Original Scientific paper
10.7251/AGREN2403117L
UDC 633:551.575.21(81)

CLIMATE INSTABILITY, RESILIENCE AND RURAL DEVELOPMENT IN PARAÍBA, BRAZIL

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ABSTRACT

The majority of farmers in the state of Paraiba, located in the northeast of Brazil, practice rainfed agriculture, which depends on rainfall for its full development. The crops studied in this research are rice, beans, cassava and corn, that are mostly grown in the state, especially by family farmers. These crops provide income, occupation and food security for families. The specific objectives of the research are: to assess whether these rainfed crops have sustainable yields and incomes as a result of climate variability in the state between 1945 and 2020; and to assess whether rainfall instabilities interfere with the production forecast for these crops. Crop production data was taken from the Brazilian Institute of Geography and Statistics (IBGE). Annual rainfall data for the state was collected from the National Oceanic and Atmospheric Administration (NOAA). The research used the Box and Jenkins method to draw the trajectories of productivity and aggregate income per hectare. Geometric Growth Rates (GGR) were estimated to assess whether there was sustainability in productivity and income over the period investigated. The results show that the state had high rainfall instability (measured by a coefficient of variation of 26%) and that rainfall interferes in predicting aggregate productivity, but does not directly interfere in predicting aggregate income per hectare of the crops studied. In general, farmers were able to maintain sustainable agricultural production in Paraiba and were self-resilient to the effects of the stresses caused by the unstable rainfall observed during the period studied.

Keywords: *Brazilian semi-arid region, rain fed crops, Box and Jenkins model, Sustainable productivity and income, drought.*

INTRODUCTION

The semi-arid climate is marked by high temperatures, low humidity and high rainfall variability, which are concentrated in a short period of the year, with frequent years of drought (Marengo et al., 2017; Salviano et al., 2020). This climatic instability, together with the degradation of natural resources, affects the distribution and production of crops, increasing the risks of inadequate agricultural practices.

Productivity is already suffering negative impacts, highlighting the need for farmers and policymakers to adapt (Lobell et al., 2011; Nelson et al., 2010).

The growth of Brazilian agriculture took place under a model of land concentration, mainly affecting the North and Northeast regions. In the semi-arid region, the population faces climatic, economic and social vulnerabilities, especially in rural areas. Farmers, mostly grow rainfed crops, and are dependent on irregular rainfall and poor soil quality to determine productivity (Lemos, 2020).

Despite these difficulties, farmers develop adaptive methods to cope with rainfall instability, demonstrating adaptive capacity or self-resilience (Devendra, 2016; Praxedes, 2021). This behavior fits into the concept of Climate Resilient Agriculture (CRA). In the semi-arid region of Paraiba, farmers apply techniques that indicate CRA practices (Bezerra, 2022; Praxedes, 2021; Rao et al., 2016).

In the state of Paraíba, Brazil, the crops of beans, cassava and corn, and to a lesser extent rice, are essential, widely cultivated and important for food security and the family economy, according to the 2017 Agricultural Census (IBGE, 2019). These rainfed crops are mainly grown by family farmers and are essential for food security and family income (Costa Filho, 2019; Pereira; Silva Junior, 2018; Salviano, 2021).

This study seeks to answer whether rainfed crops of rice, beans, cassava and corn in Paraíba are resilient to the climate. The aim is to assess the resilience of these crops to climate instability from 1945 to 2020. Specifically, we intend to: a) analyze rainfall in Paraíba from 1901 to 2020, classifying it into dry, normal and rainy periods; b) create an index that evaluates the synergy between the production variables of rice, beans, manioc and corn from 1945 to 2020; and c) verify the resilience of agricultural production by analyzing the relationship between the index created and the rainfall observed.

MATERIALS AND METHODS

The data used in this work is of a secondary nature. The annual rainfall of the state of Paraíba, in millimeters, for the years 1901 to 2020, was extracted from the Global Historical Climatology Network-Monthly (GHCN-M) of the National Oceanic and Atmospheric Administration (NOAA, 2022). The data on agricultural production of rice, beans, manioc and corn in Paraíba from 1945 to 1973 was obtained from the IBGE Statistical Yearbooks, and from 1974 to 2020, from the Municipal Agricultural Survey (IBGE, 2021). The variables used were: annual rainfall (1901-2020); harvested areas (ha/year); annual yields (kg/ha); and annual prices (R$/kg) for rice, beans, cassava and corn, corrected to 2020 values by the General Price Index-Internal Availability (IGP-DI) of the Getúlio Vargas Foundation.

For the first objective, the years were organized into each period based on the fluctuations of half the standard deviation (SD) around the average rainfall observed over the years analyzed: Dry (RF < Average – 0.5 SD), Normal (RF =

Average ± 0.5 SD), Rainy (RF > Average + 0.5 SD), as defined by Lemos and Bezerra (2019).

We assess whether the averages of the rainfall periods (RF) are numerically and statistically different using dummy variables: $RF_t = \beta_0 + \beta_1 D1 + \beta_2 D2 + \epsilon_t$. Where, D1 = 1 in the normal period and D1 = 0 in the other periods; D2 = 1 in the rainy period; D2 = 0 in the other periods; D1 = D2 = 0 in the dry period. The random term ϵt, by hypothesis, is white noise, and the coefficients can be estimated using the Ordinary Least Squares (OLS) method (Wooldridge, 2015).

If the linear coefficient β_0 is statistically different from zero, with D1 = D2 = 0, this is the average rainfall for the dry period; if β_1 is statistically different from zero, with D2 = 0 and D1 = 1, the average rainfall for the normal period differs from the other periods. If the β_2 coefficient is statistically different from zero, with D1 = 0 and D2 = 1, the average rainfall for the rainy season will differ from the other periods.

The level of stability/instability of the rainfall averages in each period was indicated by the coefficient of variation (CV), which measures the percentage relationship between the standard deviation and the mean. The CV classification is: CV < 10% (low); 10% ≤ CV ≤ 20% (medium); 20% ≤ CV ≤ 30% (high); CV ≥ 30% (very high) (Gomes, 1985).

In this study, it is assumed that the measurement of crop resilience can be reproduced by constructing a Dryland Crop Resilience Index (IRLS) for the years 1945 to 2020, with subsequent analysis of the fluctuation of this index in relation to the rainfall periods defined in objective “a”. Factor analysis (FA) was used to find the interaction between the variables selected for this stage, using the principal component decomposition method. The criteria adopted in the factor analysis were: rejection of the null hypothesis of Bartlett’s test of sphericity with a p-value no greater than 10%; Kaiser-Meyer-Olkin (KMO) values above 0.5; variance explained by the factors greater than 50%; Varimax rotation method; determination of the number of factors by the latent root criterion, selecting factors with eigenvalues greater than one (1) (Hair et al., 2009; Fávero & Belfiore, 2017; Pallant & Tennant, 2007).

The coefficients generated in factor analysis are used to calculate factor scores for the standardized original variables, transforming them and reducing them to factors. These scores have a mean of zero and a variance of one (1). For economic phenomena, the indices constructed must be strictly positive (Briguglio & Galea, 2003; Lemos, 2012). The following Equation is used so that the values only remain positive, but without affecting the original relative distances: $F_{Pj} = \frac{F - F_{min}}{F_{max} - F_{min}}$. Where F_mine F_max are the minimum and maximum weighted values for the factor scores associated with the state in each year observed.

The Resilience Index for Rainfed Crops (IRLS) is calculated using the arithmetic mean, as shown in this Equation: $IRLS_t = \frac{\sum F_{Pj}}{n}$. Where IRLSt refers to the Dryland Crop Resilience Index associated with the state of Paraíba in year t (t = 1945, 1946, ..., 2020). These values vary between zero and one. To make it easier to understand, the index is transformed into percentage values, making the highest value generated equal to 100 and the others as shown: $IRLS_{j100} = \left(\frac{IR_j}{IR_{jMÁXIMO}}\right) \times 100$.

To achieve the third objective, the years in which drought occurred in the state of Paraíba, as defined in this research, were calculated in sequence and, if there were sequences of more than one year in which drought occurred, the arithmetic mean of the IRLS for that sequence of years was calculated. The observed sequences of normal or rainy years are calculated together and defined as “non-drought” periods. Resilience, in this case, can be defined as the ability to recover in non-dry periods preceded by a dry period.

Thus, after defining the “dry” and “non-dry” periods, pairs identified as “after” and “before” are assembled, given the occurrence of dry periods. Next, contrast tests of means (Student’s t-test) are carried out to detect statistically different means between the pairs of “before” and “after” groups. In this case, the null hypothesis (H0) adopted is: the difference between the average IRLS after the drought period and its average before the drought is equal to zero (0).

RESULTS AND DISCUSSION

This study has 120 years (1901 to 2020) of rainfall observations, with an average of 892.0 mm per year and a coefficient of variation of 26.0%, considered high according to Gomes (1985) (Table 1). The periods considered dry, normal and rainy were defined after analyzing the fluctuation of half a standard deviation around the average rainfall observed in the period.

The period defined as “dry” is one in which the volume of rainfall is less than 776.0 mm. It was observed that in 40 of the 120 years studied, there was an average rainfall of 669.5 mm and a coefficient of variation classified as medium (13.9%). The “rainy” period is the one in which there are years with more than 1008.0 mm of rain, covering 31 years, with an average annual rainfall of 1195.6 mm and a CV characterized as medium (15.2%). The period defined as “normal” is concentrated between the first two, comprising 49 years, average annual rainfall of 881.6 mm, with low variation around the average volume, given the coefficient of variation of 7.8%.

From the results obtained when comparing the rainfall periods defined in the previous stage, using simple regression with the aid of dummy variables, it can be seen that all the periods are statistically different at a significance level of at least 1% (0.000), as well as having a high adjusted R2 (0.752), indicating that the model used is well-suited.

That said, when the values of the dummy variables D1 = D2 = 0, we have the average rainfall for the dry period (669.5 mm); when D1 = 1 and D2 = 0, we have the average rainfall for the normal period (881.6 mm), and when D1 = 0 and D2 = 1, we have the average rainfall for the rainy period (1195.6 mm). This confirms the hypothesis that rainfall in the state of Paraíba between 1901 and 2020 can be ranked as follows:

$RF_{RAINY=1195.6} > RF_{NORMAL=881.6} > RF_{DROUGHT=669.5}$.

In a way, it is known that Paraíba is one of the states with the greatest spatio-temporal variation in rainfall within the Northeast region, given that its micro-regions have quite peculiar rainfall characteristics. The Litoral region has rainfall ranging from 1,200 mm to 1,600 mm, while the Cariri/Curimataú region has rainfall ranging from 300 mm to 500 mm (Francisco et al., 2015).

This high variability is capable of directly and indirectly affecting activities that depend on this natural phenomenon for their full development. This is confirmed by Barbosa et al. (2016) who argue that extreme rainfall events are capable of causing impacts on agricultural activities, environmental setbacks in urban areas and, consequently, on the health of the population.

To meet the second objective, the Rainfed Crop Resilience Index (IRLS) was constructed using factor analysis. The IRLS weighted aggregates the selected variables, structured into four estimated factors.

Table 2 shows that the factor analysis was statistically robust: Bartlett's test confirmed that the matrix of 12 variables is not identity, the KMO was 0.724, the total variance explained by the four factors was 84.6%, and all the communalities were greater than 0.5.

The factor loadings, ranging from -1 to +1, were all above 0.50, which is significant for interpreting the factors generated (Table 2).

Table 2. Results found when estimating the components in which the original variables were reduced, with the respective communalities and factor loadings.

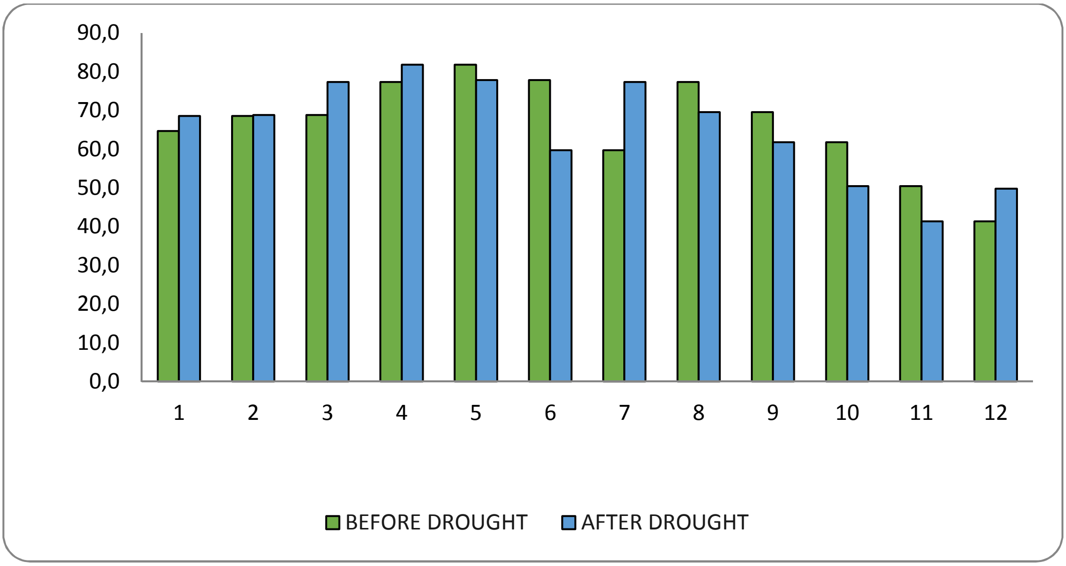
Variables	Commonalities	Factor loadings			
		F1	F2	F3	F4
Harvested area – Rice	0,735	0,388	0,481	**0,541**	-0,245
Productivity – Rice	0,945	0,047	0,146	0,045	**0,959**
Price - Rice	0,867	**0,901**	0,078	0,184	-0,126
Harvested area **–** Beans	0,934	0,107	-0,230	**0,927**	0,106
Productivity – Beans	0,878	-0,130	**0,905**	-0,050	0,198
Price- Beans	0,874	**0,804**	-0,397	0,262	0,020
Harvested area - **Cassava**	0,812	**0,644**	0,264	0,571	-0,036
Productivity – **Cassava**	0,644	0,119	**0,782**	-0,086	-0,108
Price- Cassava	0,665	**0,585**	-0,446	0,246	0,252
Harvested area -**Corn**	0,978	0,278	0,027	**0,948**	0,032
Produtividade– **Corn**	0,903	-0,199	**0,901**	0,126	0,187
Price - Corn	0,913	**0,947**	-0,019	0,084	0,094

	Results
Bartlett's test	
Chi - approximate square	834,599
Degrees of freedom	66
Significance	0,000
KMO Test	0,724
Cumulative variance (%)	84,6

Source: Survey results (2022).

This objective assessed the resilience of rice, bean, cassava and maize crops by analyzing the relationship between rainfall and the IRLS index created earlier. The averages of the dry and non-dry periods were determined, the latter combining normal and rainy years.

The Student's t-test for paired samples showed that the average for the non-dry period was approximately 66.6, while the average for the dry period was around 57.5, with a difference of 9.1. There was a statistically significant difference at less than 5% significance ($p = 0.023$), rejecting the null hypothesis of equality between the averages of the periods. Therefore, the average IRLS index in the non-drought period is statistically higher than in the dry period, indicating that agricultural production tends to be lower in drought years. The results also included an analysis of the averages for the periods before and after the droughts, showing the fluctuation of the IRLS indices in these periods, as illustrated in Graph 1.



Source: Prepared by the authors (2022).

Graph 1. Resilience Index of Dryland Crops before and after droughts in Paraíba between 1945 and 2020

CONCLUSIONS

With regard to the classification of annual rainfall from 1901 to 2020 into three previously defined periods, the study distinguished 40 years of drought, 49 years of normal rainfall and 31 rainy years. Paraíba shows high rainfall instability (CV=26%) over the 120 years analyzed, but this variability decreases within each period, with the normal period being the most homogeneous (CV=7.8%).

Annual rainfall has an impact on agricultural productivity, with productivity being on average 4% higher in rainy periods compared to dry ones. However, there is no direct interference from rainfall in predicting gross income per hectare, since in periods of good rainfall, production increases and prices fall, while in dry periods, prices increase due to scarcity.

The sustainability analysis showed that aggregate productivities were considered unsustainable, but aggregate incomes per hectare were sustainable throughout the period analyzed, despite a few exceptions.

To improve the productive and living conditions of farmers in Paraíba, policies to mitigate the effects of droughts are necessary. This includes the use of cultivars adapted to climate instability and access to rural insurance policies linked to PRONAF funding. Access to PRONAF should be facilitated not only by Banco do Nordeste, but also by the Technical Assistance, Rural Extension and Rural Development services provided by the state government. In addition, it is essential to promote safe seed storage practices, such as plate cisterns and community reservoirs, and to encourage associativism and cooperativism among farmers in order to strengthen the resilience of farming communities in the face of climatic challenges.

This study sought to analyze the effects of rainfall on dryland agricultural production in Paraiba. However, the crops analyzed here, despite being widely cultivated, do not constitute the totality of crops found in the state. It is therefore suggested that further studies be carried out from the perspective of other rainfed crops. Furthermore, it is clear that the state of Paraíba has great spatial variability in rainfall; not for nothing, the state is divided into six rainfall regions: Agreste, Alto Sertão, Brejo, Cariri/Curimataú, Litoral and Sertão. However, the rainfall volume used here comprises the total amount observed for the state. This being said, it is important to carry out new studies that take into account this particularity of the state, in order to ascertain whether the results found here are reflected in all these regions.

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