The Effects of Dry Spells on Crop Diversification in the Brazilian Northeast Region

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Abstract

The Northeast region of Brazil is characterized by low annual averages of rainfall, so it has been impacted by many droughts. Crop diversification is an adaptation practice to climate change that helps reduce farmers' vulnerability. This study aims to evaluate the effect of dry spells on crop diversification in the Brazilian Northeast region, using fixed effects panel models in 1322 municipalities between 1995, 2006, and 2017. The results show that Northeastern municipalities have adopted crop diversification as an adaptation strategy for Consecutive Dry Days. Furthermore, legal status and farm size have negative effects on crop diversification. Therefore, technical assistance promoting crop diversification should focus on small farms [15].

Keywords

Drys Spells, Consecutive Dry Days, Drought, Crop Diversification, Northeast Brazilian

1. Introduction

In some regions, drought is expected to increase under future global warming. For example, precipitation is expected to decrease in Southwestern South America, tropical Central America, and the Amazon basin [1]. The lack of rainfall is worrying because it can adversely affect economic outcomes, whether agricultural productivity, economic growth, or conflict [2].

Agricultural production depends especially on resources of water. So, a deficit in water availability can cause stress on plants and animals, which can lead to agricultural and economic losses [3, 4]. Severe drought conditions can cause premature plant death, while discontinuous drought conditions affect plant growth and development [5]. Thus, there is a need to look for strategies to overcome the reduction of precipitations.

Crop diversification is an adaptive strategy to reduce climate risks [6, 7]. This practice has different forms as intercropping, agroforestry, or integration of crop-livestock systems. Diversification results in benefits in the use of nutrients from the soil, water, light, and pest prevention [8], as well as in managing water deficits for crops [9]. Crop diversification is known

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as a Climate-Smart technology, that helps to mitigate emissions of greenhouse gases (GHG) and manage climate risk resilience [10]. Additionally, diversification is considered an important adaptation strategy in agriculture, according to the last Intergovernmental Panel on Climate Change Assessment Report [1].

However, in the literature, rainfall shocks present ambiguous results on crop diversification and even without statistically significant effects in some cases. These results depend on the geographic conditions of the regions. For example, rainfall shortage did not affect the diversification index in Ethiopia [7]. In South Africa, decreasing rainfall shows a negative effect on the diversification of crops [11]. Instead, in South America, the adoption of crop-livestock systems becomes more attractive with a slight increase in rainfall (<130 mm per month), then decreases. But it does not show effects with decreasing rainfall [12].

On the other hand, this topic research has focused on African countries, leaving a gap in other regions, especially in South America. Furthermore, most studies have measured rainfall shocks using drought events or precipitation data monthly or seasonally. There is a research gap using climate extreme indices recommended by the WMO Expert Team on Sector-Specific Climate Indices (ET-SCI) for the agriculture sector. Regarding decreasing rainfall, the maximum number of consecutive dry days index is used to measure the length of a dry spell, using daily precipitation [13].

In this context, this study evaluates the effect of dry spells on crop diversification in the Brazilian Northeast region, which is characterized by low annual averages of precipitation. We analyzed fixed-effects panel models in 1322 municipalities, using the last three Agricultural Census of Brazil (1995, 2006, 2017). The results indicate that an increase in the maximum dry spell raises the diversification in the municipalities, showing that this practice is used as an adaptation practice to reduce climate risks. Therefore, this study's findings have policy implications for accessing effective strategies to overcome water scarcity problems in agriculture.

The rest of the article is organized as follows. Section 2 briefly describes the Northeast region context. Section 3 describes the methodology and data. Section 4 presents the results and discussion. Section 5 presents the conclusions.

2. Area of study

The Brazilian Northeast region is limited to the north and east by the Atlantic Ocean and northwest and west to the Amazon Basin (Figure 1). This region has nine states: Bahia, Sergipe, Alagoas, Piauí, Ceará, Maranhão, Pernambuco, Rio Grande do Norte, and Paraíba. The area covers about 18% of the Brazilian territory and it has around 57.7 million habitants [14]. According to the last Agricultural Census, around 46% of Brazilian farms (2,3 million units) stand in this region [15]. Most of these agricultural units are considered family farming (79.2%), which engages the labor of more than 4.7 million people [16].

Nevertheless, this region has mostly a semiarid climate, which shows low and irregular precipitation, and high temperatures, so drought has been reported frequently [17]. The droughts have affected agricultural production, which impacts upon region's economy. For example, the drought caused by the severe El Niño phenomenon (2015-2016) caused high mortality of cocoa trees (15%) and decreased cocoa yields by 89% in Bahia [18]. In the same



Figure 1: Northeast region of Brazil.

way, the severe drought of 2012-2013 in Ceará led to a reduction of the planted area by 43%, resulting in average losses of 75% in crops, and caused losses in livestock, with the mortality rate of the cattle herd passing from 0.33% in 2010 to 3.05% in 2013 [19].

Additionally, future climate scenarios for the region project that temperature would increase between, approximately, 1°C (optimistic scenario) and 4°C (pessimistic scenario) [17]. Regarding precipitation, it is expected rainfall reductions and longer periods of dry spells, would let land degradation [17]. These scenarios show that the region's farmers are vulnerable, therefore it is imperative to analyze adaptation measures to reduce climate risks.

3. Methods

3.1. Econometrical model

The allocation of crops depends on several factors, such as climate variables [20]. Nevertheless, the relationship between dry spells and crop diversification can be considered a natural experiment because extreme weather cannot be predicted exactly [2]. Regarding the regional level, it is possible to know the effect of climate variation without having problems of selection bias [21, 22]. Therefore, we analyze the effects of dry spells on crop diversification in the Brazilian Northeast region at the municipal¹ level:

$$S = f(C, X) \tag{1}$$

¹The term municipality means the Minimum Comparable Area (MCA), which is an aggregation of municipalities in broader geographic areas that ensures consistent comparisons over time. The municipalities of the Demographic Censuses were made compatible from 1980 to 2010, following the methodology proposed by [23].

in which vectors of climate variables (C) and control variables (X).

In this study, we used a panel data model at the municipal level (cross-section) combined with the years of agricultural censuses 95/96, 2006, and 2017 (time series). Panel models have consistent estimations because allow the existence of unobserved effects potentially correlated with the regressors [24].

The econometric model follows a theoretical reference in which crop diversification in municipalities is affected by the dry spell and other socioeconomic, agroecological, and market variables [25]. Thus, the full version of the equation of interest (1), which was presented earlier, is:

$$S_{it} = \beta C_{it} + \gamma S E_{it} + \delta A_{it} + \zeta A_{it} + \mu_i + \theta_{rt} + \varepsilon_{it'}$$
⁽²⁾

where S_{it} represents the Simpson crop diversification index of the municipality i and year t; C_{it} represents the Consecutive Dry Days index of the municipality i; SE_{it} is the vector of the socioeconomic characteristics of the municipality and year t; A_{it} is the vector of the agricultural characteristics of the municipality and the year t; M_{it} is the vector das characteristics of the municipality i and year t; and μ_i represents the fixed effects of the municipalities, capturing fixed spatial characteristics, observed or not, removing or clashing many possible sources of omitted variances. θ_{rt} represents the fixed effects of the state, neutralizing any common state trends and ensuring that the relationships of interest are identified by idiosyncratic local clashes. ε_{it} is the term of independent and identically distributed error (*iid*) in the municipality and the year t, with mean 0 and variance σ [2]. The model was estimated using Stata software (version 12.0).

The Simpson index measures how much each crop contributes to the total agricultural income of the municipality [26]:

$$S_I = 1 + \sum_{i=1}^{N} \alpha_k^2 \qquad 0 \le S_1 \le 1$$
 (3)

where that α_k is the proportion of the production Value of each agricultural and livestock product in the total agricultural Production Value of the municipality. This index allows classification of diversification into four categories: very specialized ($S_I = 0$), which only produces one product; specialized ($0 < S_1 \le 0.35$), which has 80% or more of the Production Value from just one product; diversified category ($0.35 < S_1 \le 0.65$), in which the income of the main product is less than 80 % of the Production Value; and very diversified category ($S_I > 0.65$) in which at least three products have similar proportions in income [26].

The dry spell was measured using the Consecutive Dry Days (CDD) index, which is defined in Table 1. This index is recommended by the World Meteorological Organization - WMO's Expert Team on Sector-Specific Climate Indices (ET-SCI) for the agriculture sector. The indices were calculated using daily values of precipitation obtaining results of annual values using standardized software (ClimPACT2) [13]. The study uses five-year moving averages of CDD for each period of the Agricultural Census 95/96, 2006, and 2017 to consider the impact of the medium-term climate variability on crops perennial and temporary [21]. Additionally, this weather specification includes the five-year moving average of the annual mean temperature because there is a correlation between these two variables was 0.35. The controls, which include socioeconomic, agroecological, and market variables are defined in Table 2.

Table 1

Definition of Consecutive Dry Days indices (Adapted from [13])

Index code	Name	Definition	Unit	Event type
CDD	Consecutive Dry Days	Maximum number of consecu- tive days with PR<1,0 mm	Days	The maximum length of dry spell
Note: PR - nr	ecinitation			

Note: PR = precipitation

3.2. Data

The data used to construct the Simpson index were extracted from 1995, 1996, 2006, and 2017 Agricultural Censuses [26]. The agricultural products include the value of cattle, swine, and poultry heads sold and the value of gross production of Horticulture, Permanent Crops, Temporary Crops, Forestry, and Vegetable Extraction at the municipal level.

The Terrestrial Hydrology Research Group (THRG) database was used to analyze precipitation in the municipalities of Northeast Brazil. The construction of this database occurred through the combination of global data based on surface observations with the reanalysis of the NCEP–NCAR (National Center for Environmental Prediction/National Center for Atmospheric Research).

The data are available in files in the NetCDF format (Network Common Data Form) in spatial resolutions (0.25°, 0.5°, and 1.0°) and different temporal (3 in 3 hours, daily, monthly and annual). In this study, the daily precipitation variable (mm/day) was used with a resolution of $1.0^{\circ} \times 1.0^{\circ}$ ($\sim 110 km \ge 110 km$). In the extraction process, the NCL language (NCAR Command Language) was used to develop an algorithm that, from reading the precipitation data and a matrix mesh in the same resolution that contains the Northeast municipalities, would obtain the precipitation values for each municipality.

Data on variables representing the socioeconomic, agricultural, and market characteristics of Northeast municipalities were also extracted from 1995/1996, 2006, and 2017 Agricultural Censuses.

4. Results and discussion

4.1. Simpson index

Figure 2 illustrates how most of the municipalities are in diversified categories over the three periods. However, in the first period (1995/1996), the region had more municipalities with over 0.78 Simpson index (very diversified category). In 2006, there were many municipalities below the 0.16 Simpson index (specialized category). Similar results can be found in the literature [27], in which the Northeast municipalities have been in the diversified category, from 1985 to 2017. This result can be explained because, since colonial times, monocultures were not popular in the Northeast, since, above all, their climatic conditions have been unfavorable [28].



Figure 2: Evolution of Simpson Index in 1995/1996, 2006, and 2017 in Northeast Region of Brazil.

Table 2 shows the description of variables and summary statistics related to all northeast municipalities of Brazil. In 1996 and 2017, the Simpson index was in a very diversified category, while in 2006, it was in a diversified category. So, the northeast region diversified its agricultural production.

4.2. Maximum length of dry spell

Figure 3 shows that Consecutive Dry Days has a similar pattern in 1995/1996 and 2006. But in 2017, there is an increased dispersion of high values (>96 days) of CDD. However, the average of CDD 2006-2017 does not show the drought that affected the Northeast from 2012 to 2015, which destroyed croplands [17]. Furthermore, we can see that the 5-year moving average of the annual Consecutive Dry Days has the highest value in 2017 (see Table 2). The annual temperature has similar values between the periods.

4.3. Socioeconomic, agricultural, and market variables

Table 2 shows that the average size per farm is very small, but it is even reducing over the periods. Then, access to technical assistance has been decreasing in the last period. The highest number of farms receiving technical assistance was in 2006. Otherwise, legal status and irrigation adoption have been increasing between the agricultural censuses. Conversely, the number of Description of variables and summary statistics Northeast region

Table 2

Variable	Description	1996	2006	2017
Simpson index	Crop diversification index	0.70	0.64	0.67
CDD index	5-year moving average of the an- nual Consecutive Dry Days	47.0	40.5	48.8
Annual tem- perature	5-year moving average of annual temperature (° C)	25.9	26.2	25.1
Technical as- sistance	Number of producers receiving technical assistance	71.8	155.6	130.8
Legal status	Number of producers owning the farm	1130.9	1272.3	1355.9
Farm size	Average size per farm (ha)	53.1	41.6	39.7
Irrigation	Number of farms with irrigation	86.3	106.6	173.9
Maize farms	Number of farms with maize crops	934.3	874.1	726.3



Figure 3: Evolution of Consecutive Dry Days in 1995/1996, 2006, and 2017 in the Northeast Region of Brazil.

farms producing maize crops, which is an exportable product, has been decreasing over the periods.

Variable	-1	-2	
CDD index	0.000322***	0.000344***	
	(0.000124)	(0.000124)	
Annual temperature	-0.00129	-0.00124	
/	(0.00181)	(0.00183)	
Technical assistance	1.92e-05		
	(2.14e-05)		
Legal status	-1.62e-05**		
0	(6.56e-06)		
Farm size	-0.000346***		
	(6.91e-05)		
Irrigation	4.83e-06		
0	(1.52e-05)		
Maize farms	1.76e-05***		
	(5.75e-06)		
Fixed effects state/yeas	YES	YES	
Hausman test	416,75***	530,26***	
Modified Wald test	1.3e+31***	3.5e+31***	
Ν	3.694	3.694	
R-squared	105	91	
F statistic	13,75***	15,06***	
Number of municipalities	1.322	1.322	

Table 3

Effects of dry spells on crop diversification of Northeast region

Note: Robust standard errors are in parentheses. Significance: : *** p<0,01, ** p<0,05, * p<0,1

4.4. Econometric results

Table 3 presents the estimated results of equation (2), considering consecutive dry days. All the models are adjusted with fixed effects for municipality and state/year. Columns (1) and (2) analyze the model with controls and without controls, respectively. The results show that prolonged reduction in rainfall positively and statistically significantly influences 1% of crop diversification in the Northeast. Models (1) and (2) explain approximately 11% (with controls) and 9% (without controls), respectively, of the variation in diversification in this region. Additionally, it is observed that there is little difference in the coefficients of climatic variables, indicating that the relationship between CDD and Northeastern agricultural diversification as an adaptation strategy for Consecutive Dry Days. Regarding the control variables, the producer's legal status, the size of the property, and the demand proxy for main crops were statistically significant.

Furthermore, the fact of owning the establishment increases the level of concentration of agricultural products in the Northeastern municipalities, which is directed towards investments in more intensive cultures. However, this result was contrary to that found in a case study in Bahia, which analyzed the economic determinants of crop diversity at the producer level, using the Margalef index to measure crop richness by area of the farm [27]. In addition, small-scale farms are related to the diversification of agricultural activities in the Northeast. This

relationship follows the results of the correlation between the percentage of establishments by area groups and crop diversification (Simpson) in that study. It is worth mentioning that the average size of farms in the region has been the smallest among the Brazilian regions in the 2006 and 2017 censuses [15], as well as that the region has been classified in the category of Very Diverse throughout the three censuses. In addition, it is observed that corn production positively influences diversification in this region. Finally, it is observed that the absolute values of the farm size and the CDD index are similar and higher than the other coefficients, showing the relevance of these variables in the Northeast.

5. Conclusions

The study shows that dry spells have a positive effect on crop diversification in the Brazilian Northeast region. So, this region has adopted diversification as a strategy to manage rainfall reduction. This has policy implications because it shows that this kind of practice should be reinforced in technical assistance to reduce climate risks. Furthermore, it should focus on small producers, which are mostly in this region.

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