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Agroclimatic Risk Zoning of Papaya (*Carica papaya* L.) in the Hydrographic Basin of Paraná River III, Brazil

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Abstract

Brazil is the largest producer and consumer of papaya (*Carica papaya* L.) in the world. Despite modern technological and scientific advances, climate is still the most important meteorological variable in agricultural production. In this context, agroclimatic risk zoning should be one of the first things to be considered when planning cultivation. The purpose of this study was to carry out climatic risk zoning for papaya cultivation in the Basin of Paraná River III, Paraná state, Brazil. Were used meteorological data from 1976 to 2018, collected from 43 stations. The climatic risk analysis was based on the precipitation, water balance, average annual temperature, average insolation, and frost tolerance required for papaya cultivation. The occurrence of frosts is the key limiting factor for production in the study area. This meteorological factor limits the viability of papaya cultivation in the Center-East region of the Basin. In other areas, risk remains, however, the papaya is apt for cultivation.
Keywords: Climate aptitude. Climate variability. Agricultural planning.

Introduction

Climate is a key variable that interferes in the establishment, propagation and adaptation of annual crops, such as soybean and fruitculture. Agroclimatic zoning defines the potential and vulnerabilities of different regions. Brazil, a predominantly tropical country, is the largest producer and consumer of papaya in the world. In 2018, 1.060 million tons of papaya were produced in Brazil (IBGE, 2019). The climate of the basin of the Paraná River III is characterized by the meteorological variability of water availability and variation in thermal regimes through the year (CALDANA et al., 2019). Despite being an economically-and agriculturally promising region for papaya cultivation, in 2018, there were no records of fruit production in the area that includes the basin, while over the same period, Paraná state, in Brazil, produced 1,600 tons of fruit, in 81.0 hectares (IPARDES, 2019).

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Papaya (Carica papaya L.) is a popular and tasty fruit plant that belongs to the Caricaceae family, and is the most important tropical and subtropical fruit currently grown in the world (AKTARUZZAMAN et al., 2018; CAMPOSTRINI et al., 2018). It is a herbaceous perennial plant, replanted for 2 to 3 years, with the fruit being the key consumer product. To achieve satisfactory quality in the fruits produced, water and temperature stand out as main keys, among other factors. To resume these factors, it can be said that the plant needs an appropriately distributed water regime during the year, along with high insolation (MATOS et al., 2012; CAMPOSTRINI et al., 2018).

The ideal altitude for papaya cultivation is approximately 200.0 m. However, it can be grown at higher altitudes, in lower temperatures, but the quality of the fruit may be affected. If the farmer cultivates papaya on these climatic conditions, the quality of the fruit produced can suffer signicant losses (CAMPOSTRINI et al., 2018; PRADHAN et al., 2019; SALINAS, 2019).

According to Kist and Manica (1995), the farther a crop is grown from its ideal climate, the longer the duration of its phenological phases, with reduced growth and changes in the fruit quality. Therefore, to achieve good fruit quality while maximizing productivity and reducing risks, the applicability of studies on agrometeorological elements has been considered worldwide, in order to improve sustainable management, decision making, agricultural planning, and the cultivation of papaya in still unexplored areas (MIGLIACCIO et al., 2010; VIVAS et al., 2015; PAN et al., 2017; TREVISAN, 2017; RODRIGUES et al., 2019; SALINAS et al., 2019; SILVERIO et al., 2019; MAURYA et al., 2020; URTASUN et al., 2020).

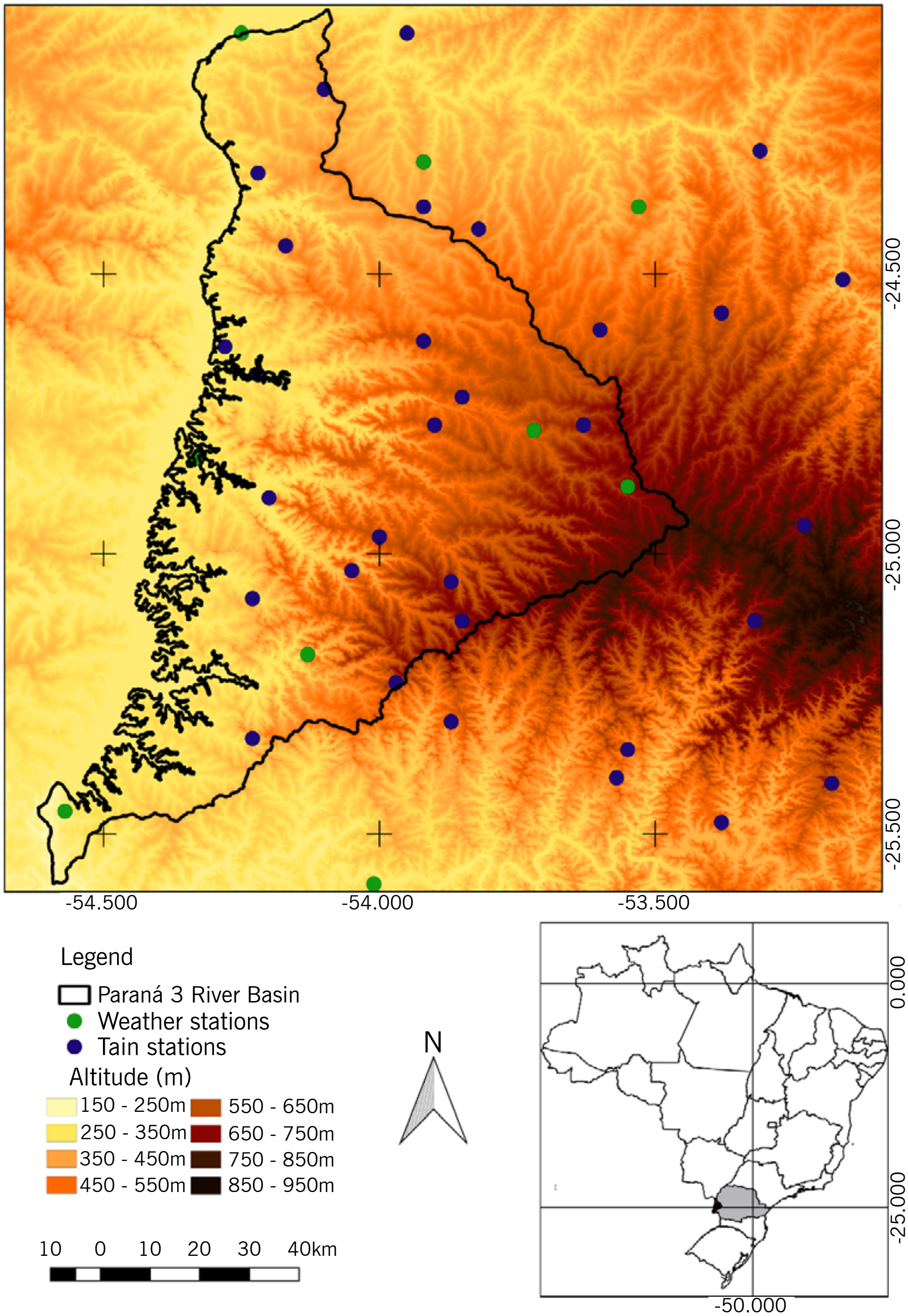
In this context, and considering the current state of papaya cultivation in the study area, the purpose of this study was to carry out agricultural zoning of climatic risk for papaya cultivation in the basin of the Paraná River III. Meteorological data from 43 stations, collected from 1976 to 2018, were used to characterize the climate in the region of the study.

Material and methods

Climate Variability

The hydrographic survey of the basin of the Paraná River III (FIGURE 1) shows that it is located in a Cfa climate, which means that it has a humid subtropical climate, according to the Köppen climate classification. This climate is characterized by the absence of seasonal drought, and by summers with higher average temperatures. It is controlled by tropical air masses (the Atlantic Tropical Mass and the Continental Tropical Mass) and the Atlantic Polar Mass. During the Summer, continental equatorial air masses can influence the Cfa zone and, during the Winter, the area can be influenced by the climatic front systems (NITSCHE et al., 2019).

Figure 01 – Hypsometry and locations of stations in the hydrographic map of the basin of Paraná River III.



Source: Elaborated by the authors (2020).

For this study, the hydroclimatic conditions required by the target species, as well as the annual, seasonal, monthly and daily time series of weather data clipped from 1976 to 2018 were choosed to be researched. In order to analyze climate variability and produce a climate risk zoning map, data from meteorological stations distributed around the basin were used. The database is comprised of data from numerous weather stations, including six IAPAR stations (Instituto Agronomico do Paraná), with available data from 1976 to 2018; ten SIMEPAR stations (Sistema Meteorológico do Paraná), with available data from 2000 to 2018, included to bolster analyses, despite the shorter time period; and 27 Águas Paraná stations, with available data from 1976 to 2018. To a better understanding of the stations (Figure 1).

For this study, data from stations that had long-term data series (1976–2018) were used. The spatialization of the data was done via interpolation, which is an effective method for spatial visualization of climate data. This was done using isohyets and spatially filling the values through adjusted regression statistics, using the inverse distance weighted spatial interpolation algorithm (LEM et al., 2013). The maps were created using the QGIS software.

The punctual data of the rainfall stations were entered into the QGIS software and transformed into a raster file with the aid of the IDW interpolator. This new file displayed a regular surface adjusted to points of data of interest with a spatial resolution pixel of 1.0 km by 1.0 km. Subsequently, isohyets and their values were added for better visualization of areas with similar precipitation patterns and/or insolation, and to regionalize the stations. The distribution of annual precipitation was also evaluated, using one station by region: Missal (West), Cascavel (South), Vera Cruz do Oeste (Center), Foz do Iguaçu (South), and Terra Roxa (North).

The Shuttle Radar Topography Mission (SRTM) model map was used as a base to apply the meteorological values, accepting 30.0 m scale, considereing the temperature. This method was necessary to spatialize and regionalize data in areas that do not have accurate temperature data.

For the spatialization of 'average temperature' and 'frost' data, multiple linear regression equations and the climatic factors latitude, longititude and longititude were used. Thus, we got a regression equation $y = a + b.lat + c.long + d.alt$, at which a, b, c, d are regression coefficients. This mathematical formula was applied to the SRTM file in ArcGIS geoprocessing software, enabling the creation of maps with a spatial resolution of 30.0 m.

Rainfall data (from the monthly totals of each year) and the monthly average temperature (from the monthly averages of the daily values of each year) were extracted. Potential evapotranspiration (PET) was then calculated according to the Thornthwaite method. First, the standard potential evapotranspiration (PET, mm/month) was calculated, using the empirical formula:

$$\text{For: } 0 < Tn < 26.5\ °C \quad (1)$$

$$PET = \left(10\frac{T_N}{I}\right)^a \quad (2)$$

$$\text{For: } Tn \geq 26.5\ °CTn^2 \quad (3)$$

$$PET = -415\ 85, + 32\ 24, Tn - 43.0\ Tn^2 \quad (4)$$

at which: Tn is the average temperature of month 'n' (where n = 1 is January, n = 2 is February, etc.) in °C, and I is an index that expresses the heat level of the region.

The value of I is dependent on the annual temperature cycle, considering the thermal effect of each month, and is calculated using the formula

$$I = 12(0.2\ Ta)^{1514} \quad (5)$$

The exponent "a", being a function of I, is also a regional thermal index, and is calculated using the expression

$$\alpha = 0.49239+1.7912x10^{-2}\ I - 7.71x10^{-5}\ I^2 + 6.75x10^{-7}\ I^3 \quad (6)$$

The PET value represents the total monthly potential evapotranspiration that would occur under the thermal conditions of a standard 30-day month, with a 12-hour photoperiod (N) for each day. Therefore, PET should be corrected for N and the number of days in the period.

$$COR = \left(\frac{N}{12}\right)\left(\frac{NDP}{31}\right) \quad (7)$$

Agroclimatic risk zoning

The factors selected for agroclimatic risk zoning were:

a. *Annual precipitation*: Data on monthly and annual precipitation from a series of 27 meteorological stations located in the river basin were used. The results obtained were interpolated in a geographic information, through the IDW. Risk was classified as follows: 'high risk' as annual precipitation of less than 1,200 mm, and 'low risk' as annual precipitation greater than 1,200 and less than 3,100 mm annually, distributed throughout the year (FONSECA et al., 2004).
b. *Annual Water Deficiency (AWD):* AWD was estimated using the method described by Thornthwaite and Matter (1955), and obtained by calculating the normal climatological water balance for the meteorological stations. A value of 100 mm for the available water capacity in the soil was used, as the avocado root system penetrates the soil profile to a depth of more than 1.0 m [26]. The results obtained were interpolated using the *ArcGIS* 10.0 geographic information system to generate annual water deficit maps. The water deficiency risk associated with the following thresholds are as follows: 'high risk' – AWD > 80 mm; 'low risk' – AWD < 80 mm (FONSECA et al., 2004).
c. *Average Annual Temperature (Ta)*: Meteorological data from a historical series of average temperatures recorded inside meteorological shelters were used to estimate the average annual temperature. Using the Ta value, a regression was applied to the entire river basin as a function of latitude, longitude, and altitude. The risk associated with different annual temperatures are as follows: High Risk: *Ta* below to 22°C e Low Risk: *Ta* from 22°C to 26°C (COELHO FILHO et al., 2011; DANTAS e JUNGHANS, 2013).
d. *Relative humidity*: The upper limit of the high risk of > 85.0 % and the lower limit for a drought of < 60.0 % was considered. High values of relative humidity grow the risks of the fungal deseases of the plants (FONSECA et al., 2004; COELHO FILHO et al., 2011; DANTAS e JUNGHANS, 2013).
e. *Frost Risk*: Meteorological data from the historical series from the weather stations were used, taking into account occurrences of temperatures of 1.0 °C or below recorded in meteorological shelters, to calculate the risk of frost. The probability of annual frost occurring

was calculated and compared with altitude and latitude, resulting in a regression equation for the risk of frost. Using adjusted regressions, probability values exceeding 20.0 % indicated a high frost risk (COELHO FILHO et al., 2011; DANTAS e JUNGHANS, 2013).

To create the thematic maps and the final zoning map, ArcGIS software was used. First, the numerical values from the meteorological stations were transformed into points according to their geographical coordinates. Then, edaphoclimatic requirements of the avocado species for data spatialization were used, in order to delimit the representative bands of the avocado climate requirements. Thus, the station values were replaced by apt (1) or inapt (2), according to the papaya physiological requirements for each meteorological variable analyzed. Later, papaya cultivation aptitude in the Basin of Paraná River III were classified in 1 or 2.

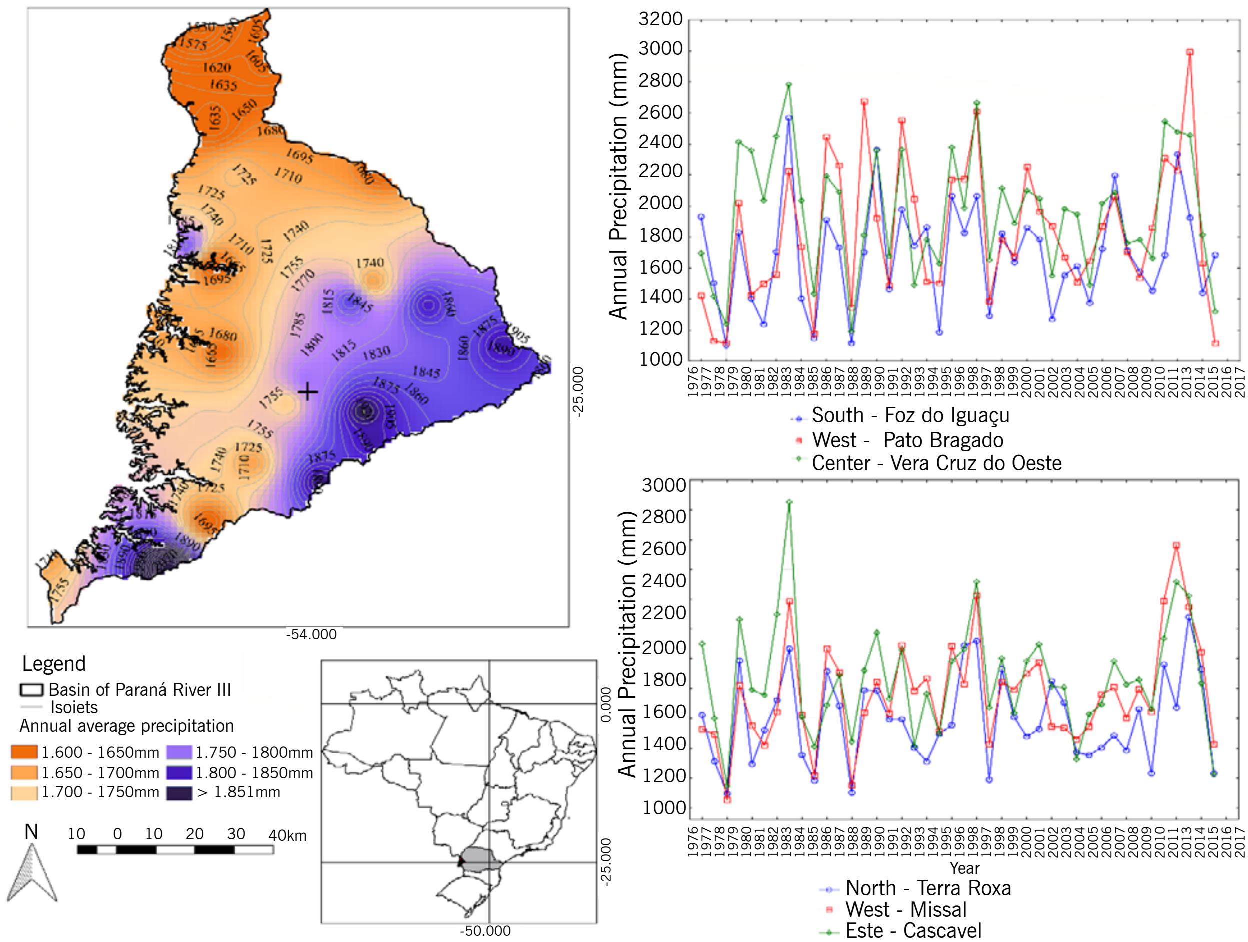
Subsequently, standardization of the pixel classifications was performed by dissolving the vector classes. In this way, agroclimatic zoning classes were grouped, thus defining regions of suitability for the target species. The final map showing the agroclimatic zoning fitness for each crop provided an estimate of the area represented by each risk class, informing its suitability for cultivation at the site.

Results and discussion

Precipitation is not a limiting factor for papaya cultivation in the basin of Paraná River III (Figure 2). We verified the variability of precipitation from 1,200.0 mm to 1,680.0 mm, in the northern end of the basin.

Few areas recorded less than 1,200.0 mm of precipitation, even in the dryer regions of the basin. Foz do Iguaçu and Missal stations, located in the southern and western edges respectively, presented only three incidences of low precipitation each. All stations recorded an annual precipitation average exceeding 1,000.0 mm.

Figure 2 – Annual rainfall average in the hydrographic map of basin of the Paraná River III.

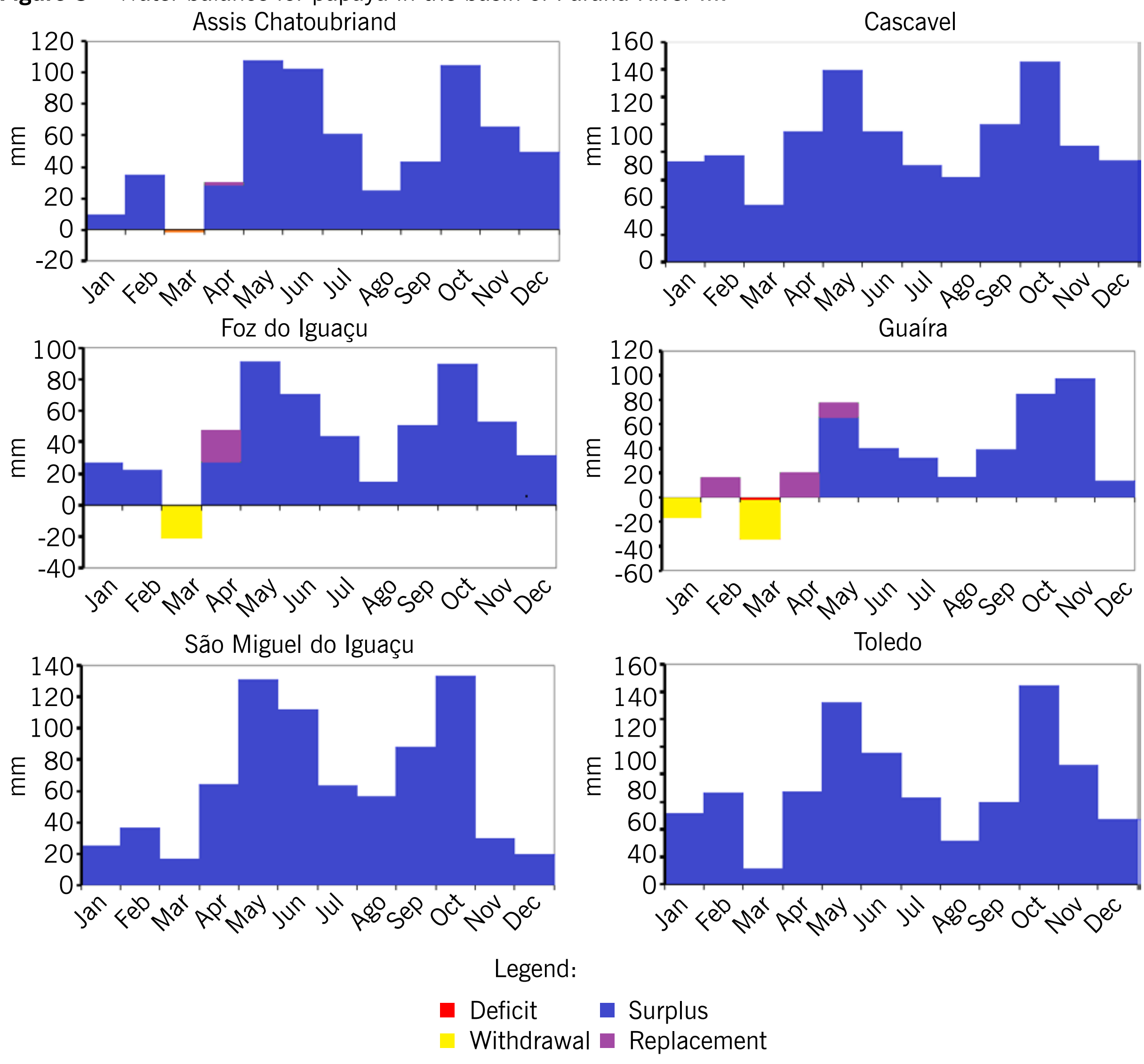


Source: Elaborated by the authors (2020).

The papaya is a plant that requires a significant quantity of water during both periods of the growth cycle: vegetative and reproductive. Thus, it is necessary to meet the water needs of the plant by installing irrigation systems in areas characterized as 'dry' or that suffer from an irregular distribution of precipitation. As the papaya is sensitive to excess water, the farmer should avoid flood irrigation (DANTAS and JUNGHANS, 2013). In the Paraná River III basin, is possible to know that the water necessary for papaya cultivation is available after checking the water balance (Figure 3).

We verified that no weather station presented risk of droughts periods for papaya cultivation, in the basin of Paraná River III. The municipality of Guaíra, which had the greatest water deficiency, had a AWD value of 56.0 mm. However, the water balance for the months January to April is less favorable when compared with the other months, due the average temperature and evapotransporation, that are greater in January to April. Thus, the farmer have to pay attention and provide irrigation when necessary.

Figure 3 – Water balance for papaya in the basin of Paraná River III.

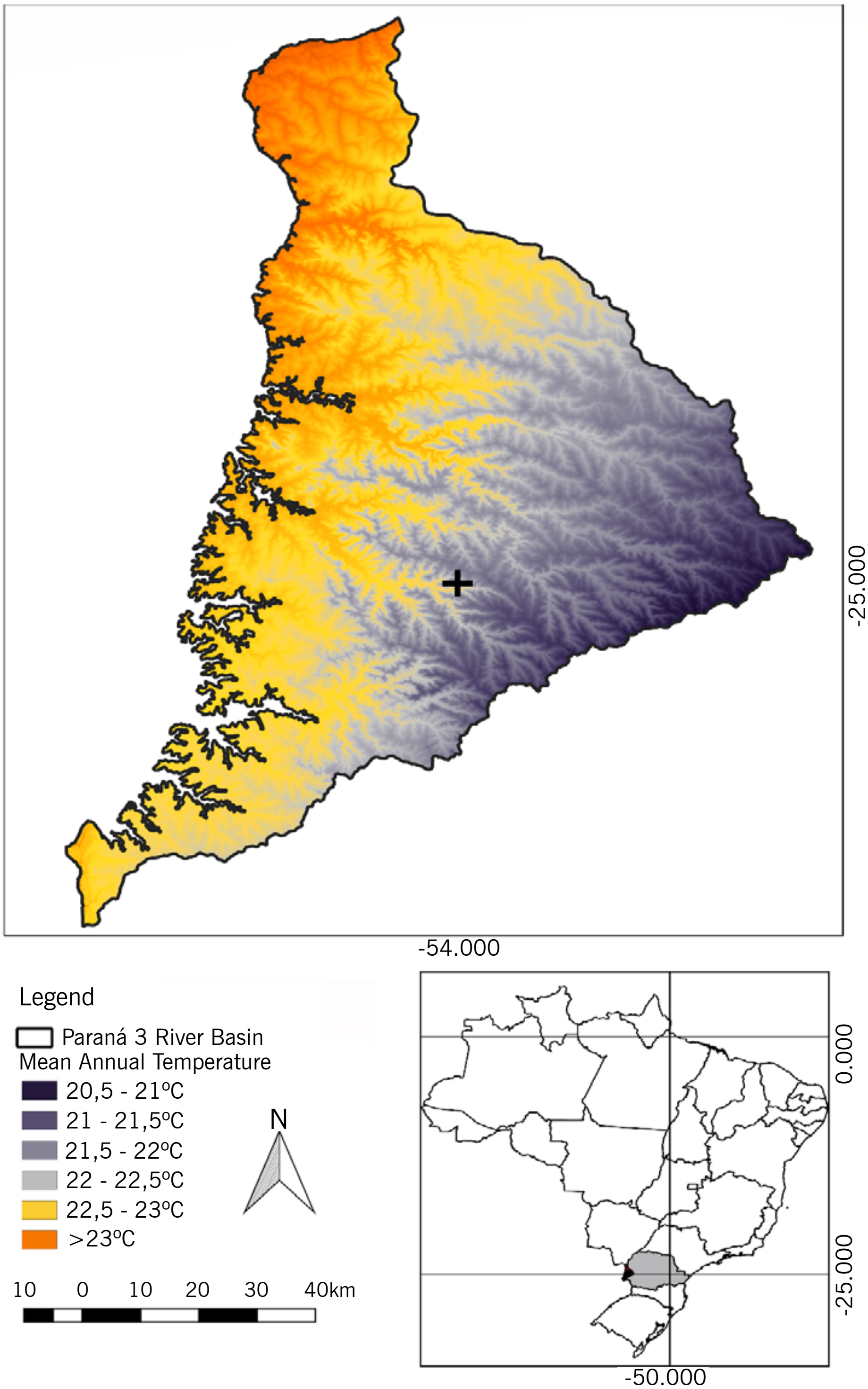


Source: Elaborated by the authors (2020).

The optimum temperature for papaya cultivation ranges from 22.0 °C to 26.0 °C. Because of that, papaya is considered as a tropical plant (DANTAS; JUNGHANS, 2013). It was verified that the altitude is a key factor for the temperature variability (FIGURE 4). The Central-East of the hydrographic basin of Paraná River III showed average temperature at approximately 21.0 °C. That means this region of the basin is an inapt area for papaya cultivation.

The highest average temperatures (over 23.0 °C) were observed in the Guaíra region, in the northern end of the river basin. The light gray strip on the map shows the portion suitable for the development of papaya cultivation in the region. This covers the entire western portion close to the Paraná River.

Figure 4 – Annual average temperature in the basin of Paraná River III.



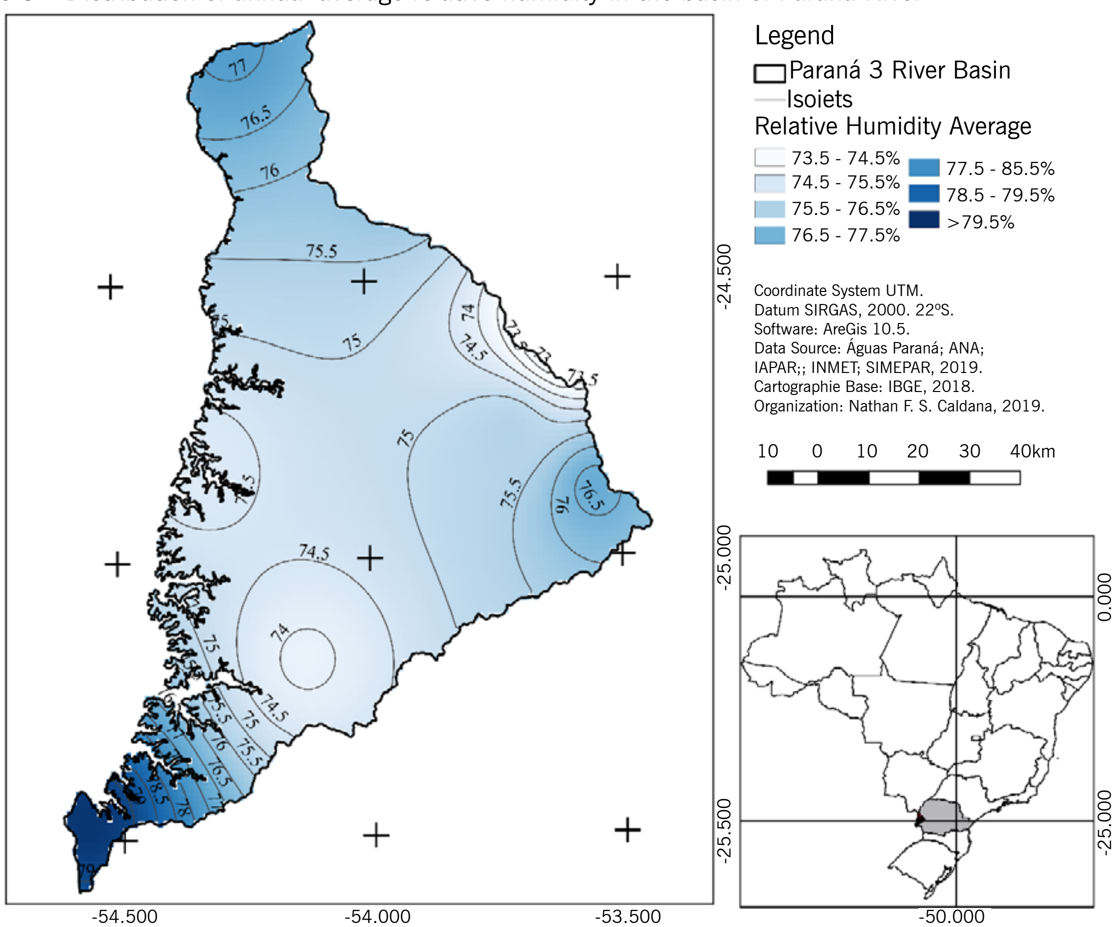
Source: Elaborated by the authors (2020).

Coelho Filho et al. (2011) studied the climatic suitability of papaya cultivation and the impact of climate change for the Bahia state, Brazil. For these authors, 900.0 mm are sufficient for papaya cultivation. Also, they made a projection where, in 2070, papaya will be cultivated in almost 100.0% of the area of the Bahia state, due the IPCC projections, that are indicating significant increase of the average temperature for that area, changing and inapting other crops that nowadays are cultivaded in Bahia state (COELHO FILHO et al., 2011).

High humidity (FIGURE 5), in conjunction with relatively low temperatures, predisposes crops to getting aggressively attacked by fungi and viruses. The maximum humidity level classified as suitable for planting papaya is 85.0 %, while the minimum, which is linked with water levels too low to meet the requirement of the plants, is 60.0 %.

The average relative humidity in the region is highest in Foz do Iguaçu, located on the edges of the Iguaçu and Paraná River. In this location, the humidity reached 79.0 %. At the edges of the region, close to the municipality of Assis Chateaubriand, there was a decrease in humidity, dropping to 73.0%. Thus, none of the regions are limited by relative humidity levels, and they should plan to cultivate papayas.

Figure 5 – Distribution of annual average relative humidity in the basin of Paraná River III.

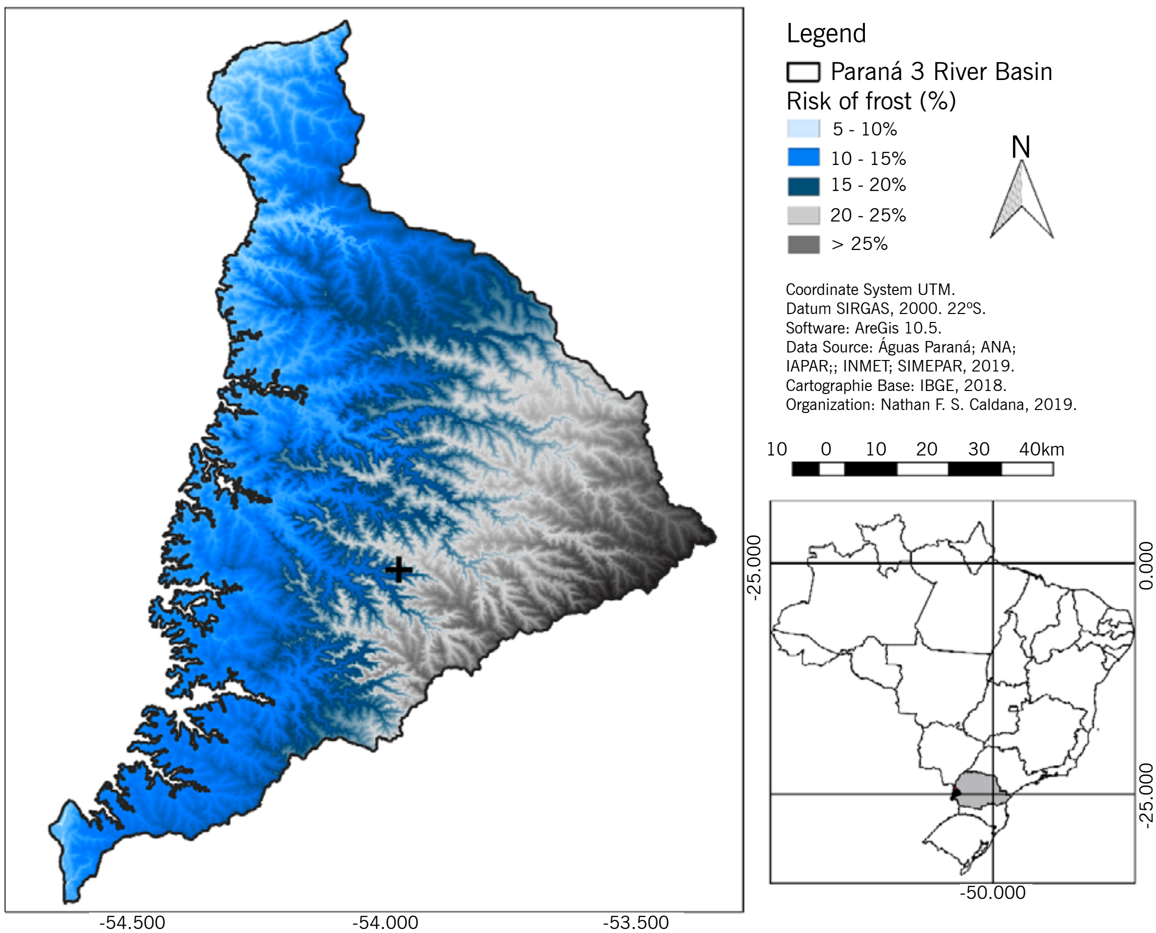


Source: Elaborated by the authors (2020).

At low temperatures, the papaya stops its vegetative development, reducing flowering, delaying ripening, and producing low-quality fruit. Cold winds and frost can cause leaf scorch, reducing the area available for photosynthesis and, consequently, decreasing papaya production. Thus, the occurrence of frost is the main parameter that should be considered when planning papaya planting, as it is considerably harmful for the cultivation of papaya.

The frost risk in the region (FIGURE 6) showed a distribution similar to the average temperature, with greater frost risk present in the eastern area, close to the municipalities of Cascavel and Santa Tereza do Oeste, in the upper portion of the basin, as well as in some valley bottoms in the central region. The central portion of the basin presented a 10.0 to 20.0 % frost risk, while in the lower portions, close to the valley of the Paraná River, mainly along the north-south axis from Guaíra/Terra Roxa to Foz do Iguaçu/Santa Terezinha de Itaipu, the risk falls to about 5.0 %.

Figure 6 – Frost risk in the basin of Paraná River III.

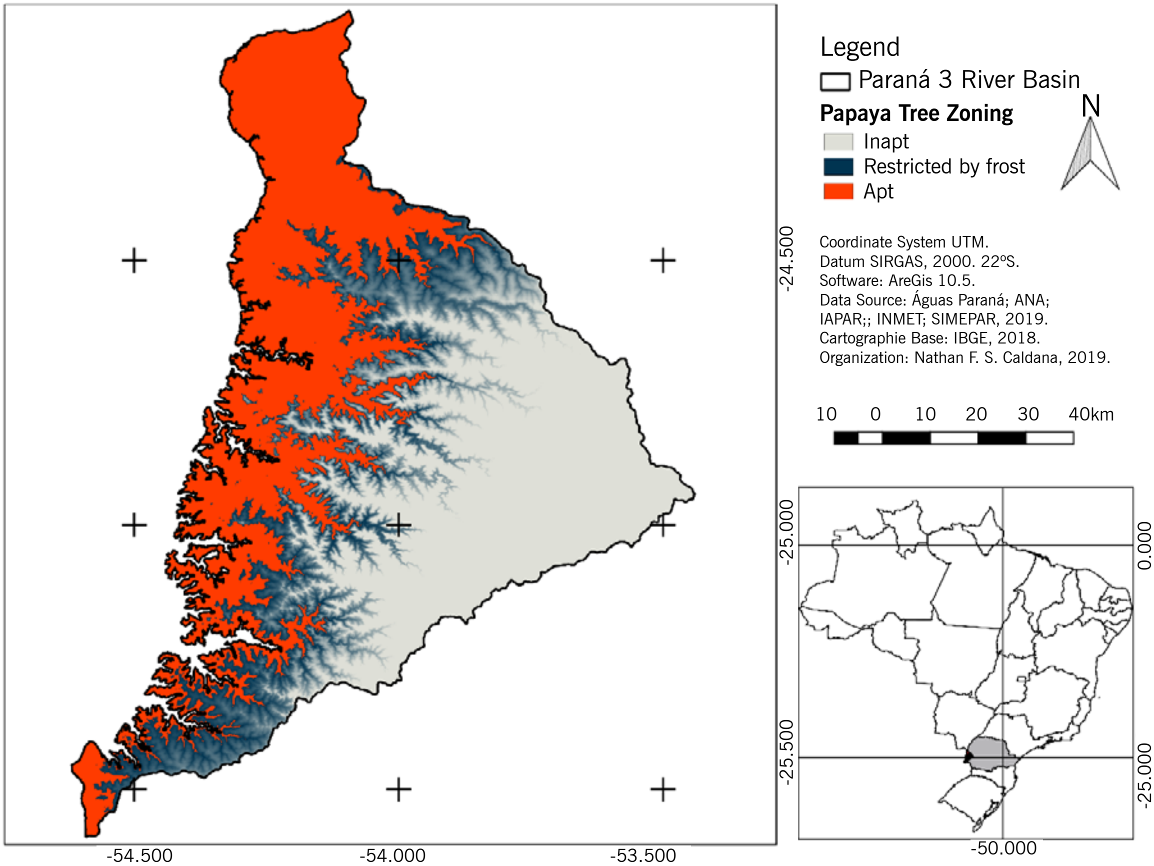


Source: Elaborated by the authors (2020).

The final agroclimatic zoning map (FIGURE 7) shows limitations due to the average temperature, which interferes with the biological cycle of the papaya, and frost can cause the senescence of the species.

Thus, the highest region and, consequently, the coldest, has restriction for the cultivation of papaya. The entire central and eastern region of the basin has also been classified as unsuitable. A small area located at intermediate ranges was classified as restricted, since the risk of frost occurring was 10.0 %.

Figure 7 – Agroclimatic risk zoning of papaya (*Carica papaya*) in the basin of Paraná River III.



Source: Elaborated by the authors (2020).

Even in suitable regions, there is a risk of frost, so producers must avoid valley bottoms, and give preference to cultivation in areas that are not very sloped, to facilitate the displacement of cold air. Preferably, the top of the relief and the top half of a slope should be cultivated, particularly north-facing areas, since, as highlighted, the cold front is preferentially displaced in the south-southwest and northeast directions (CALDANA et al., 2018; CALDANA et al., 2019; CALDANA; MARTELÓCIO, 2019).

For cultivation in non-viable areas without irrigation, seedlings must be sown in the field at the beginning of the rainy season and planted on cloudy or rainy days. Papaya will begin producing fruits about 8 to 10 months after seedlings are planted in the field, depending on the region.

It should be noted that zoning does not completely eliminate risks; it simply identifies conditions more favorable for the development of papaya plantations. Agriculture is a risky activity, and like all other activities, it is susceptible to extreme climate events, which may cause issues for farmers. In the context of sustainable agriculture and climate change, agroclimatic zoning provides guidance and some level of confidence in decision-making and agricultural planning in the Paraná River III basin.

Conclusions

The basin of Paraná River III has a small strip of land in the western portion that poses a low climatic risk for papaya cultivation, mainly in the areas at lower altitudes on the edges of the Paraná River.

Precipitation and water balance were sufficiently low-risk in all scenarios studied for papaya cultivation.

The greatest limiting factors for production are the occurrence of frost, as frost damages the tree and the fruits; and the average temperature, which restricts the development and growth of the species. Thus, the cultivation of papaya is restricted by these factors at the central-eastern portion of the basin.

Management techniques can be used to minimize the risk of frost. Avoiding areas with a significant probability of frost occurrence can better guarantee success for the cultivation of papaya in the region.

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Zoneamento de Risco Agroclimático do Mamoeiro (*Carica Papaya* L.) na Bacia Hidrográfica do Rio Paraná III

Resumo

O Brasil é o maior produtor e consumidor mundial de mamão. A fruticultura é um segmento de destaque da agricultura brasileira. Apesar dos recentes avanços tecnológicos e científicos, o clima é ainda a variável mais importante na produtividade agrícola. Nesse contexto, o zoneamento agroclimático deve ser uma das primeiras informações a serem consideradas ao iniciar o cultivo de determinada cultura. Dessa forma, o objetivo deste trabalho foi realizar o zoneamento de risco agroclimático para o Mamoeiro (*Carica Papaya* L.) na bacia do Rio Paraná III, estado do Paraná. Para isso, foram utilizados dados meteorológicos de 43 estações com recorte temporal de 1976-2018 A análise do risco agroclimático foi pautada nas exigências da espécie, sendo estas: precipitação, deficiência hídrica anual, temperatura média anual, insolação e risco de geada. A ocorrência de geadas foi o fator mais limitante para a produção na região. Esse fator meteorológico restringiu o plantio na porção centro-leste da bacia. Nas demais áreas, o risco é presente, mas foi garantida a aptidão para o plantio do mamoeiro.

Palavras-chave: Aptidão climática. Variabilidade Climática. Planejamento Agrícola.

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