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Climatic Instability And Resilience In The Agricultural Production Of Rainfed Crops In The State Of Paraiba, Brazil

Laura Cunha Rebouças Lessa [1], José De Jesus Sousa Lemos [2],
Erika Costa Sousa[1], Milena Monteiro Feitosa[3]

[1](Phd Student In Agricultural Economics At Federal University Of Ceará (UFC), Brazil)
[2](Full Professor In Post Graduation Program Of Agricutural Economics. Department Of Agricultural Economics, Federal University Of Ceará (UFC), Brazil)
[2](Phd Student In Program Of Developmente And Environmente At Federal University Of Ceará (UFC), Brazil)

Abstract:
In Paraíba, most farmers practice rainfed agriculture, which depends on rainfall for its full development. The rainfed crops studied were rice, beans, cassava and corn. The objectives of the research were: a) to identify the behavior of rainfall in the state of Paraíba between 1901 and 2020 and try to classify it into three specific periods: dry, normal and rainy; b) to gauge the levels of instability/stability of annual rainfall c) to design an instrument that is capable of gauging, in a weighted and compressed manner, the synergy that exists between the defining variables of rice, bean, manioc and corn production in Paraíba from 1945 to 2020, the years in which data is available at an aggregate level for the state; and d) to assess the existence of resilience in agricultural production by analyzing the cause-effect relationship between the instrument designed in objective "b" and the rainfall observed in the state. Factor analysis was used to construct the Rainfed Crop Resilience Index (IRLS), which was used to assess the behavior of rainfed production in Paraíba. The results showed that the state had high rainfall instability over the 120 years analyzed. There was evidence of the resilience of dryland farmers in the face of rainfall instability during the period.
***Key Word**: Climate resilient agriculture; Semi-arid; Rainfall instability; Family farmers; Rainfall spatial and temporal variability; Climate variation.*

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I. Introduction

The semi-arid climate is characterized by the contrast between high temperature and low relative humidity and by high spatial and temporal variability of rainfall, which occurs for a short and concentrated period in the year, in addition to the common occurrence of years without rainfall [1,2].

These climatic instabilities influence the distribution and production of crops and increase the risks associated with agricultural practices in general and inadequate ones in particular. Crop yields experience negative impacts, reinforcing the need to adopt adaptation measures both by farmers who are already doing so in some way and by public policy decision-makers [3,4].

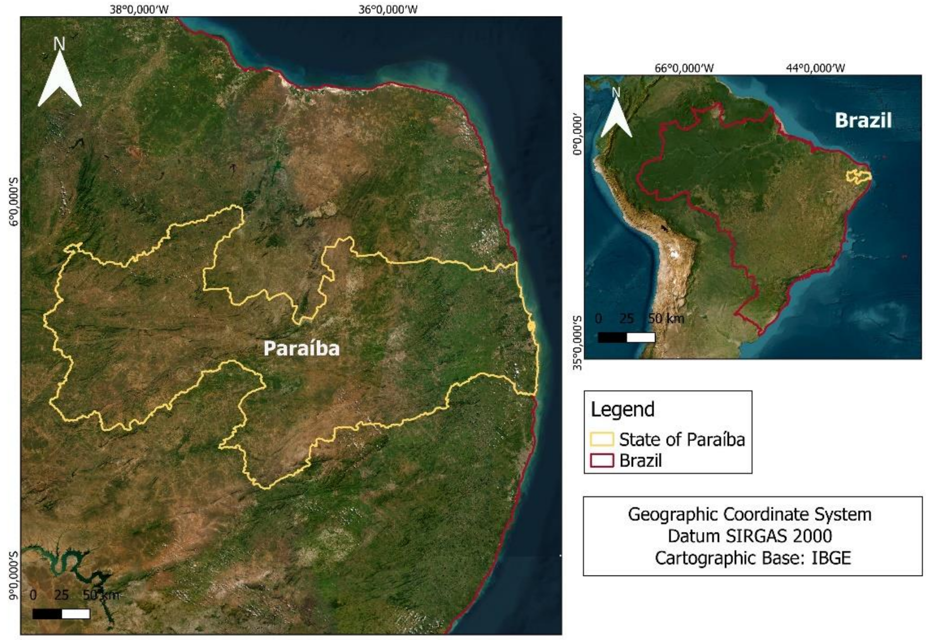
The population living in the semi-arid region is subject to climatic, economic and social vulnerabilities, especially in rural areas. Farmers, the vast majority of whom grow dryland food crops, are held hostage by the instability of rainfall and the poor quality of the soil in order to define the productivity of their crops [5].

However, it is well known that farmers, especially those who cultivate rainfed crops, are able to develop adaptive methods to cope with these rainfall instabilities that are intrinsic to agricultural activity in general. This behaviour can be characterized as a self-defence mechanism and identified as adaptive capacity or self-resilience [6,7].

Thus, the self-resilience of farmers can be framed within the concept of Climate Resilience Agriculture (CRA). In the Brazilian semi-arid region as a whole, and particularly in the state of Paraíba, farmers apply techniques in their areas that may be indicative of practices and procedures inherent to what is currently known as CRA [8,7,9,10].

In Paraíba (FIGURE 1), bean, cassava and corn crops are among the five largest harvested areas in the state in 2020 (IBGE/PAM). Although rice is grown in smaller numbers of establishments, it is also of significant importance at state level, according to information from the 2017 Agricultural Census [11]. These four are rainfed food crops that are mostly grown by family farmers and are considered to be some of the main activities in regional agricultural production. They also contribute to providing food security and occupation for families, as a source of income and animal feed [12,13,14,15].

Figure 1: Geographic location map of the State of Paraíba, Brazil.



Souce: IBGE (2022).

Anchored in these characteristics, this study sets out to answer the following question: can it be inferred that the ways in which crops such as rice, beans, cassava and corn, grown in rainfed environments by farmers in Paraíba, are resilient to the climate? To answer this question, the research has the following specific objectives: a) to identify the behavior of rainfall in the state of Paraíba between 1901 and 2020 and try to classify it into three specific periods: dry, normal and rainy; b) to gauge the levels of instability/stability of annual rainfall c) to design an instrument that is capable of gauging, in a weighted and compressed manner, the synergy that exists between the defining variables of rice, bean, cassava and corn production in Paraíba from 1945 to 2020, the years in which data is available at an aggregate level for the state; and d) to assess the existence of resilience in agricultural production by analyzing the cause-effect relationship between the instrument designed in objective "b" and the rainfall observed in the state.

In addition to this introductory section, the article has a second theoretical section, followed by the methodology, results and discussion and, finally, the final considerations.

II. Climate Resilient Agriculture

Climate variation, which is difficult to gauge, especially in the long term, since it takes a long time to get a sense of the problem, can be of natural origin, due to events such as ocean currents, the occurrence of the El Ninho and La Ninha phenomena, the tilt of the earth, continental drift and volcanoes, for example. But it can also be of anthropogenic origin, caused by the advance of essentially urban areas, industrialization, the burning of fossil fuels, deforestation and the inadequate practice of agricultural activities [16].

Nevertheless, it is known that farmers develop adaptive strategies for living in this environment full of intrinsic characteristics and affected by changes in the climate. These strategies are learned from living with relatives and/or from their own experiences as farmers. In this way, farmers' behavior can be understood in the concept of self-resilience [8,6,7,9]. Resilience can be understood as the ability of a system to absorb impacts and reorganize itself, maintaining its initial characteristics [17,18].

It is in this environment that the definition of Climate Resilient Agriculture (CRA) is inserted. According to Rao et al. (2016)[10], CRA is understood as mitigation, adaptation and other agricultural practices capable of increasing the productivity of the system in the face of different climate vulnerabilities, resisting the damage caused by these events and returning to the initial balance as soon as the stress causing the imbalances is overcome, guaranteeing a so-called sustainable production.

Climate Resilient Agriculture is achieved through the implementation of various strategies, such as the cultivation of drought-tolerant varieties, correct soil management, rainwater harvesting and storage, crop diversification in arable areas and the cultivation of crops with a shorter production cycle [10,19]. In the semi-arid region in general, there are practices implemented by farmers that can be understood as CRA. These include storing rainwater and the best seeds for later cultivation, saving stored water to avoid future shortages, and growing several crops in the same area to reduce losses due to the adversities faced [9]. The definition of climate resilient agriculture can be seen as one of the pillars for achieving Climate Smart Agriculture (CSA) [20].

In 2010, the Food and Agriculture Organization of the United Nations (FAO) developed the definition of Climate Smart Agriculture (CSA) and presented it at the Hague Conference on Agriculture, Food Security and Climate Change. This concept reflects the synergy between the economic, social and environmental dimensions of sustainable development, seeking to find food security under the challenge of climate change [20].

The concept of climate-smart agriculture has three anchors: sustainable growth in productivity and income in the agricultural sector; adaptation and building resilience to climate variability; and removal and/or reduction of greenhouse gas emissions, where possible [20]. In addition, the CSA seeks to identify the technical and economic concepts that could encourage climate change intelligence actions. The FAO points out that it may not be possible to achieve the three pillars on which the CFS is based simultaneously. It is necessary to evaluate each particularity, priorities and dilemmas that need to be overcome [20].

III. Material And Methods

The data used in this work is of a secondary nature and consists of the annual rainfall, in millimeters, observed for the state of Paraíba, from 1901 to 2020, extracted from the Global Historical Climatology Network-Monthly (GHCN-M), of the National Oceanic and Atmospheric Administration [22]. The figures for agricultural production of rice, beans, manioc and corn in the state of Paraíba between 1945 and 2020, the years in which this information is available at state level. The information for the years 1945 to 1973 was obtained from the IBGE Statistical Yearbooks [22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48]. Data for the years 1974 to 2020 was taken from the Municipal Agricultural Survey [49].

The variables used were: annual rainfall in Paraíba between 1901 and 2020; harvested areas (ha/year), annual yields (kg/ha); and average annual prices of R$/kg for rice, beans, manioc and corn. Prices were adjusted to 2020 values using the General Price Index - Domestic Availability (IGP-DI), from the Getúlio Vargas Foundation. Based on the average exchange rate for 2020, prices were converted into USD/kg.

Methodology applied to meet objective "a"

The first objective of the research consists of classifying Paraíba's rainfall from 1901 to 2020 into three specific periods: dry, normal and rainy, as defined by Lemos and Bezerra (2019)[7]. The organization of the years in each period was based on the fluctuations of half the standard deviation (SD) around the average rainfall observed over the years analyzed, as shown in Table 1:

Table 1 - Classification of rainfall into 3 distinct periods (dry, normal and rainy), according to the mean (MD) and estimated standard deviation for the period from 1901 to 2020

Periods	Range
Drought	Rainfall < Average – 0,5 Standard deviation (sd)
Normal	Rainfall = Average ± 0,5 Standard deviation (sd)
Rainy	Rainfall > Average + 0,5 Standard deviation (sd)

Source: Lemos and Bezerra (2019).

We assess whether the averages of these periods are numerically and statistically different. To do this, we use the dummy variables defined in equation (1):

$$CH_t = \beta_0 + \beta_1 D_1 + \beta_2 D_2 + \epsilon_t \quad (1)$$

In Equation (1): 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 [50].

If the linear coefficient β0 is statistically different from zero, with D1 = D2 = 0, this is the average rainfall for the dry period; if β1 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 β2 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. It is hoped that the average rainfall periods in Paraíba between 1901 and 2020 can be ranked as follows: CHwet > CHnormal > CHdry.

Methodology used to meet objective "b"

The coefficient of variation (CV) was used to assess the levels of stability/instability of rainfall throughout the historical period and in the periods in which the rainfall was classified. The Coefficient of Variation (CV) is the percentage ratio between the standard deviation and the mean of a random variable. In practice, the CV measures the degree of homogeneity or heterogeneity of the distribution of the values of a random variable around its mean. It can be assumed that the CV measures the instability/stability of the way in which the observations of a random variable are distributed around its expected value. The greater the magnitude of the CV, the more unstable or heterogeneous the distribution of the observed values of the random variable around its mean. Thus, the CV can also be interpreted as a measure of risk and has the added advantage of comparing variables obtained in different units of measurement [51,52].

Gomes (1985)[51] established ranges of variation for CVs in order to classify them. These values are shown in Table 2.

Tabela 2 - Classificação do CV de acordo com a sua amplitude

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

Sorce: Gomes (1985).

Methodology applied to meet objective "c"

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) using the principal component decomposition method was used to find the interaction between the variables selected for this stage.

Overview of the factor analysis method as it applies to this research

Factor analysis (FA) is a multivariate statistical technique whose main objective is to describe the variability of a vector of observed variables (n) in terms of a smaller number of random variables ($p < n$). These random variables, called common factors, are unobserved variables (latent variables) that represent a salient feature of the data. The reduction to a smaller number of factors maximizes the explanatory power of the vector that encompasses all the variables and allows subgroups of evaluative questions with specific characteristics to be identified [53,54].

According to Mingoti (2007)[54], the factor analysis model can be explained as follows in Equation 2:

$$X_{px1} = A_{pxr}F_{rx1} + \varepsilon_{px1} \tag{2}$$

In equation 2, X is the vector of original variables; F is the vector of common factors; A is the matrix of factor loadings; ε is the vector of random errors; r is the number of factors; p is the number of variables.

The factor analysis method reduces the N original variables that are observed to use r unobservable factors that each gather specific characteristics of the original variables and a single error term (ε). The most widely used estimation method is principal component decomposition (PCD), which is based on the use of characteristic vectors and roots and allows the matrix of orthogonal or independent factors to be calculated [53,55,56].

Factor analysis can only be used if the correlation matrix between the variables is not an identity, so that they do not correlate with each other. To check whether this hypothesis is true (the matrix of variables is not an identity), the Bartlett test of sphericity is carried out. For this purpose, the chi-squared statistic is used. The null hypothesis is that the matrix obtained from the correlations between the variables is an identity. Therefore, this must be rejected with a p-value of no more than 10% significance, in order to accept the alternative hypothesis that the matrix is factorable [57,53,58].

Another statistical requirement that needs to be met in order to verify the method's suitability is the Kaiser-Meier-Olkin (KMO) test, also known as the sample adequacy index, which is responsible for showing the fraction of the variation in the variables that is being described by a latent or unobservable variable, the factor[57]. Mathematically, the test consists of the ratio between the square of the total correlations and the square of the partial correlations [59]. The KMO test returns values between zero and one ($0.0 \leq KMO \leq 1.0$). However, authors such as Fávero and Belfiore (2017)[53] consider that KMO values of less than 0.5 are considered unacceptable. In addition, the variance explained by the factors must be greater than 50% [57,53].

The factors generated during the factor analysis procedure can be rotated by rotating the respective coordinate axes, altering the factor loadings in order to facilitate interpretation and to define the latent dimension

[57]. The possible rotation procedures can generate oblique or orthogonal factors. In this research, where the aim is to create an index from the results of the factor analysis, it is necessary for them to be independent or orthogonal. Therefore, the Varimax orthogonal rotation procedure is used to generate independent factor components [53,60].

The number of factors used in the analysis must follow an objective selection criterion. In this study, the latent root criterion (Kaiser criterion) is used, in which the number of factors is selected according to the characteristic roots greater than one (1), as they show how much each factor can explain of the total variance [54].

The result of factor analysis is the generation of coefficients that are used in the standardized original variables (with a mean of zero and variance of one) to form factor scores, in which the original variables are transformed and aggregated according to the correlations, being reduced into these factors. Factor scores have a mean of zero and a variance of one (1), so they have positive or negative values that fluctuate between the mean and zero. In the case of economic phenomena, it is interesting that the indices constructed are strictly positive [61,62].

To this end, it is important that the factor scores are composed only of positive values. In fact, Equation 3 is used so that the values only remain positive, but without affecting the original relative distances:

$$F_{Pj} = \frac{F - F_{min}}{F_{max} - F_{min}} \tag{3}$$

where F_{min} F_{max} are the minimum and maximum weighted values for the factor scores associated with the state in each year observed. With this, all the factor scores will be positive and will remain within the closed interval between zero and one. The Resilience Index for Rainfed Crops (IRLS) is calculated using the arithmetic mean, as shown in Equation 4:

$$IRLS_t = \frac{\sum F_{Pj}}{n} \tag{4}$$

Where $IRLS_t$ 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 in Equation 5:

$$IRLS_{j100} = \left(\frac{IR_j}{IR_{jMÁXIMO}}\right) \times 100 \tag{5}$$

Strategy applied to meet objective "d"

The fourth objective of this research is to assess the existence of resilience to climate instability in dryland agricultural production, by analyzing the cause-effect relationship between the Dryland Crop Resilience Index (IRLS) designed in objective "b" and the rainfall periods defined in objective "a".

To do this, 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 in order 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), as shown in Equation 6:

$$H_0: \mu_1 - \mu_2 = 0 \tag{6}$$

In equation (6) μ_1 is the average IRLS after the drought period and μ_2 is the average IRLS before the drought period.

Developed by William Sealy Gosset in 1908, the Student's t-test is widely used to assess the statistical difference between two dependent or independent means and is represented by Equation 7:

$$t = \frac{\overline{X_1} - \overline{X_2}}{EP\ (\overline{X_1} - \overline{X_2})} \tag{7}$$

In Equation (7), the numerator consists of the difference between the means of the two groups analyzed and the denominator represents the standard error (SE) of the difference between these two means. The value of the t-statistic obtained after the calculation was compared with the tabulated tcritical value, located using the degrees of freedom and the significance level adopted in the research [63,64].

IV. Results

The presentation of the results will follow the order of the research objectives.

Results found for objective "a"

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)[51]. 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, and the results are shown in Table 3:

Table 3 - Averages and coefficient of variation (CV) estimated for the periods in which the annual rainfall in Paraíba was classified between 1901 and 2020

Periods	Range (mm)	Ocurrence Years		Average (mm)	CV (%)
		Absolute (Years)	Relative (%)		
Drought	Rainfall < 776,0	40	33,33	$669,5^{C}$	13,9
Normal	776,0 > Rainfall < 1008,0	49	40,83	$881,6^{B}$	7,8
Rany	Rainfall > 1008,0	31	25,83	$1195,6^{A}$	15,2
TOTAL		120	100	892,0	26,0

Source: Research results (2022). The capital letters placed as super indices of the means indicate that they can be herarchized as follows: A>B>C.

The results shown in Table 3 suggest that in the 120 years studied, one third of them (40 years) were drought years, as defined in this research (rainfall < 776mm). The highest percentages of occurrences (40.83%) took place in normal years and rainy periods were observed in 31 years.

The results shown in Table 4 confirm that the classification of rainfall in the state of Paraiba outlined in Table 3 is possible. In fact, the adjusted coefficient of determination was 75.2% and the estimated regression coefficients for the dummy variables were statistically different from zero at levels of approximately 0.000% error. In this way, the rainfall averages observed in each of the periods can be ranked as follows: $Mean^{CHVOSO}$ > $Mean^{NORMAL}$> $Mean^{SECO}$.

Table 4 - Results of the comparison to define the periods in which the annual rainfall observed in the state of Paraíba between 1901 and 2020 was characterized

Variable	Coefficients	t statístics	sign.	Adjusted R²
Constant	669,5	36,649	0,000	0,752
D1	212,1	8,615	0,000	
D2	526,1	19,028	0,000	

Source: Results of the survey (2022).

Results found for objective "c"

In order to meet the third objective was constructed the Resilience Index of Dryland Crops (IRLS) using the factor analysis method. The IRLS index aggregates, in a weighted way, the variables selected for this study, which were structured into four estimated factors.

From the evidence shown in Table 3, it appears that the FA adjustment to create the IRLS was robust from a statistical point of view, given that the matrix made up of 12 variables is not identical, as shown by the Bartlett test. The KMO test = 724, the total variance explained by the four orthogonal factors generated was 84.6% and all the communalities were greater than 0.5, which is considered the minimum acceptable value. A summary of these results is shown in Table 5.

Table 5 - Results found when estimating the components in which the original variables were reduced, with the respective communalities and factor loadings

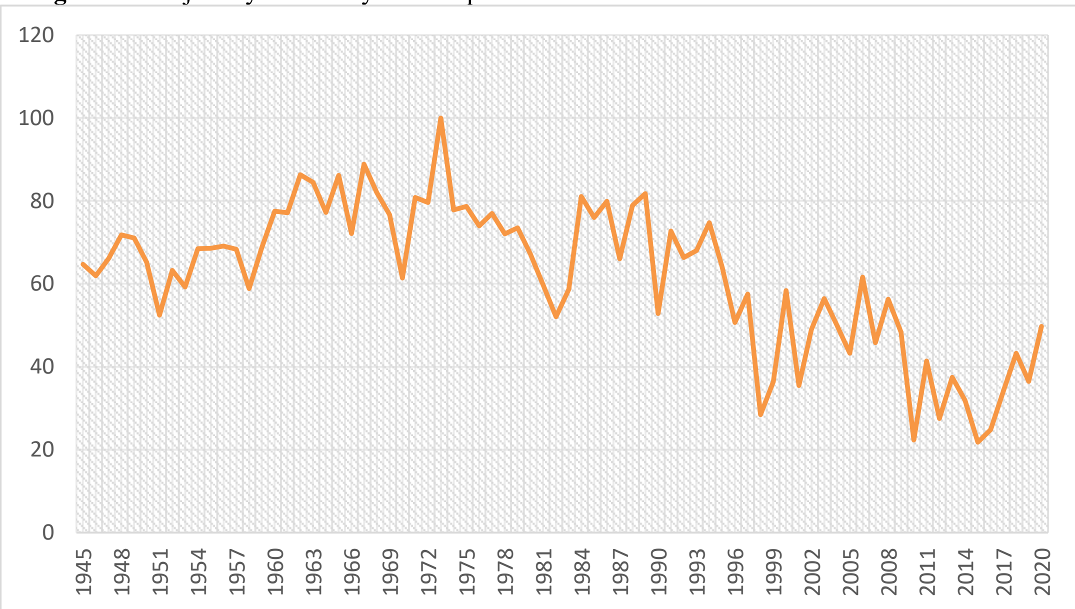
Variables	Commonalities	Factor loadings			
		F1	F2	F3	F4
Harvested area - RICE	0,735	0,388	0,481	**0,541**	-0,245
Productivity - RICE	0,945	0,047	0,146	0,045	**0,959**
Price - RICE	0,867	**0,901**	0,078	0,184	-0,126
Harvested area - BEANS	0,934	0,107	-0,230	**0,927**	0,106
Productivity - BEANS	0,878	-0,130	**0,905**	-0,050	0,198
Price - BEANS	0,874	**0,804**	-0,397	0,262	0,020
Harvested area - MANDIOCA	0,812	**0,644**	0,264	0,571	-0,036
Productivity- MANDIOCA	0,644	0,119	**0,782**	-0,086	-0,108
Price- MANDIOCA	0,665	**0,585**	-0,446	0,246	0,252
Harvested area - CORN	0,978	0,278	0,027	**0,948**	0,032
Productivity- 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
Accumulated variance (%)	84,6

Source: Results of the survey (2022).

Based on the estimated factor scores, after making the factors independent via orthogonal rotation using the varimax method, the IRLS was constructed, ranging from zero (0) to one hundred (100). The closer the value of the estimated index is to 100 for a given year, the better the synergistic performance of the variables used in the research to define the production of rainfed crops in Paraíba over the time period studied. Figure 1 shows the oscillation of the index over the years, with a considerable drop from 1997 onwards.

Figure 1 - Trajectory of the Dryland Crop Resilience Index for Paraíba between 1945 and 2020



Source: Prepared from the Results of the survey (2022).

Results found for objective "d"

This objective sought to assess the existence of resilience in rice, bean, cassava and corn crops based on the cause-effect analysis between rainfall and the IRLS index created in the previous objective. To do this, the averages were determined for the periods defined as drought and non-drought, the latter being the result of aggregating the years considered normal and rainy. Table 6 shows the averages obtained in these periods and the differences between them. It can be seen that, of the 12 periods defined, only in 2 of them was the average of the non-drought period lower than that of the drought period.

Table 6 - Difference in IRLS averages between non-droght and droght periods in Paraíba between 1945 and 2020

Periods		Differences
non-droght	droght	
64,71	61,90	2,81
68,54	60,85	7,69
68,82	65,34	3,48
77,36	86,32	-8,97
81,75	81,98	-0,23
77,81	70,34	7,46
59,72	55,35	4,37
77,28	52,80	24,48
69,52	68,01	1,51
61,76	32,40	29,36
50,45	22,30	28,15

41,38	32,16	9,22
49,75	-	-

Source: Results of the survey (2022).

The Student's t-test for paired samples shows that the overall average for the non-dry period is approximately 66.6, while the overall average for the drought period is close to 57.5 and the difference between the two periods is 9.1. The test also reveals that there is a statistical difference at less than 5% significance, rejecting the null hypothesis of equality between the averages of the periods. Therefore, the overall average of the IRLS index in the non-drought period is statistically higher than the average observed in the dry period (Table 7). In fact, indicators relating to agricultural production in general tend to be more modest in years with discrete rainfall.

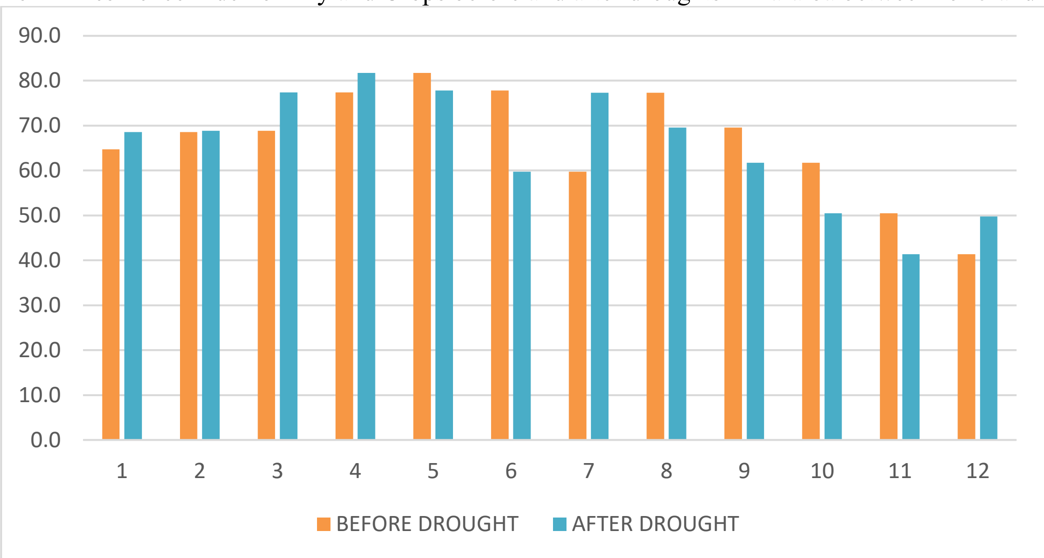
Table 7 - Paired samples t-test between the " non-drought" and " drought " periods in Paraíba between 1945 and 2020

Teste de amostras emparelhadas					
Pairs	**Averages**	**Difference**	**t Statistics**	**df**	**Sign. (bilateral test)**
non-drought	66,5917	9,11250	2,635	11	0,023
drought	57,4792				

Source: Results of the survey (2022).

From the results obtained for the non-drought and drought periods, the averages are calculated for the periods defined as before and after the occurrence of drought years. Figure 2 shows the fluctuation of the average IRLS indices in these periods.

Figure 2 – Resilience Index of Dryland Crops before and after droughts in Paraíba between 1945 and 2020



Source: Prepared from the Results of the survey (2022).

Table 8 shows the results of the Student's t-test for paired samples in the periods before and after the occurrence of drought years. The overall average of the periods defined as "before" was close to 66.6, while the overall average of the periods defined as "after" was 65.3 and the difference between the two was 1.2. The test accepts the null hypothesis of equality between the periods before and after the droughts, by returning results that are not significant to at least 10%.

Table 8 - Paired samples t-test between the periods "before" and "after" the occurrence of droughts in Paraíba between 1945 and 2020

Paired samples test					
Pairs	**Average**	**Difrerence**	**t- statístics**	**df**	**Sign. (bilateral test)**
Before drought	66,5917	1,24667	0,424	11	0,680
After drought	65,3450				

Source: Results of the survey (2022).

This confirms the hypothesis of the existence of resilience in rice, beans, cassava and maize cultivation, which partly explains the continuity of this type of activity among Paraiba farmers with a high associated risk, despite being carried out in a region with great rainfall instability and sometimes considered hostile to agricultural practice. Similar results were found by Praxedes (2021) in his assessment of the resilience of the variables associated with the production of beans, cassava and corn in the face of rainfall variations in the Sertão Central and Inhamuns regions in the state of Ceará. The interaction between the selected variables was captured by constructing the Synergy Index (INS) for certain regions of Ceará.

V. Conclusion

With regard to the classification of annual rainfall from 1901 to 2020 into three previously defined periods, the exercise proposed in the first specific objective. The study was able to distinguish 40 years with a drought period, 49 years with normal rainfall and 31 rainy years. It is noteworthy that the state of Paraíba had high rainfall instability over the 120 years analyzed (CV = 26%), but this variability is reduced when analyzed within each period, with the normal period being more homogeneous.

As for the second and third specific question, the aim was to design an instrument capable of measuring the synergy between the variables that define rice, bean, manioc and corn production in the state under analysis in a weighted and compressed way. Between 1945 and 2020, the explanatory capacity of the variables used to construct the Dryland Crop Resilience Index (IRLS) is considered from a statistical point of view, given the robust results found by the statistical modeling used, in which the factors generated were able to explain more than 80% of the accumulated variation.

The fourth objective of the research was to assess the existence of resilience to rainfall variations on the part of these dryland crops practiced in Paraíba, in those years in which rainfall was at least normal, preceded by years of drought, which caused stresses in the production of the crops studied, as captured by the IRLS. It was found that there was no statistical difference between the periods immediately before and after the occurrence of years with water stress caused by drought. Therefore, these periods (before and after the droughts) showed the same volume of agricultural production from a statistical point of view. Similarly, there were statistical differences between the average IRLS in the "non-drought" and "drought" periods, with the latter having lower average values due to the loss of agricultural production caused by the lack of rainfall. This resilience can be understood as an element that favors rural development.

The research evidence showed that farmers were able to develop adaptive capacities to the rainfall instability that occurred in Paraíba during the period under investigation. This information can be used to explain the persistence of the practice of agricultural production in an environment full of risks and uncertainties. Most of the time, this happens without the help of public policies or specialized technical assistance.

It can be inferred that the productive conditions and, consequently, the quality of life of families who use farming as a source of survival in Paraíba, a state that has most of its municipalities in the semi-arid region, could be less unstable if they had access to more policies to mitigate the effects of droughts. For this to happen, farmers could take advantage of research that has already been carried out, which shows the use of cultivars of these crops that have shorter cycles and are better adapted to climate instability. This depends on a more appropriate technical assistance, extension and rural development service, which will enable families to improve their ability to adapt, or resilience, to droughts, as pointed out in this research.

Farmers could have access to rural insurance policies that minimize material losses resulting from droughts. This rural insurance could be linked to financing via PRONAF (National Program for Strengthening Family Farming) in Family Farming Units. Access to PRONAF would have to be assisted not only by the financing agent, which in the Northeast is mainly Banco do Nordeste, but also by the Technical Assistance, Rural Extension and Rural Development services provided by the state government. The Rural Extension Program should include, among other actions, the dissemination of practices for the safe storage of seeds, so that they can wait out any longer periods of water deficiency. One example is water storage policies, such as slab cisterns and the construction of community water reservoirs with the water mirror protected from evaporation losses. This can be done by growing vigorous species, such as bamboo, around these reservoirs.

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