 1).

Table 2 presents the tests to assess whether the estimated means for the shortfall, normal and rainy periods between 1933 and 2020 are statistically different. It can be seen that the adjusted multiple determination coefficient was 78% and that the regression coefficients associated with the dummies variables used to test the differences between the means are all statistically different from zero with an error level of less than 1%. This confirms that the means are different both, in numerical magnitude and from a statistical point of view.

These results allow us to rank the observed rainfall in Maranhão between 1933 and 2020, in the periods defined in Table 1 and the results shown in Table 2, as follows, according to the assumption of this study:

Rainy period average > normal period average > shortfall period average.

Table 2 - Result of the comparison between the rainfall periods defined for Maranhão between 1933 and 2020

Varible	Coefficients	Student Statistics (t)	Sign.	Adjusted R^2
Constant	1280.40	44.23	0.000*	
D1	328.00	8.826	0.000*	0.780
D2	688.91	17.31	0.000*	

Source of the original data: NOAA (2022). *significant at 1% level of significance.

3.2 AVERAGE, MAXIMUM, MINIMUM VALUES AND COEFFICIENTS OF VARIATIONS OF HARVESTED AREAS, AGGREGATE PRODUCTIVITIES OF ANNUAL YIELDS PER CAPITA, AND IN THE PERIODS WHEN RAINFALL WAS CLASSIFIED IN MARANHÃO BETWEEN 1933 AND 2021

The annual per capita production of these crops was 157.46 kg/person, with a CV=53.89%, thus very high, according to Gomes' (1985) classification. This result shows a very high instability in the per capita production of these agricultural products in Maranhão during the investigated period. This very high instability is confirmed when we observe that around this average oscillated values ranging from 25.89 kg per person in 1941, a year of shortfall (1,280.98 mm), and 349.54 kg/person in 1982. In that year it rained 1,504.17 mm considered as a normal rainfall year according to what was defined in this research.

The survey results also show that the greatest instability was observed in the aggregate of harvested areas (CV=64.52%), classified as very high, and that the instability measured for the aggregate of yields was 28.94%, classified as high on the scale defined by Gomes (1985). The smallest harvested area (6,208.25 hectares) occurred in 1941. In that year, rainfall was 1280.98 mm, classified as insufficient. The largest aggregated area harvested with these crops (572,028.25 hectares) occurred in 1982, a year classified as normal, when it rained 1,504.17 mm. The average of the areas harvested between 1933 and 2021 was 226,008.84 hectares.

From the evidence shown found in the research, it is also evident that aggregate productivities had instability classified as high (28.94%). The average productivity was 3,062.26 kg per hectare. Its minimum value observed between 1933 and 2021 was 1,606.33 kg per hectare in 1967. In that year it rained 1,934.79, therefore classified as rainy. This confirms that excess rainfall can create problems for agricultural activities, especially if soils do not have adequate drainage. The maximum aggregate yield of 5,789.56 kg per hectare occurred in the year 1940, in which the rainfall of 1,491.23 mm which is classified as normal.

Table 3 shows the results found in the measurements of the aggregated per capita production, productivity, and harvested areas of the crops, in the shortfall, normal, and rainy periods. It can be observed by the evidence shown in this table that the greatest instabilities occurred in the harvested areas, all of them very high, according to the classification of Gomes (1985), reaching the greatest magnitude in the periods shortfall rainfall (CV = 82.19%). As for the productivity, it is observed that the greatest instability occurred during periods of shortfall rainfall (CV = 33.72%), also classified as very high according to Gomes (1985). These high instabilities of yields and harvested areas were transmitted to the observed per capita production, whose CV varied from 46.44% in the rainy periods to 60.03% in the shortfall periods. Therefore, all were classified as very high (Table 3).

As the instabilities estimated for Maranhão, measured by the coefficients of variation ranged from a CV = 8.53% in the shortfall period to CV = 10.72% in the rainy period, it can be inferred that the rainfall that occurred in Maranhão between 1933 and 2020, despite having contributed to the instabilities of harvested areas (the largest), productivities and per capita productions, were not the decisive factors for this to happen. Which, in a way, is surprising.

Table 3 - Minimum, maximum, average values and coefficients of variation (CV) of per capita production, productivity and aggregate harvested areas of crops estimated for the shortfall, normal and rainy periods between the years 1933 and 2021 in Maranhão.

Per capita production ($Kg.person^{-1}$)				
Periods	**Minimum**	**Maximum**	**Average**	**CV (%)**
Shortfall	25.98	309.16	134.32	60.03
Normal	29.10	349.54	169.20	54.70
Rainy	56.56	297.86	164.44	46.44
Productivity ($Kg.ha^{-1}$)				
Periods	**Minimum**	**Maximum**	**Average**	**CV (%)**
Shortfall	1,947.29	5,725.19	3,056.43	33.72
Normal	2,064.37	5,789.56	3,138.79	26.12

Rainy	1,606.33	5,204.26	2,944.28	29.28
		Harvested area (ha)		
Periods	Minimum	Maximum	Average	CV (%)
Shortfall	7,262.50	508.711.75	208,300.68	82.19
Normal	6,208.25	572.028.25	222,377.19	62.74
Rainy	13,092.50	458,640.75	247,840.90	53.90

Source of the original data: IBGE (several years).

3.3 ARIMA MODELS ESTIMATED TO FORECAST THE YIELDS AND AGGREGATED AREAS OF THE CROPS STUDIED IN MARANHÃO STATE

Next, the results found in the research are shown in the estimation of the ARIMA models that achieved the best adjustments to make the productivity and aggregate area forecasts for the crops studied between the years 1933 and 2021.

The unit root tests reveal that the original series were not stationary. The aggregate yields series became stationary through differentiation (d =1). The series associated with the harvested areas, with the inclusion of the log, showed to be orginally non-stationary, were differentiated twice (d=2) so that the stationarity of the series was achieved.

Table 8 shows the results obtained in the estimation of parameters and the tests associated with the two series studied. These results show that the adjustments obtained are parsimonious and robust, from a statistical point of view. In the best adjustments found, which are shown in Table 4, it is observed that the Pearson's linear correlation coefficients that gauge the relationship between the observed series and the predicted values were 0.983 and 0.948, respectively for the prediction of aggregate yields and harvested areas.

ISSN: 1696-8352

Table 4 - Models fitted to forecast yields and aggregate harvested areas of rice, beans, cassava and corn in Maranhão between 1933 and 2020

	Productivity (kg.ha^{-1})	**Harvested area (ha)**
Estimated model (p, d, q)	1, 1, 0	0, 2, 1
AR (1)	-0.303*	-
MA (1)	-	0.941*
R^2	0.648	0.906
Ljung Box	20.415^{NS}	6.368^{NS}
MAPE	10.618	11.385
BIC	12.526	21.440
R Pearson	0.983*	0.948*

Source of the original data: IBGE (several years).* Coefficient statistically different from zero with less than 1% error probability. NS. statistic not significantly different from zero with at least 30% error.

3.3 FORECASTS OF AGGREGATE PRODUCTIVITIES, AGGREGATE AREAS, POPULATIONS AND ANNUAL PER CAPITA PRODUCTIONS BETWEEN THE YEARS 2022 AND 2031

As shown in the methodology of this paper, to make the forecasts of the aggregated per capita productions of rice, beans, cassava and corn, two scenarios were created. In the first one the population growth rate was estimated based on the series from 1933 to 2021. In the second scenario, the population growth rate was estimated considering the most recent period from 2000 to 2021. The results found showed that in the period 1933/2021 the population growth rate of Maranhão was 2.3% per year. Between 2000 and 2021 the growth rate was 1.2% per year.

The results found in the research show that the average per capita production, over the 88 years studied was 157.5 kg/person, with a coefficient of variation of 53.9%, therefore with a very high instability according to Gomes 1985 classification. Around this average, values varied from 26 kg/person in 1941 (1941 1280,98mm a shortfall year) to 349.5 kg/person in 1982. The rainfall ein this year was 1504,17m classifad as normal in thies search.. It was also observed that in 54 years (61.4%) of the years observed, the per capita production was below the average (Table 5).

ISSN: 1696-8352

Table 5 - Observed values (2000/2021) and Forecasts of productivities, harvested areas, population and aggregate per capita production of rice, beans, cassava and corn in Maranhão in the period 2022 to 2031.

Year	Producti-vities (Kg.ha^{-1})	Harvested areas (ha)	Production (ton)	Popula-tion (pers.)	Popula-tion (pers.)	Per capita (Kg.pers.^{1})	Per ca-pita Kg.pers.^{1})
2000[1]	2,485.90	250,872.50	623,643.95	5,651,475	5,651,475	106.17	106.17
2001[1]	2,544.19	249,369.75	634,444.02	5,730,432	5,730,432	113.93	113.93
2002[1]	2,590.35	255,028.00	660,611.78	5,803,283	5,803,283	132.39	132.39
2003[1]	2,614.61	271,284.75	709,303.82	5,873,646	5,873,646	117.33	117.33
2004[1]	2,682.29	284,153.25	762,181.42	5,943,807	5,943,807	123.46	123.46
2005[1]	2,695.08	293,275.75	790,401.61	6,103,338	6,103,338	149.81	149.81
2006[1]	2,787.89	291,226.25	811,906.75	6,184,543	6,184,543	116.28	116.28
2007[1]	2,835.59	293,355.50	831,835.92	6,265,102	6,265,102	73.07	73.07
2008[1]	2,762.38	282,221.25	779,602.34	6,305,539	6,305,539	100.27	100.27
2009[1]	2,488.31	271,666.50	675,990.47	6,367,111	6,367,111	83.83	83.83
2010[1]	2,607.56	287,256.25	749,037.91	6,574,789	6,574,789	79.03	79.03
2011[1]	3,063.90	287,155.25	879,814.97	6,645,761	6,645,761	84.37	84.37
2012[1]	2,750.01	286,473.75	787,805.68	6,714,314	6,714,314	89.37	89.37
2013[1]	2,812.62	298,246.50	838,854.07	6,794,301	6,794,301	106.17	106.17
2014[1]	3,345.96	306,739.00	1,026,336.42	6,850,884	6,850,884	113.93	113.93
2015[1]	3,358.04	239,074.00	802,820.05	6,904,241	6,904,241	132.39	132.39
2016[1]	2,936.61	173,037.50	508,143.65	6,954,036	6,954,036	117.33	117.33
2017[1]	3,530.95	198,783.75	701,895.48	7,000,229	7,000,229	123.46	123.46
2018[1]	3,412.04	172,852.25	589,778.79	7,035,055	7,035,055	149.81	149.81
2019[1]	3,537.71	158,046.00	559,120.91	7,075,181	7,075,181	116.28	116.28
2020[1]	3,685.70	162,870.25	600,290.88	7,114,598	7,114,598	73.07	73.07
2021[1]	3,750.67	170,446.25	639,287.64	7,153,262	7,153,262	100.27	100.27
2022	**3,736.95**	**169,442.83**	**633,199.40**	**7,346,400**[2]	**7,239,101**[3]	**86.19**[2]	**87.47**[3]
2023	**3,735.14**	**169,874.44**	**634,504.80**	**7,544,753**[2]	**7,325,970**[3]	**84.10**[2]	**86.61**[3]
2024	**3,735.69**	**170,726.17**	**637,780.00**	**7,748,461**[2]	**7,413,882**[3]	**82.31**[2]	**86.03**[3]
2025	**3,735.52**	**172,025.08**	**642,603.10**	**7,957,670**[2]	**7,502,849**[3]	**80.75**[2]	**85.65**[3]
2026	**3,735.57**	**173,802.30**	**649,250.70**	**8,172,527**[2]	**7,592,883**[3]	**79.44**[2]	**85.51**[3]
2027	**3,735.56**	**176,093.68**	**657,808.50**	**8,393,185**[2]	**7,683,997**[3]	**78.37**[2]	**85.61**[3]
2028	**3,735.56**	**178,940.63**	**668,443.50**	**8,619,801**[2]	**7,776,205**[3]	**77.55**[2]	**85.96**[3]
2029	**3,735.56**	**182,391.05**	**681,332.70**	**8,852,536**[2]	**7,869,520**[3]	**76.96**[2]	**86.58**[3]
2030	**3,735.56**	**186,500.46**	**696,683.70**	**9,091,554**[2]	**7,963,954**[3]	**76.63**[2]	**87.48**[3]
2031	**3,735.56**	**191,333.29**	**714,737.00**	**9,337,026**[2]	**8,059,521**[3]	**76.55**[2]	**88.68**[3]

Source of the original data: IBGE (several years). *1 – Observed data ; 2 – Forecasted population (1933/2021 ; IGGR = 2.3% per year) ; 3 – Forecasted population (2000/2021 ; IGGR = 1.2% per year).

It is also observed that between 2000 and 2021 the average of per capita production was only 109.2 kg/person, which represents 69.3% of the average observed for the 88 years studied and CV = 20.4%, showing an high average instability for this variable in this period. Also in this period, the highest per capita production happened in 2005 (149.8kg/person) and the lowest per capita production happened in the years 2007 and 2020 (73.7 kg/person). It is also observed that from 2014 there was an almost constant decline in per capita production of rice, beans, cassava and corn in Maranhão, reaching 100,27 kg/person in 2021.

Based on the models adjusted for harvested areas, for yields and for populations (in two scenarios) the values shown in Table 5 are projected. The evidence shown in this table suggests that in a scenario of annual population growth (2.3% per year) the per capita production of these foods will vary from 86.2 kg/person to 76.6 kg/person between 2022 and 2031. On the other hand, in a more conservative population rate growth scenario (1.2% per year), the per capita production of food will vary from 87.5 kg/person in 2022 to 88.7 kg/person in 2031 (Table 5).

4 CONCLUSIONS

The work classified the rainfall precipitation in Maranhão for the period 1933 to 2000 in periods of scarcity, normal and rainy, The research demonstrated that the rainfall precipitation in the state for the period has high average, but presents instability classified as average and that the most unstable period, among the three defined in the research, is the rainy one,

From the evidence demarcated in the research, it is also clear that, throughout the entire trajectory observed for the rainfed crops studied, which covered the period from 1933 to 2021, both the harvested areas and the aggregate productivity of the crops presented very high instabilities, however, the harvested areas had a greater magnitude in this item.

It is also observed that both productivity and harvested areas and, consequently, per capita productions, had higher average values in normal periods and lower average values in rainy periods. In an evidence that the excess of rainfall in Maranhão causes problems in the production of rainfed crops studied.

The adjusted models to forecast productivity and harvested areas, besides being parsimonious, presented robust results from a statistical point of view, From these models the total forecasted productions for the period 2022 and 2031 were estimated, To estimate the growth of the populations, the work carried out two simulations, One considered the instantaneous annual growth rate (AARC) for the entire period analyzed (1933/2021) and the other considered only the populations estimated by IBGE from the 2000 Demographic Census, As expected, the TGC for the longer period was much higher, Even so, the forecasts of per capita production of these products between the years 2022 and 2031 were made.

Making a temporal cut also for the observed values of the harvested areas, productivity and per capita production, for the period from 2000 to 2021, we can see an evident decline in the per capita production of food starting after 1982, when the per capita production of these foods in Maranhão reached its highest value.

The overall conclusion of the research is that the annual rains in Maranhão, as they are in general, cause instabilities both for productivity, but mainly for the areas harvested with rice, beans, cassava and corn. However, it was observed that the instabilities of harvested areas, yields and yields per capita are much higher than those observed for rainfall. This suggests that there are other factors of instability even greater than those caused by rainfall instability. A problem that raises the search for new research to know what are these factors that add to unstable rainfall to cause more instability in agricultural production of rainfed crops studied in this research.

REFERENCES

ALLISON. P. D. “Measures of Inequality.” *American Sociological Review*. 43. p. 865-880. 1978.

BOX. G. E. et al. *Time Series Analysis. Forecasting and Control*. John Wiley & Sons. Hoboken. 2015.

BOX, G.; JENKINS, G. M. *Time series analysis. San Francisco*: Holden-Day. 1976.

BRASIL. Ministério da Saúde. DATASUS. Informações de Saúde (TABNET). *Taxa de crescimento da população*. 2018. Disponível em: http://tabnet.datasus.gov.br/tabdata/LivroIDB/2edrev/a03.pdf. Acesso em: 10 de março de 2022.

COCHRANE. John H. Time series for macroeconomics and finance. *Manuscript*. University of Chicago. 1997.

COSTA. A. de S. Modulação regional das chuvas no Estado do Maranhão. 2016. 85 f. Dissertação (Mestrado em Meteorologia) – *Programa de Pós-Graduação em Meteorologia*. Centro de Tecnologia e Recursos Naturais. Universidade Federal de Campina Grande. Paraíba. Brasil. 2016.

FAO. Food and Agriculture Organization of the United Nations. Refinements to the FAO methodology to restimation the prevalence of under nourishment indicator**.** *Working Paper*. n. 14. 5. 2014. Disponível em: http://www.fao.org/3/a-i4046e.pdf. Acesso em: 28 maio 2022.

GARCIA. C. H. *Tabelas para classificação do coeficiente de variação*. Piracicaba: Ipef. 1989. 12p. (Circulartécnica. 171).

GOMES. F. P. *Curso de estatística experimental*. 13. Ed. São Paulo: ESALQ/USP. 1985.467p.

GUJARATI. D. N.; PORTER. D. C. *Econometria Básica*. 5. Ed. Porto Alegre: AMGH. 2011.

HILL. R.C. GRIFFTHS. W. E.; JUDGE. G.G. *Econometria*.São Paulo. Editora Saraiva. 2003.

IBGE/SIDRA. *Censo Agropecuário 2017: resultados definitivos*. Rio de Janeiro: IBGE. 2019. Disponível em: https://sidra.ibge.gov.br/pesquisa/censo-agropecuario/censo-agropecuario-2017. Acesso em: 05 maio 2022.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Censo Demográfico do Brasil de 2010*. Rio de Janeiro. 2010.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1946*. Rio de Janeiro: IBGE. 1947.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1947*. Rio de Janeiro: IBGE. 1948.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1948*. Rio de Janeiro: IBGE. 1949.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1949*. Rio de Janeiro: IBGE. 1950.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1950*. Rio de Janeiro: IBGE. 1951.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1951*. Rio de Janeiro: IBGE. 1952.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1952*. Rio de Janeiro: IBGE. 1953.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1953*. Rio de Janeiro: IBGE. 1954.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1954*. Rio de Janeiro: IBGE. 1955.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1955*. Rio de Janeiro: IBGE. 1956.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1956*. Rio de Janeiro: IBGE. 1957.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1957*. Rio de Janeiro: IBGE. 1958.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1958*. Rio de Janeiro: IBGE. 1959.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1959*. Rio de Janeiro: IBGE. 1960.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1960*. Rio de Janeiro: IBGE. 1961.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1961*. Rio de Janeiro: IBGE. 1962.
Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1962.* Rio de Janeiro: IBGE. 1963.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1963.* Rio de Janeiro: IBGE. 1964.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1964.* Rio de Janeiro: IBGE. 1965.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1965*. Rio de Janeiro: IBGE. 1966.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1966.* Rio de Janeiro: IBGE. 1967.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1967.* Rio de Janeiro: IBGE. 1968.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1968.* Rio de Janeiro: IBGE. 1969.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1969.* Rio de Janeiro: IBGE. 1970.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1970.* Rio de Janeiro: IBGE. 1971.

Instituto Brasileiro de Geografia e Estatística (IBGE). *Anuário Estatístico do Brasil de 1973.* Rio de Janeiro: IBGE. 1974.

KWIATKOWSKI. Denis et al. Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root?. *Journal of econometrics*. v. 54. n. 1-3. p. 159-178. 1992.

LEMOS. J. J. S. et al. Rainfed Crops Forecasting in the Semi-arid Region under Scenarios of Rainfall Instability in Ceará. Brazil. *Journal of Agricultural Science and Technology*. Volume 12. Number 2. Mar.-Apr. 2022.

LEMOS. José de Jesus Sousa; BEZERRA. Filomena Nádia Rodrigues. Interferência da instabilidade pluviométrica na previsão da produção de grãos no semiárido do Ceará. Brasil. *Brazilian Journal of Development*. v. 5. n. 9. p. 15632-15652. 2019.

LI. Shuyu; YANG. Xuan; LI. Rongrong. Forecasting coal consumption in India by 2030: using linear modified linear (MGM-ARIMA) and linear modified nonlinear (BP-ARIMA) combined models. *Sustainability*. v. 11. n. 3. p. 695. 2019.
MAKRIDAKIS. S.. Wheelwright. S.. & Hyndman. R. J. *Forecasting methods and applications* (3rd ed.). New York: John Wiley & Sons. 1998.

MENEZES. Ronaldo Haroldo Nascimento de. *Caracterização agroclimática e análise do rendimento agrícola do Estado do Maranhão*. Brasil. 2009.

MORRETIN. P. A. & TOLOI. C. M. C. *Previsão de séries temporais* (2a ed.) São Paulo: Atual Editora. 1987.

NASCIMENTO CAMELO, Henrique do et al. Proposta para previsão de velocidade do vento através de modelagem híbrida elaborada a partir dos modelos ARIMAX e RNA. *Revista Brasileira de Meteorologia*, v. 33, p. 115-129, 2018.

NAYRY. K.S.; RAO. A.K. Tests of coefficients of variation of normal population. *Communications in Statistics-Simulation and Computation*. v. 32. n. 3. p. 641-661. 2003.

NOAA. National centers for environmental information (NCEI. EUA). *Global Historical -Monthly Climatology Network (GHCN-M).* 2022 Disponível em: https://www.globalclima temonitor.org/#. Acesso em 20 abr. 2022.

NUGEO/LABGEO. *Atlas do Maranhão*. UEMA. São Luís-MA. 2002.

O'REILLY. C. A.; CALDWELL. D. F.; BARNETT W. P. "Work Group Demography. Social Integration. and Turn-over." *Administrative Science Quarterly*. 34. p. 21-37. 1989.

PUNT. C. Measures of Poverty and Inequality: A Reference Paper. *Provide Technical Paper*. 4. 2003. Disponível em: http://ageconsearch.umn.edu/bitstream/15623/1/tp030004.pdf. Acesso em: 25 maio 2022.

SANTOS. Carla; DIAS. Cristina. Note on the coefficient of variation properties. *Brazilian Electronic Journal of Mathematics*. v. 2. n. 4. p. 101-11. 2021.

SUDENE. *Nova delimitação do Semiárido*. 2021. Disponível em: https://www.in.gov.br/web/dou/-/esolução-condel/sudene-n-150-de-13-de-dezembro-de-2021-370970623. Acesso em: 01 jan 2022.

TAVARES. J. M. S.; PEREIRA NETO. C. Aspectos do crescimento populacional: estimativas e uso de indicadores sócio demográficos. *Revista Formação* (ONLINE). v. 27. n. 50. jan-abr/2020. p. 3-36. ISSN: 2178-7298. E-ISSN: 1517-543X. Disponível em: https://revista.fct.unesp.br/index.php/formacao/article/view/5928/5599. Acesso em: 20 mar. 2023.

TEIXEIRA, Jacson Moura. *Perfil dos Produtores de Arroz (Oriza sativa L.) na comunidade barroca da vaca, município de Chapadinha-MA*. 2017.

WIERSEMA. M.; BANTEL. K. “Top Management Team Turnover as na Adaptation Mechanism: The Role of the Environment.” *Strategic Management Journal*. 14. p. 485-504. 1993.

WOOLDRIDGE. J.M. *Introductory econometrics: A modern approach*. South Western Educational Publishing. 881 p. 2015.