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Potential impacts of climate change on food crops in the state of Piauí, Brazil

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ABSTRACT

Climate change has made food security vulnerable. Therefore, it is important to have discussions on the subject and take actions that minimize the environmental impacts on family farming, that will be directly or indirectly affected by climatic events. With this in mind, this study aimed to identify climate changes in the state of Piauí based on climate projections and to verify their possible impacts on the suitability of growing food crops, such as beans, corn, cassava, and cashew. The climate scenarios analyzed were 2011–2040, 2041–2070, and 2071–2100. The observed data on current climate came from the National Institute of Meteorology (INMET), and future climate projections came from the Brazilian Portal of Climate Projections of the National Institute for Space Research (INPE). Based on the climatic data obtained (current and future), the climatological water balance was calculated, using the method proposed by Thorntwaite, with consecutive characterization of the suitability for crops. All maps were generated in QGIS. According to the results, crops that may suffer from water deficit are beans and cashews. The latter, in the RCP 8.5 scenario (2071–2100) shows unsuitability for cultivation throughout the state. The population with the highest rate of social vulnerability is the one that will be most damaged by the events caused by climate change.

Keywords: climate zoning; family farming; social vulnerability.

INTRODUCTION

The debate on climate change has attracted the attention of the scientific community from several areas, thus giving rise to a series of studies that seek to identify and measure changes in climate variables (Salazar *et al*. 2007; Santos & Alves, 2020). One of the main challenges addressed by the World Summit on Food Security is the need for countries to adequately address the impact of climate change to achieve food security (Giannini *et al*., 2015).

Climate change is generating a great deal of international attention, since it affects food production, availability, access, quality, use, and stability of food systems, reducing the yield of the main crops (Mekonnen *et al*., 2021).

Due to its large territorial extension, Brazil is vulnerable to climate change and agricultural expansion (Magalhães *et al.* 2021). According to Jin *et al.* (2021), understanding the effects of global warming is crucial, as it is considered a threat to natural resources, leading to a decrease in agricultural production and, consequently, compromising food security and economic development.

The Northeast region is likely to be one of the most affected, especially the arid and semi-arid regions, due to the increase in air temperature predicted in both optimistic and a pessimistic scenarios, resulting in an elevation in evapotranspiration and, consequently, water scarcity. The increase in the number of days of drought and heat waves significantly influences agriculture and population health (Queiroz *et al.*, 2016).

In the state of Piauí, there is a diversity of regional production, with corn, beans, cassava, and cashew farming (SEMCASPI, 2018), and family farming establishments mainly practice agriculture and livestock for subsistence and to generate income. However, prolonged periods of drought severely affect the agricultural production of temporary and permanent crops (Lima *et al.*, 2017).

Thus, understanding the process of climate change from a holistic and multidisciplinary perspective becomes essential, since its impacts soil moisture, temperature, the amount and intensity of precipitation, and plant growth, interfering with agricultural production and, consequently, affect the economic sector (Hasegawa *et al*., 2016; Hsiang *et al*., 2017).

Therefore, the present work aimed to identify the trends of climate change in the state of Piauí from climate projections and to verify their possible impacts on the aptitude for the cultivation of important food value in the region.

MATERIAL AND METHODS

The study area covered the state of Piauí, located in the northeast region of Brazil, at 2º 44’ and 10º 52’S latitude and 40º 25’ and 45º 59’W longitude (Figure 1). It had an estimated population of 3,289,290 people in 2021, with a land area of 251,755,485 km^2 and a GDP of 6.4% (IBGE, 2021). The State has a high temperature and relative humidity because the region is subject to the action of climatic factors such as the Intertropical Convergence Zone

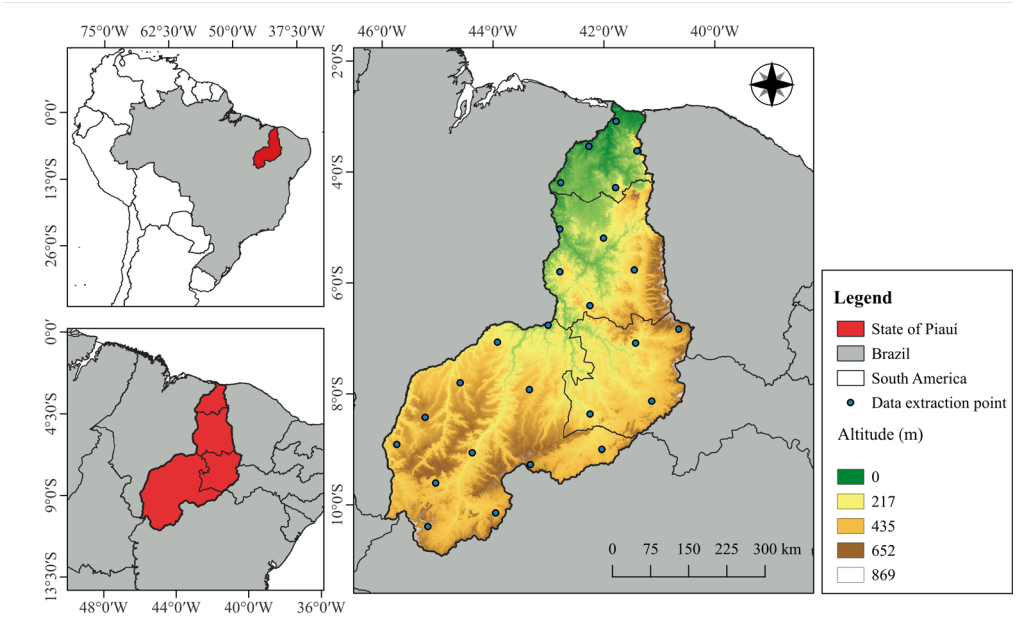

Figure 1: Mesoregions and distribution of data extraction points in the state of Piauí, Brazil. Source: elaborated by the authors.

(ITCZ), South Atlantic Convergence Zone (SACZ), and Atlantic Equatorial and Continental Equatorial air masses (Coelho & Terra, 1998). The region has two climatic types, Semiarid (D) and Dry Subhumid (C1), with the Semiarid type being predominant, especially in the Southwest, Southeast, and part of the Center-North mesoregions (Silva *et al.,* 2021).

The climate scenarios analyzed were the years 1981 to 2010 (in situ, historic data), and future projections from 2010 to 2040, 2040 to 2070, and 2070 to 2100, derived from climate modeling. The historical data (1981–2010) were obtained from the website of the National Institute of Meteorology (INMET) (INMET, 2021). Climate projections were obtained from the Brazil Climate Projections Portal (PCBR, 2022) of the National Institute for Space Research (INPE), from the regional Eta model, of the coupled global model called *Model for Interdisciplinary Research on Climate*, version 5 (MIROC5), with a spatial resolution of 20 km, in matrix data format. Additionally, an extraction of point data was carried out from the matrix data derived from the model, whose points can be seen in Figure 1.

The scenarios used were the RCPs (Representative Concentration Pathways) 4.5 and 8.5, presented in the fifth IPCC report, where according to the PBMC (2014) scenario 4.5 predicts storage of 4.5 wm^{-2} in the terrestrial system, with an increase of terrestrial temperature between 1.1 ºC to 2.6 ºC. On the other hand, RCP 8.5 would represent the worst scenario, in which due to the accelerated growth of emissions, the storage of the system would be 8.5Wm^{-2}, in this situation, the Earths's surface would heat between 2.6 ºC and 4.8 ºC throughout the century.

The climatological water balance (BHC) was calculated using the methodology of Thornthwaite & Mather (1955), using a Microsoft Excel spreadsheet developed by Rolim *et al.* (1998), an Available Water Capacity (CAD) of 100 mm was assumed. From the estimated water balance, the water index (Ih) and the humidity index (Iu) were calculated, according to the methodology of Thornthwaite (1948), according to equations 1 and 2 respectively:

$$Ih = \frac{100 * \Sigma EXC}{\Sigma ETP} \quad (1)$$

$$Iu = \frac{(100 * \Sigma EXC - 60 * \Sigma DEF)}{\Sigma ETP} \quad (2)$$

where: DEF = annual water deficit; EXC = annual water excess; ETP = annual potential evapotranspiration.

The data were interpolated using the IDW (inverse power distance) method, due to its greater simplicity and because it represents a smaller margin of error for meteorological variables (Amorim *et al.,* 2008). After interpolation, suitable and unsuitable areas were defined for food crops, based on the climatic requirements highlighted in Table 1.

Piauí's social vulnerability was calculated according to the Municipal Social Vulnerability Index (IVSM), which is derived from the Municipal Human Development Index (MHDI) data obtained from the Atlas of Human Development in Brazil 2013 (PNUD, 2013). The IVSM method is calculated by subtracting the MHDI value from 1. The higher the result of this subtraction, the more vulnerable the municipality is due to the lower MHDI (Busman *et al.,* 2017). The region was then classified according to the MHDI, identifying the social vulnerability of each municipality in the state. The IVSM classification legends used were high, low and moderate (Table 2), and the classification of the municipalities can be seen in Figure 2.

The municipalities classified according to social vulnerability (Table 2) were extracted, generating three different mask layers. After extraction, the area occupied by each aptitude class at the different levels of vulnerability was quantified. These spatial analyses were carried out using QGIS 3.8.3 (QGIS Development Team, 2019).

RESULTS AND DISCUSSION

From the projections carried out, it was possible to verify that for the bean crop (Figure 3), in the historical period, which serves as a basis for comparison between the other periods studied, a large part of the State was considered moderately suitable due to excess water (AM+), this is because the planting is carried out in March, which is the rainy season, with January, February, and March being the wettest in the Piauiense territory (Fernandes *et al.*, 2020).

However, in the RCP 4.5 scenario, the zones of moderate suitability for deficiency (AM) tend to advance by state (Figure 3) in all analyzed periods. The AM zones were projected to be more concentrated in the south and southeast of the region. In the North and Central-North regions, in all periods studied, bands of zones of full suitability (AP), moderate full for rainy periods (AP+) and AM+ (Table 1) were observed, as evidenced by Silva *et al.* (2021), indicating that these mesoregions present the highest rainfall totals in the state compared to others.

Table 1: Crop requirements and suitability

Culture	Aptitude	Climate index (mm)
Bean	Full suitability (AP)	$EXC_1 \geq 0$; $DEF_{2,3} \leq 5$; $P_4/EP_4 < 0,75$
	Full fitness, may have rainy season (AP+)	$P_4/EP_4 \geq 0,75$
	Moderate fitness due to excess water - harvest difficulty (AM+)	$\sum EXC_J > 180$
	Moderate fitness due to water deficiency (AM)	$EXC_1 \geq 0$; $DEF_{2,3} < 25$; $P_4/EP_4 < 0,75$
	Disability due to severe water deficiency (IN)	$DEF_1 > 0$; $DEF_2 \geq 40$
Corn	Full suitability (AP)	$EXC_1 \geq 0$; $DEF_{2,3} \leq 5$; $P_4/EP_4 < 0,75$
	Full fitness, may have rainy season (AP+)	$P_4/EP_4 \geq 0,75$
	Moderate fitness due to excess water - harvest difficulty (AM+)	$\sum EXC_J > 180$
	Moderate fitness due to water deficiency (AM)	$EXC_1 \geq 0$; $DEF_{2,3} < 25$; $P_4/EP_4 < 0,75$
	Disability due to severe water deficiency (IN)	$DEF_1 > 0$; $DEF_2 \geq 40$
Cassava	Full suitability	$-35 < Iu \leq -10$ mm
	Full fitness, may have rainy season (AP+)	$-10 < Iu \leq 40$ mm
	Moderate fitness due to excess water - harvest difficulty (AM+)	$Iu \geq 40$ mm
	Moderate fitness due to water deficiency (AM)	$-45 < Iu \leq -35$ mm
	Disability due to severe water deficiency (IN)	$Iu \leq -45$ mm
Cashew	Full suitability (AP)	$Ih > -10$; $DEF < 100$ mm
	Moderate fitness due to excess water - harvest difficulty (AM+)	$Ih < -10$; $100 < DEF < 200$ mm; $200 < D < 700$ mm
	Moderate fitness due to water deficiency (AM)	$700 < DEF < 900$ mm
	Disability due to severe water deficiency (IN)	$DEF > 700$ mm

where: EXCi = Water excess of month i; Defi = Water deficiency in month i; Pi/EP = precipitation over potential evapotranspiration in month i; Ih = water index; Iu = Moisture Index.

On the other hand, in the RCP 8.5 scenario, the period ranging from 2011 to 2040, areas of AP (Figure 3) were identified, and may have AP+ throughout the southwest portion of the state of Piauí. In the period from 2041 to 2070, some areas of unsuitability (IN) or AM were observed, while in the period ranging from 2071 to 2100, there was a marked growth of these areas, the areas that were previously suitable for cultivation in the southwest region presented difficulties for agriculture. These results corroborate studies carried out by others, such as Queiroz *et al*. (2021), who emphasize that the increase in temperature will affect water availability for cowpea cultivation in the state of Maranhão.

In the case of corn cultivation, zones of AP and AP+ were larger in the scenarios studied. In the historical period (reference period for analyzing the evolution of climatic types), there is a predominance of AP in almost the entire State, varying only in a small part of the southwestern mesoregion of Piauí, where it borders the state of Bahia (Figure 4).

In the RCP 4.5 scenario (Figure 4), in the period ranging from 2011 to 2040, there was a predominance of AP in the region for corn, with small bands of AP+ and AM+ variations in the north and southwest portions. In the same scenario (RCP 4.5), in the periods from 2041 to 2070 and from 2071 to 2100, there was scarcely any variation in the suitability zones, indicating that corn cultivation would be suitable in nearly all regions. Corn cultivation is important in this semiarid region, mainly due to its prominent role in the economy, favoring the generation of agricultural income and its importance in human and animal nutrition (Santos *et al.*, 2010).

In the RCP 8.5 scenario (Figure 4), in the periods ranging from 2011 to 2040 and from 2041 to 2070, the expanse of AP+ was appreciable. Considering the possibility of this climate scenario, it is crucial to discover methods to minimize the loss of productivity in this scenario, such as delaying the sowing date, because, according to Embrapa (2013) the conditions of excess water in the soil are harmful to the establishment of corn in the initial period. The pollination-physiological maturation sub-period is constrained by excess water. However, when observing the period from

Table 2: Classification of the Municipal Social Vulnerability Index (IVSM)

Subtitle	Index
High	0,43 – 0,52
Moderate	0,34 – 0,43
Low	0,25 – 0,34

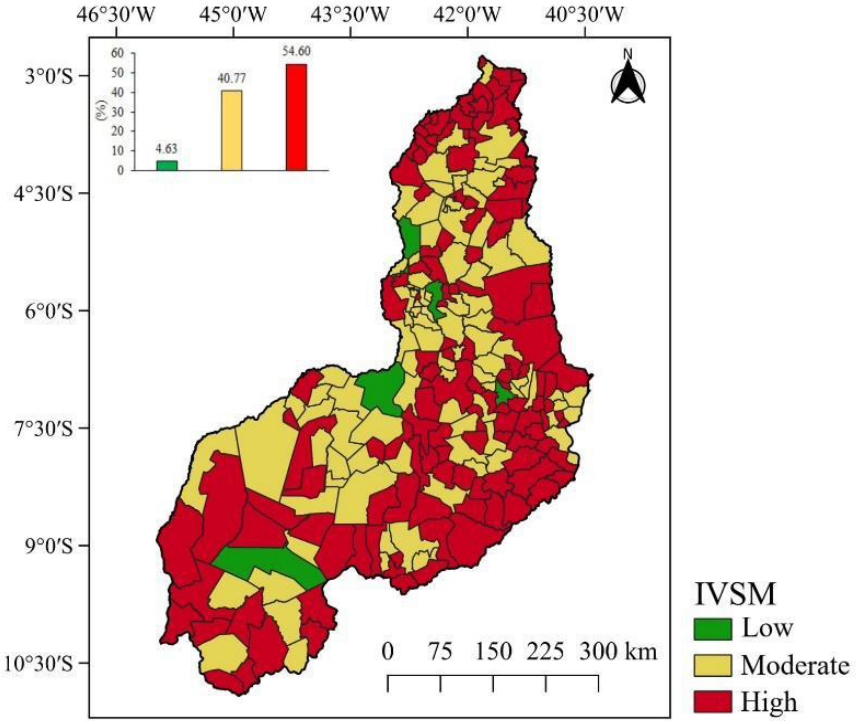

Figure 2: Regions with their respective classifications according to social vulnerability indices in the state of Piauí, Brazil.

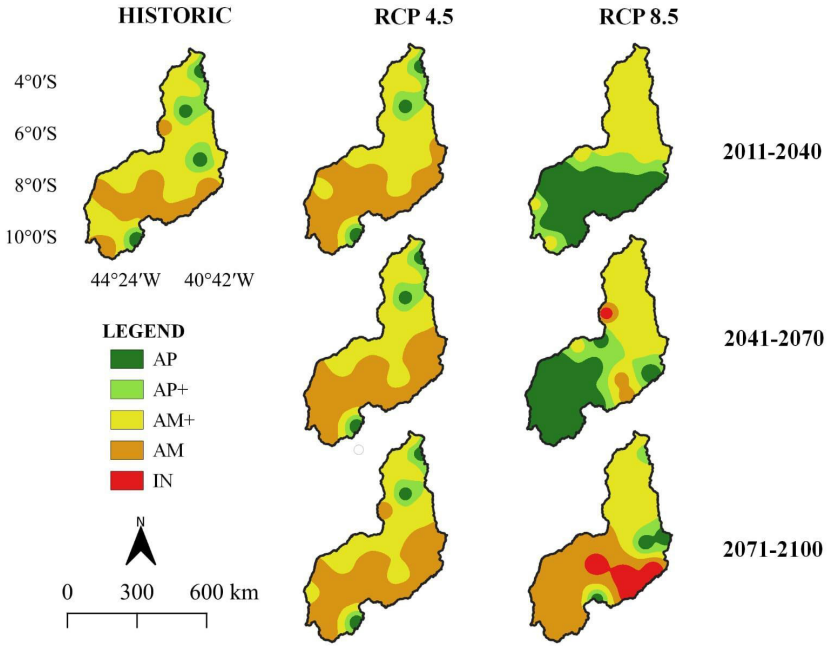

Figure 3: Map of climate scenarios for the suitability of bean crop in the state of Piauí, Brazil.

2071 to 2100, zones of AM+ and IN for cultivation began to appear. Under this scenario, the effects of the rise in temperature and the decline in precipitation are amplified, a finding also noted in a study conducted by Marcos Júnior *et al.* (2018), wherein the RCP 8.5 scenario predicts more pronounced climate anomalies.

More less suitable conditions (AM+ and IN) were observed for cashew cultivation (Figure 5). In the historical and RCP 4.5 scenarios spanning from 2011 to 2040, zones of AM+ predominated throughout Piauí. Considering the most pessimistic scenario, RCP 8.5, there were suitable zones, except for in a small area in the southeastern portion of Piauí. However, in other periods, IN zones tend to grow across the State (Figure 5).

In the RCP 4.5 scenario (Figure 5), even if the unsuitable zones were to grow throughout the State, there would still be a limited strip of the region that can be used for cultivation, which comprises part of the southwest region, because cashew flowering occurs during the dry period (Serrano, 2016), starting in June when there is little cloud cover and high insolation, the periods of maximum floral differentiation and flowering will occur between June to September, where in August there is a peak of flowering.

However, in the last period of the RCP 8.5 scenario, the state may become entirely unfit for cashew cultivation (Figure 5). According to Serrano (2016) the optimal temperature range for cashew cultivation is from 32 ºC to 35 ºC, however, by the end of the 21st century global surface temperature changes are expected to exceed 1.5 °C under all scenarios (Machado Filho *et al.* 2016).

According to the assessment of the RCP 8.5 scenario for cashew cultivation (Figure 5), temperatures will be 3.7°C above historical levels, making the cultivation of some crops unfeasible. According to Marcos Júnior *et al*. (2018), under this scenario, the average rainfall, especially in the last 30 years of the century, will decrease in the north and northeast of the country, and evapotranspiration will increase, making the cultivation of some crops difficult. In Piauí, according to IBGE (2017) data, cashew represents a high percentage of fruit production in the state, accounting for 18.5%, and of the area planted with fruit in the state, cashew cultivation accounts for 92.0% of the total area. Also, according to IBGE (2020), the State is the second largest producer of cashew nuts in Brazil, with a production value reaching R$ 64,765.00 in 2020.

Cassava cultivation remained stable for the historical and RCP 4.5 scenarios. The state of Piauí remained suitable for the cultivation of the crop throughout the whole mesoregion, varying only in the ranges of full suitability in the RCP 4.5 scenario, where in the periods ranging from 2041 to 2070 and from 2071 to 2100 the state was divided between suitability full (AP) located in the south of the state and full aptitude with the prolonged rainy season (AP+) located in the north of the state (Figure 6).

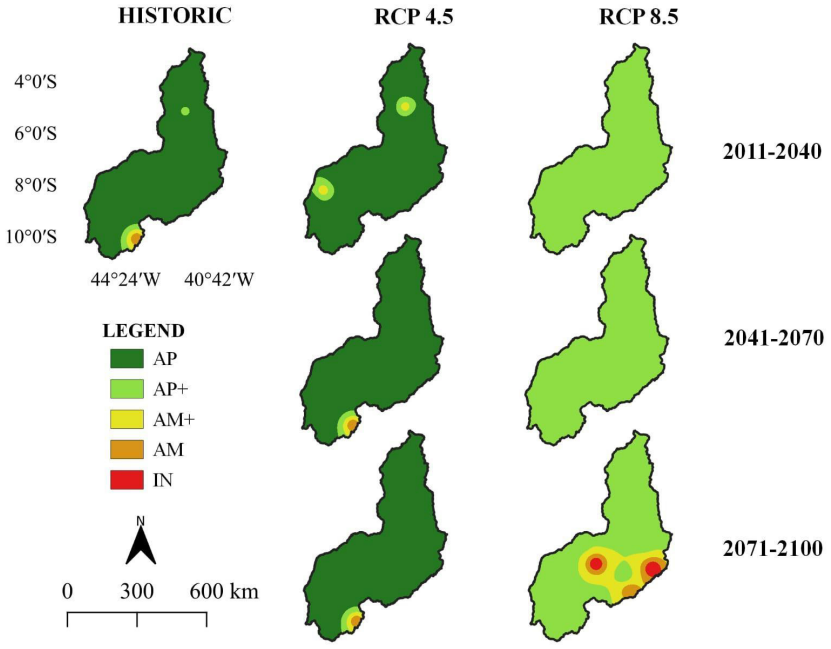

Figure 4: Map of climate scenarios for the suitability of corn crop in the state of Piauí, Brazil.

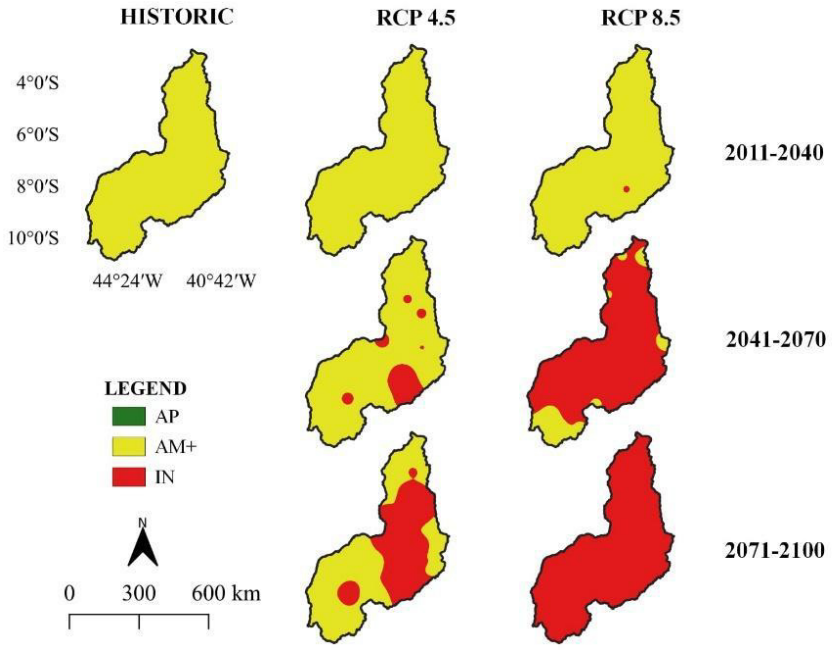

Figure 5: Map of climate scenarios for the suitability of cashew crop in the state of Piauí, Brazil.

A similar study carried out by Fernandes *et al.* (2021) showed that the state of Piauí showed an aptitude for cassava cultivation. However, according to the authors, the areas that were classified as AP+ may have restrictions for this crop due to excess water, and the authors recommend cultivation at times when there is the lowest rainfall since the culture demands low water content.

In the RCP 8.5 scenario from 2011 to 2040, Piauí should present favorable conditions for cassava cultivation (Figure 6). However, in subsequent periods, there is variation in the suitability zones. In the period from 2041 to 2070, the state will show moderate suitability due to water deficit (AM) in the southeast portion of the state, while in the central-north region, there will be a small unsuitable area (IN). In the period from 2071 to 2100, the zone of moderate suitability for water deficiency (AM) will begin

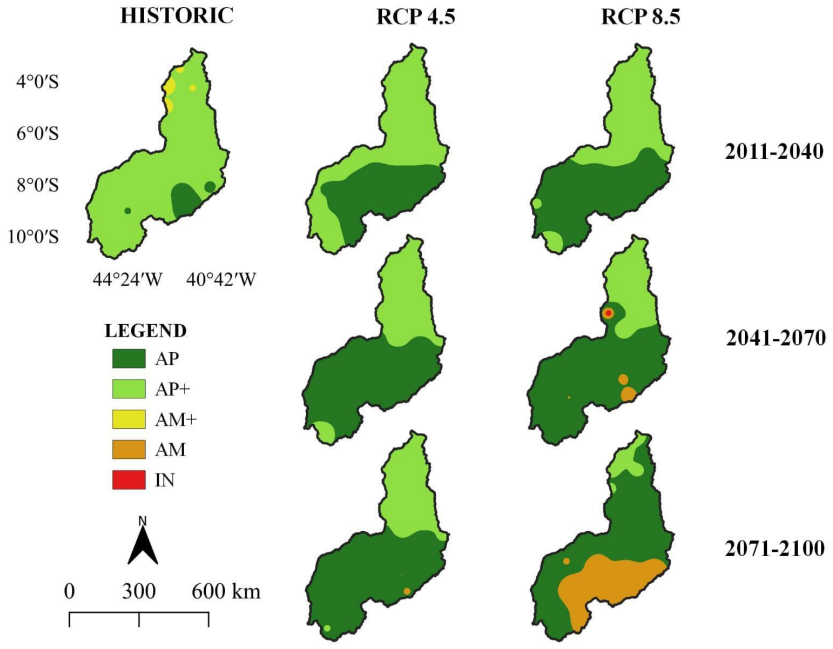

Figure 6: Map of climate scenarios for the suitability of cassava crop in the state of Piauí, Brazil.

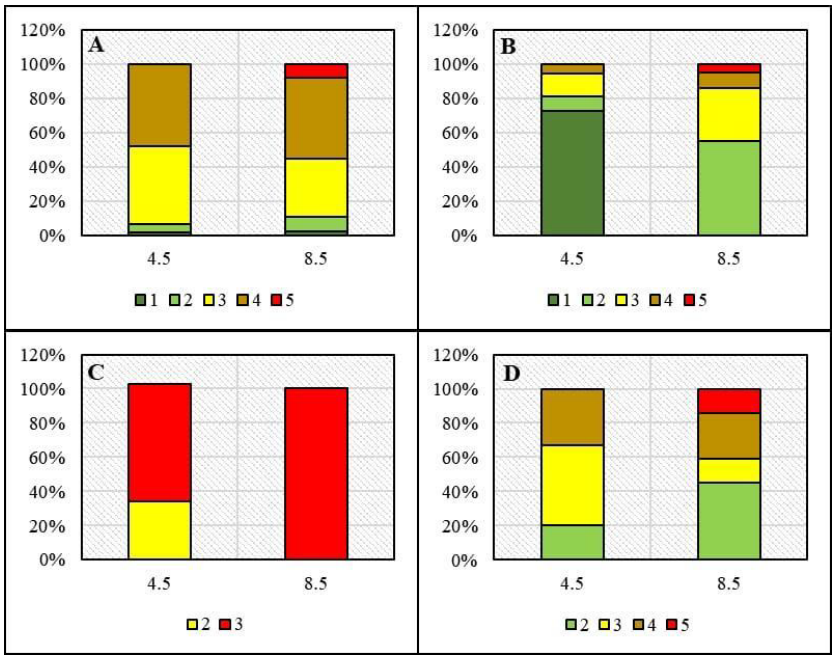

Figure 7: Percentage area of each suitability class of bean (A), corn (B), cashew (C), cassava (D) for the distant period (2071 to 2100) in scenarios RCP 4.5 and 8.5, in areas of high vulnerability. Where: 1 – AP; 2 - AP+; 3 - AM+; 4 – AM; 5 – IN. In cashew culture, class 2 is AP, and 3 - AM.

to expand in the state, showing that in some locations cassava cultivation will be restricted, which could affect the economy and/or farmers' consumption. According to a study carried out by Fernandes *et al.* (2021), analyzing the period 2003-2018 in the state of Piauí, there was an increase of 75.8% in area of moderate suitability due to water scarcity in regions cultivated with cassava.

Considering the areas of greatest social vulnerability (Figure 2), in the 2071–2100 period, bean cultivation (Figure 7A) will present difficulties for its implementation, considering that the percentage of the moderated suitability zone for water deficit (4) tended to grow in both scenarios, presenting an increase of approximately 48.7% and 47.34%, respectively.

For corn cultivation (Figure 7B), the suitability zones are the vast majority in the state in both scenarios, however, in scenario 8.5, a range of unsuitability is observed with 4.91%. Lima & Magalhães (2017) show the greatest reductions in corn yield are due to the reduction in precipitation, mainly in places with higher air temperature. Both excess rainfall and water deficit can cause difficulties for farmers living in the high social vulnerability range of the state of Piauí, as the damage to seed germination caused by these events can result in the non-establishment of the culture.

The cashew crop (Figure 7C) will be the most affected by climate change. In scenario 4.5, the unfit zone is predominant throughout the state, covering 68.56% of the land area. In scenario 8.5, cultivation will be unfeasible, since the unfit rate is 100%. Cashew cultivation for the production of beverages or the use of its pseudofruit is one of the main sources of income in Piauí. According to IBGE data (2020), Piauí is the second-largest producer of cashew nuts in Brazil.

For cassava, which is considered a "rustic" crop, and which is predominantly exploited in semi-arid regions due to its ability to use water efficiently, there will be impacts due to water deficit (Figure 7D). In both scenarios, most of the region will present moderate suitability due to lack of water, and in scenario 4.5, AM presents a percentage of 32.75% of predominance, in scenario 8.5, there is an area of unsuitability of 14.03%. This is because part of the population with a high level of vulnerability is found in the Southeast and Southwest mesoregions (Figure 2), and these regions will be suitable for AM, as seen in Figure 6. This problem will affect the population, since, according to Gomes & Marinho (2017), cassava is the economic basis of thousands of small properties and the food security of millions of Brazilians, mainly in the North and Northeast of the country. On the other hand, Freitas *et al*. (2011) show Brazil is one of the largest cassava producers, representing more than 15% of world production.

CONCLUSIONS

From an assessment during the base period (1981–2020) of beans, corn, cashew and cassava crops, it was possible to observe that the state of Piauí had suitable areas for the cultivation of these crops.

Analyzing the future projections of the RCP 4.5 scenario (2011–2040, 2041–2070, and 2071–2100), a progressive trend was noted in the cultivation of beans in the AM zone, whereas corn demonstrated predominance in the AP zone. For cashew cultivation, the 2011 to 2040 scenario, showed that the AM+ zone dominates the state, with an inclination towards the manifestation of the IN zone between 2041 and 2070, which expands even further between 2071 and 2100. Cassava cultivation will see the expansion of moderately suitable areas in this region in the future.

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