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Agroclimatic risk zoning of lemon (*citrus aurantifolia*) in the hydrographic basin of Paraná River III, Brazil

Zoneamento de risco agroclimático para o limão (*citrus aurantifolia*) na bacia hidrográfica do Rio Paraná III, Brasil

Zonificación de riesgo agroclimático de limón (*citrus aurantifolia*) en la cuenca hidrográfica del río Paraná III, Brasil

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Abstract

The lemon tree is one of the most important variety of fruits in Brazil, considered the fifth largest world producer. The purpose of this study was to carry out agroclimatic risk zoning for lemon (Citrus aurantifolia) in the basin of Paraná River III. Technical maps through interpolation and regressions, and graphics for risks analysis probabilities were elaborated. The agroclimatic risk for lemon was established according to the species requirements, such as precipitation, water deficiency, average and maximum air temperature, thermal unit/degrees days and risk of frost. Larger region in the basin is recommended for cultivation of lemon. It was not found inapt areas for cultivation, only restrict, exhibiting considerable potential for cultivation of lemon, in the region of study.

Key words: Climate aptitude. Climate variability. agricultural planning.

Resumo

A lima ácida Tahiti está entre as dez variedades de frutas mais importantes produzidas e consumidas no Brasil, sendo o quinto maior produtor mundial. O objetivo desse trabalho foi realizar o zoneamento de risco agroclimático para o limoeiro (Citrus aurantifolia) na bacia do Rio Paraná III. Foram elaborados mapas temáticos por meio de interpolação e regressões, além de gráficos de probabilidade para a análise do risco. O risco agroclimático para o limoeiro foi pautado nas exigências da espécie, sendo estas, precipitação, deficiência hídrica, temperatura do ar média e máxima, unidade térmica/graus dia e risco de geada. A maior parte da área da bacia foi apta para o cultivo. Não houve áreas inaptas, apenas restritas demonstrando assim, o potencial para a produção na região.

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

Resumen

El limonero es una de las variedades de frutas más importantes de Brasil, considerado el quinto mayor productor mundial. El propósito de este estudio fue realizar la zonificación del riesgo agroclimático para el limón (Citrus aurantifolia) en la cuenca del río Paraná III. Se elaboraron mapas técnicos mediante interpolación y regresiones, y gráficos para las probabilidades de análisis de riesgos. El riesgo agroclimático para el limón se estableció de acuerdo con los requisitos de la especie, tales como precipitación, deficiencia de agua, temperatura media y máxima del aire, unidad térmica / grados días y riesgo de heladas. La mayor parte del área de la cuenca era apta para el cultivo. No se encontraron áreas inactivas para el cultivo, solo restringir, exhibiendo un potencial considerable para el cultivo de limón, en la región de estudio.

Palabras clave: Aptitud climática. Variabilidad climática. Planificación Agropecuaria.

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Introduction

The climate is the key variable that most interferes in the establishment, propagation and adaptation of fruticulture. The Tahiti acid lemon, known as Tahiti lemon (Citrus latifolia Tan) is among the ten most important fruit varieties produced and market in Brazil (FAO, 2017). Brazil has a continental territory and significant part is considered as tropical climate, appropriate for cultivation of lemon. According to the FAO (2017), Brazil occupies the fifth position in the world production of limes and lemons, producing approximately 1.3 million tons.

The basin of Paraná River III presents areas of relevant agricultural potential due to its climatic variability. Its thermal and water regime has different variations during the year (CALDANA et al., 2019). The lemon has unexpressive production in the region. The numbers for the 2017 and 2018 confirm this condition. The registered productions were not greater than 400 tons (391 and 400 respectively), harvested in 40 hectares (IPARDES, 2019). There was no expansion of areas, indicating that production is concentrated in the hands of a few farmers. The Paraná State, Brazil, at the same period, produced about 16 thousand tons of lemon (IPARDES, 2019).

The acid lime Tahiti is characterized by producing fruits with medium to large size of 70 to 100 g and devoid of seeds. The plant is medium to large in size, blooms all year and the fruit ripens between 120 and 170 days after flowering (MARCONDES, 1991;

STUCHI et al., 2003). Fruit development varies according to the canopy variety, rootstock used, thermal regime and water availability in the producing region (SAM et al., 1988). Flowering in citrus occurs after low temperatures or deficiency of water, which act in differentiating and breaking dormancy of flower buds, especially in branches with 6 to 18 months that do not have fruits (MATTOS et al., 2003b). At the global scale and in the context of sustainable agriculture and climate change, several studies are carried out to improve citrus management and production techniques (ZHAO et al., 2017; AL-AAMRI et al., 2018; NDO et al., 2019; OWI et al., 2019; LADANIYA et al., 2020).

From this, the destination of the fruits is the consumption in domestic or external markets or for juice. The essential oil extracted from the peel has industrial use as food flavorings and perfumery ingredients and cab be used as medicinal herb such as digestive stimulants, antioxidants and homeopathic formulations (MATTOS et al., 2003a).

In this sense, and considering the inexpressiveness of acid lime in the area of this study and its considerably the economic potential, the purpose of this study was to carry out agricultural zoning of climatic risk for lemon trees in the hydrographic basin of Paraná River III. For this, the requirements were raised hydroclimatic species and meteorological data of annual, seasonal, monthly and daily time presenting series from 1976 to 2018 for knowledge of the local climate.

Material and Methods

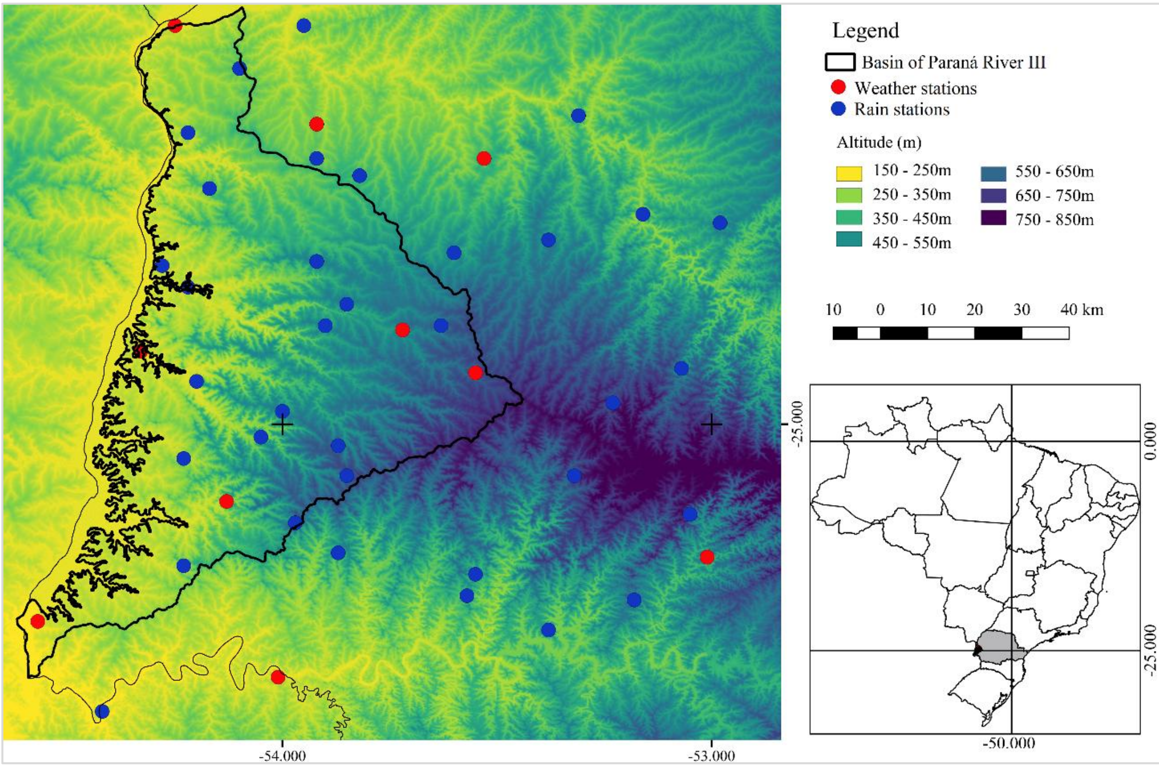
Climate Variability

The hydrographic basin of Paraná River III is located in a Cfa climate, which means that it has a humid subtropical climate according to the Köppen climate classification. This is characterized, mainly, by the absence of drought seasons and by summers with higher average temperatures (NITSCHE et al., 2019; CALDANA et al., 2019).

We selected the hydroclimatic requirements of the studied species and weather data of annual, seasonal, monthly, and daily time series with clipping from 1976 to 2018 (CALDANA et al. 2019). The database comprises data from numerous weather stations, located at the Basin, including from IAPAR (Instituto Agronomico do Paraná), SIMEPAR (Sistema Meteorológico do Paraná) and Águas Paraná from 1976 to 2018 (CALDANA et al., 2019).

The spatialization of these data was performed by interpolation, it was done using isohyets and/or by 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 QGIS software (CALDANA et al., 2019).

Map 1 - Hypsometry and locations of stations in the hydrographic basin of the Paraná River III.



Source: Caldana et al. (2019), adapted and organized by the authors (2020).

The punctual data of the rainfall stations were entered into the Qgis *software* and transformed into a *raster* file, with aid the IDW interpolator. This new file displays a regular surface adjusted to these point data of interest with spatial resolution pixel of 1 km by 1 km. Isohyet and their values were inserted for a better visualization of areas with similar precipitations and/or insolation and to regionalize them. Was also evaluated the distribution of annual precipitations using one season by region: Missal (West), Cascavel (South) and Vera Cruz do Oeste (Center), Foz do Iguaçu (South) and Terra Roxa (North), according to the Caldana et al. (2019) method.

The *Shuttle Radar Topography Mission* - SRTM base was used to apply the meteorological values to the maps using the geographical factors of relief and altitude in the 30 m scale. These factors are used given the influence on temperature (CALDANA te al., 2019).

Were adjusted to multiple linear regression equations for the spatialization of the average temperature and frost data the values measured in the meteorological stations, linking the stations values observed with the geographic factors of altitude, latitude and longitude, obtaining estimation equations, such as: y = a + b.lat + c.long + d.alt, where a, b, c, d are regression coefficients (CALDANA et al., 2019). This mathematic formula is applied in Arcgis geoprocessing *software* over the SRTM file, with spatial resolution of 30 m (CALDANA et al., 2019).

We used this formula to calculate the degrees day:

$$GD = \left(\frac{Tmax + Tmin}{2}\right) - Tbase$$

Where:

GD: Degrees day.

Tmax: Maximum daily temperature of the meteorological shelter.

Tmin: Minimum daily temperature of the meteorological shelter.

Tbase: Base temperature for citrus (Tbase = 13°C).

We evaluated 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. We calculated potential evapotranspiration (PET) according to the Thornthwaite method (CALDANA et al., 2019).

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

$$\text{PET} = 16\left(10\,\frac{\text{Tn}}{\text{I}}\right)^{\text{a}} \quad (2)$$

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

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

Where

Tn is the average temperature of month n (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 depends on the annual temperature cycle, integrating the thermal effect of each month, and is calculated using the formula

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

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

$$a = 0.49239 + 1.7912 \text{ x } 10^{-2}\, I - 7.71 \text{ x } 10^{-5}\, I^2 + 6.75 \text{ x } 10^{-7}\, I^3. \quad (6)$$

The PET value represents the total monthly potential evapotranspiration that would occur under the thermal conditions of a standard 30 day month, and with a 12 hour photoperiod (N) each day. Thus, PET should be corrected for N and the number of days in the period (CALDANA et al., 2019).

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

Agroclimatic Risk Zoning Factors

a) *Annual precipitation*: We selected data on monthly and annual precipitation from meteorological series of 27 meteorological stations in the basin. The results obtained were interpolated in a geographic information system for the generation of maps with the regionalization of data through the IDW. Was admitted risk of annual precipitation less than 1500 mm and presenting an adequate precipitation during the year, with, approximately, 120 mm monthly (SANTOS FILHO et al., 2005).
b) *Annual Water Deficiency (AWD):* Was estimated using the method of Thornthwaite and Matter (1955), and obtained by calculating the normal climatological water balance for the weather stations. We consider 100 mm for the water capacity in the soil (SOUZA et al. 2006). The results obtained were interpolated using the *ArcGIS* 10.0 geographic information system to generate the annual water deficit maps. The following thresholds were considered for the risk of water deficiency: high risk—AWD > 100 mm; low risk—AWD < 100 mm (SANTOS FILHO et al., 2005; CALDANA et al., 2019).
c) *Average Annual Temperature (Ta)*: We used Meteorological data from historical series of average temperatures to estimate the average annual temperature. The risk classes defined for Ta were as follows: high risk – High risk: less than 18°C and low risk: from 18 to 31°C (SANTOS FILHO et al., 2005; CALDANA et al., 2019).
d) *Maximum Daily Temperature*: We used meteorological data from historical series of maximum daily temperatures observed inside meteorological shelters to estimate the average annual temperature. The following risk classes for AT were defined: High Risk: annual frequency superior than 20 % probability of occurrence of absolute maximum temperatures above 36°C (SANTOS FILHO et al., 2005).
e) *Thermal unit*: We calculated the accumulation of degrees daily considering the base temperature for the citrus (minimum 13° C and maximum 39°C). So that it is possible to estimate the regional cycle of the species. The restrictive factor was at least 2,000°C accumulated during the year (WREGE et al., 2004; SANTOS FILHO et al., 2005).
f) *Frost Risk*: We used meteorological data from the thirteen-season historical series, taking into account occurrences of temperatures of 0°C or below as observed within the meteorological shelters, to calculate the risk of frost. The probabilities of annual frost occurrence were calculated and correlated with

altitude and latitude, obtaining a regression equation for the risk of frost. When we observe values greater than 20 %, we consider to be high risk (WREGE et al., 2004; SANTOS FILHO et al., 2005; CALDANA et al., 2019).

For the creation of thematic maps and the final zoning map, ArcGIS software was used. Firstly, the numerical values from the meteorological stations were transformed into points, according to their geographical coordinates. We then used the edaphoclimatic requirements of the avocado species to produce data spatialization, which was used for the delimitation of the representative bands of the avocado climate requirements. Thus, the station values were replaced by "1. Apt" or "2. Restricted", according to the physiological requirements for each meteorological variable analyzed.

The next step was to combine the matrix images. Each pixel was assigned with the values "1" or "2", as already described. If the combination for a point was filled only with values "1", the region was classified as fit. If it had a value of "2" it was restricted by a given variable. If two or more "2" values were assigned, the location was classified as unfit.

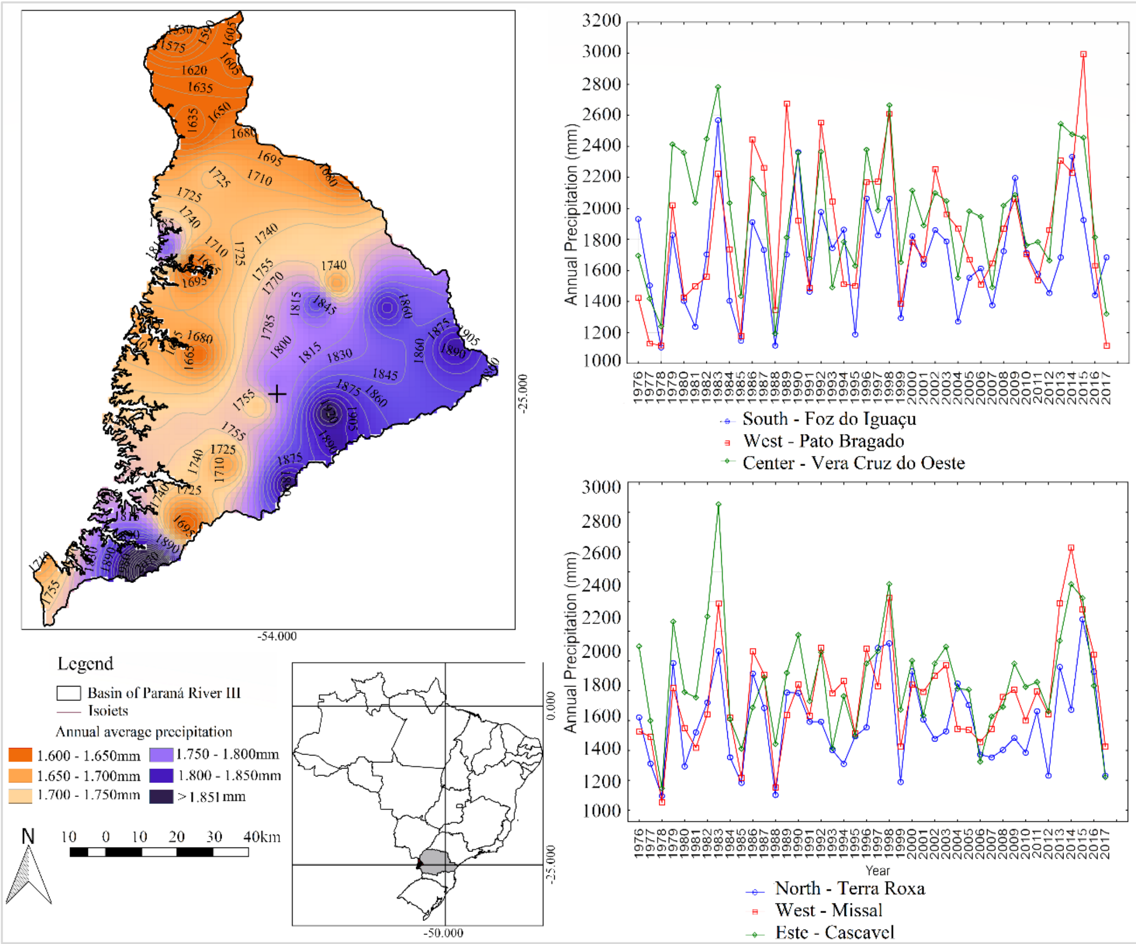
Then, standardization of the pixels using classifications was performed by dissolving the vector classes. In this way, the agroclimatic zoning classes were grouped, thus defining regions of suitability for the studied species. The final map showing the agroclimatic zoning of each crop will provide an estimate of the representative area of each risk class, ensuring its suitability for the site.

Results and Discussion

The precipitation of the basin of Paraná River III was not restricted for cultivation of lemon tree (map 2). The annual requirements for citrus are between 900 mm and 1,500 mm (SANTOS FILHO et al., 2005). As noted in the graphs, precipitation less than 1,000 mm does not occur in the region, but less than 1,500 mm can occur frequently, but does not present a risk to production of lemon. The lowest record was 1680 mm at the northern end of the basin in the Guaíra region.

Acid lime is a drought-resistant species. In the North, Northeast and Midwest regions of Brazil, apt regions are classified with water surpluses above zero and annual water deficiency below up to 300 mm. For the production success limit in the South, the acceptable limit in the water balance was 100 mm (SANTOS FILHO et al., 2005).

Map 2 - Annual rainfall average in the hydrographic basin of Paraná River III.

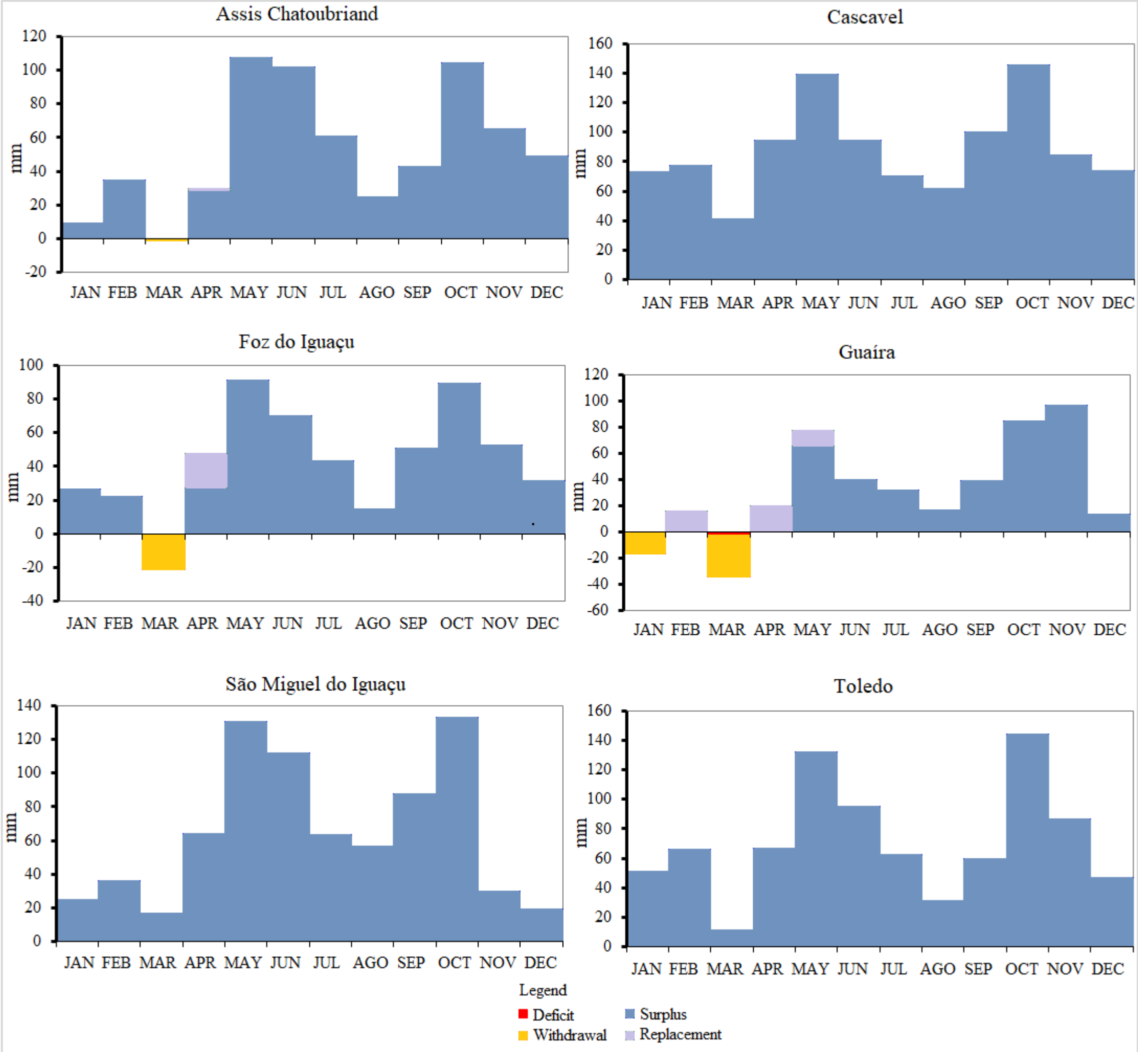


Source: Caldana et al. (2019), adapted and organized by the authors (2020)

However, as noted, even in extremely dry years, such as in 1978 (map 2), the water balance exceeds the acceptable average of water deficit for production in Brazil. The producer should be aware that, in the event of extreme drought or prolonged summer, water deficiency causes the citrus leaves to curl, the most evident symptom in regions with a warmer and drier climate. This symptom subsequently leads to partial closure of the stomata and reduced sweating and photosynthesis, due to dehydration of the canopy of the plants, under conditions of water limitation, which can cause serious losses to production (MACHADO et al., 1999; SILVA et al., 2005; VOLPE et al., 2009).

For the water balance verified in the region (graphics panel 1) as the risk observed was 100 mm accumulated annually, no season presented a risk for the cultivation of the lemon tree. In municipality of Guaíra, that presented significant deficiency, the accumulated figure was 56 mm. The extracts show less favorable water balance in the months from January to April, thanks to high temperatures and an increase in evapotranspiration, and the farmer have to pay attention to the species during this period, and in extreme cases, utilizing appropriated irrigation systems.

Graphics panel 1 - Water balance for papaya tree crop in the hydrographic basin of Paraná River III

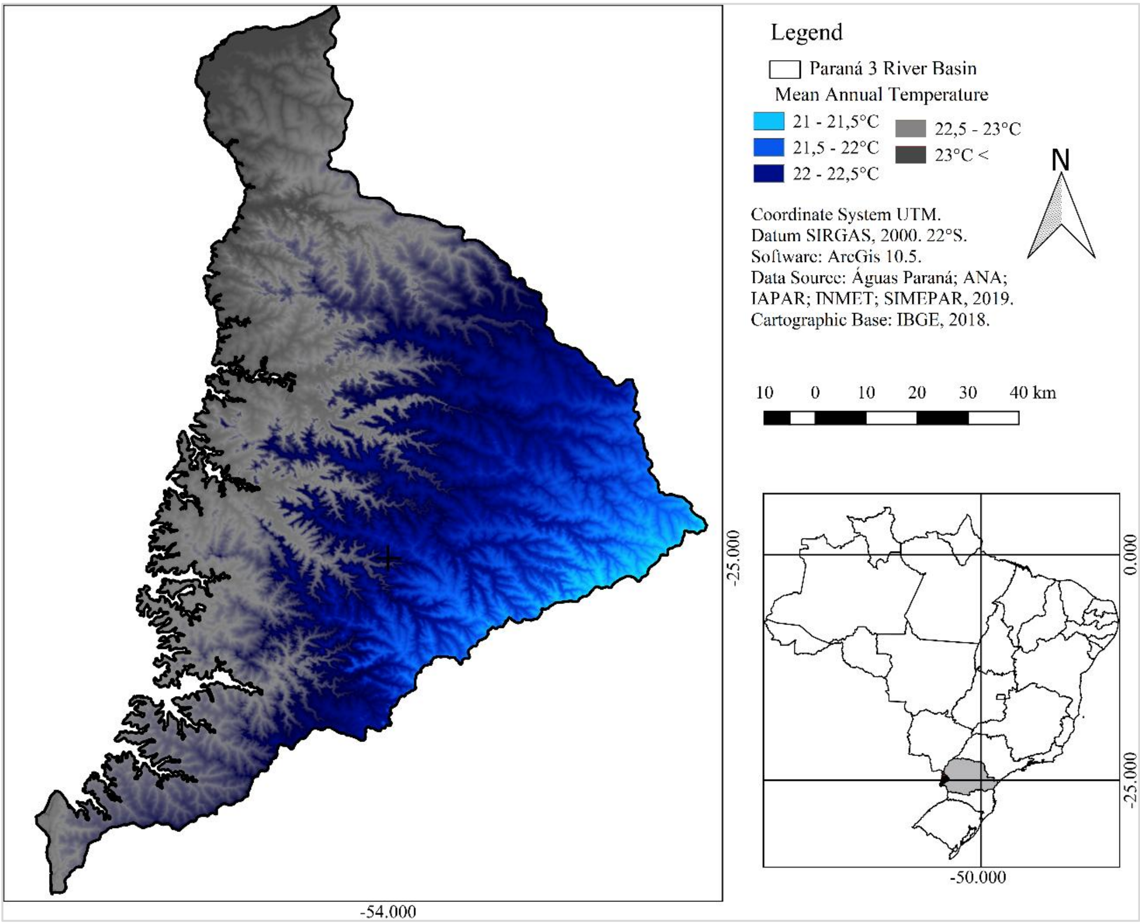


Source: Caldana et al. (2019), adapted and organized by the authors (2020).

The air temperature is the conditioning factor of the internal and external color of the citrus orchards. The color of the peel is associated with low temperatures (< 13°C) during maturation. The averages temperatures between 25° C and 30° C, during the day, and 10° C to 15° C, during the night, are the most suitable for the color, flavor and size of the fruits. According to the literature, we established the average temperature average standard of at least 18°C in the average annual (SANTOS FILHO et al., 2005).

No area in the basin was inapt for these variables (map 3). The highest average temperatures were observed in the region of Guairá, in the far north of the basin, reaching over 23°C, while the lowest do not exceed 20.5°C, in the region of Cascavel.

Map 3 - Annual average temperature in the hydrographic basin of Paraná River III.

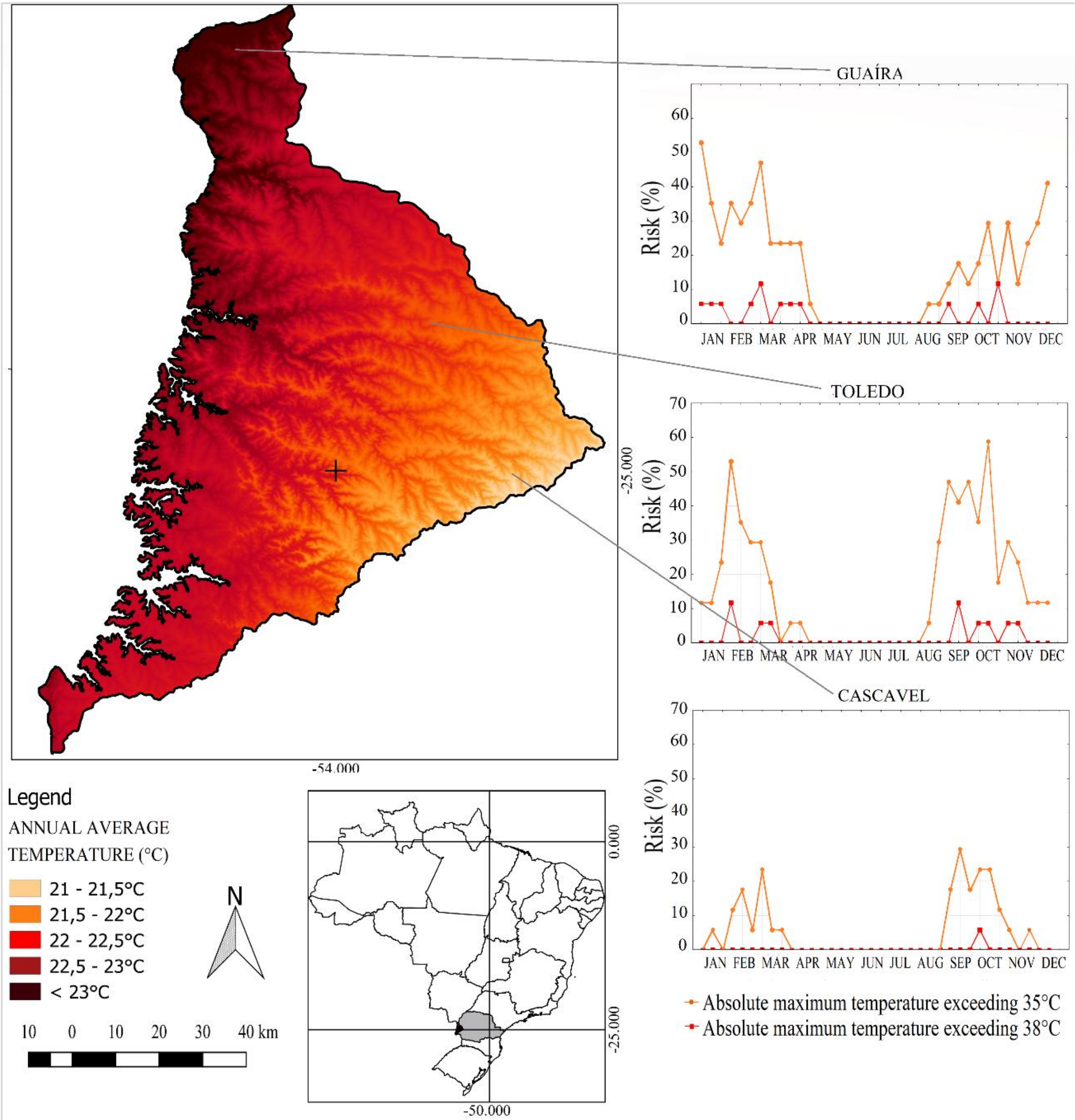


Source: Caldana et al. (2019), adapted and organized by the authors (2020).

The extreme maximum temperatures also interfere with the development of the lemon tree, since, from 32°C, there is a decrease in the growth rate, until it stops completely above 39°C. At temperatures equal to or greater than 36°C, it is observed that the respiration rate is higher than that of photosynthesis. With excessive heating of the leaves, there is destruction of chlorophyll and blockage of water translocation resulting in the disorganization of the nutritional balance of the lemon tree (SANTOS FILHO et al., 2005). The risk for maximum temperatures per decade was estimated with a probability of occurrence higher than 20 %.

On average, the areas with the highest altitudes (map 3), close to municipality of Cascavel, had the lowest average maximum temperatures, around 25°C and the lowest region, the highest average temperatures. The southern, western and northern region of the basin, closer to the Paraná River channel, presented average values above 26°C, along its entire length. The highest average temperatures were observed in the Guairá region, in the far north of the basin, reaching over 27.5°C.

Map 4 - Annual average and maximum temperature and probabilities of extreme temperature occurrences for the lemon, in the basin of Paraná River III.



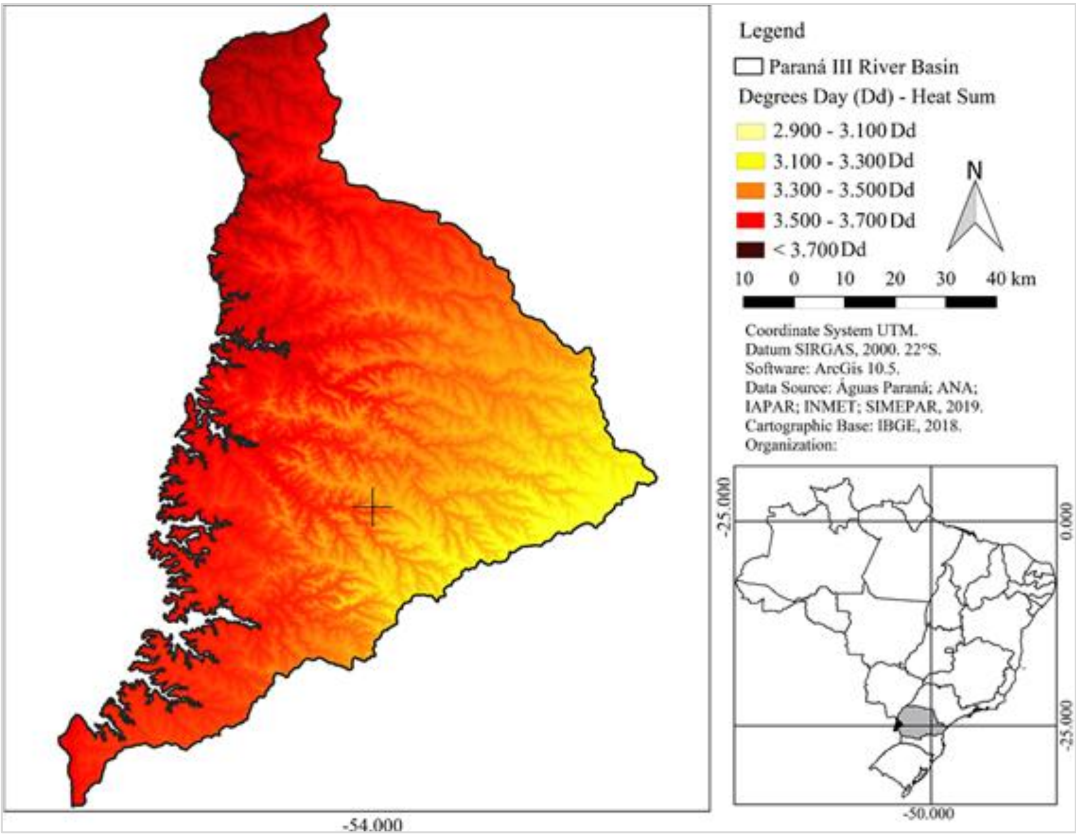
Source: Caldana et al. (2019), adapted and organized by the authors (2020).

Through the graphs, a risk of 38°C was identified in just one decade of Cascavel, with a probability of occurrence of 4 %, even if temperatures above 35°C remain low in this season, not exceeding 30 %. In municipality of Toledo, the risk remains low as well, not exceeding the probability of occurrence of 10 % per 10-year period.

In municipality of Guairá, temperatures above 35°C showed a high frequency in the spring and summer months. The risk of temperatures above 38°C increases in that season, but does not present a risk greater than 20 %. The strip near the Paraná River channel is not inapt for cultivation due to this variable, however, it is restricted, and the farmer in that area can use practices that protect the cultivars when the thermometers reach these temperatures.

The knowledge of the accumulated degree degrees for the implantation of citrus orchards is important to guide the producer in the evaluation of vegetative development and harvest time in a new climatic region (SANTOS FILHO et al., 2005). The risk assessed for the annual accumulation was 2,000°C per year, and as identified the lowest annual values were 2,900 degrees day accumulated in the region of Cascavel (map 5), thus, presenting no restriction for production, due to this variable analyzed. The highest values reach almost double that required by the species, on the edges of the Paraná River, in the far north of the region, reaching over 3,700°C per year on average.

Map 5 - Annual average of thermal sum distribution in degree days for the lemon in the basin of Paraná River III

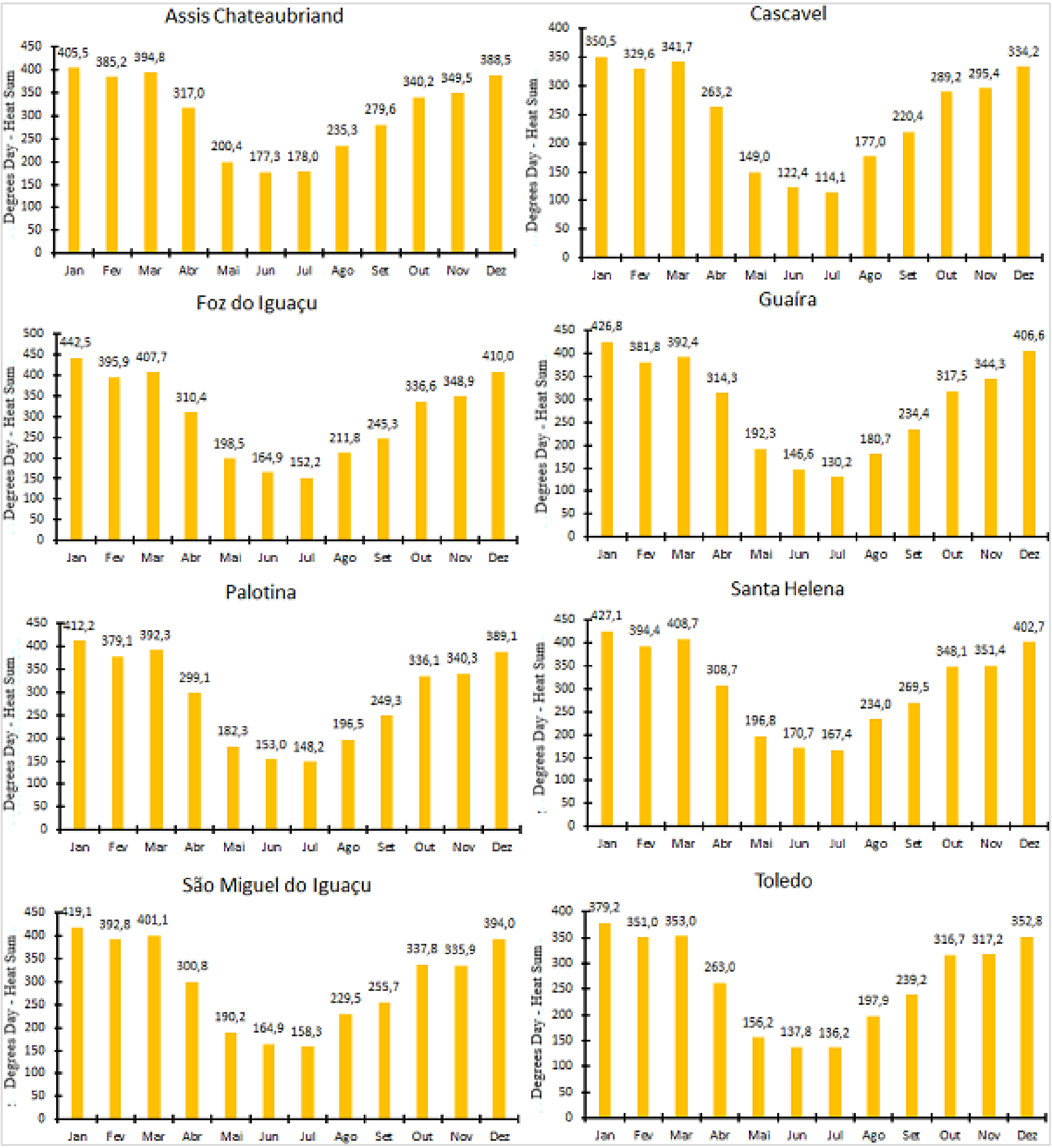


Source: Caldana et al. (2019), adapted and organized by the authors (2020).

To recommend the planting season, attention should be paid to the fact that citrus orchards are more sensitive to water deficit during budding, flower buds emission, fruiting and the beginning of fruit development until it reaches 2.5 cm in diameter, when the demand for water is considerable (SANTOS FILHO et al., 2005). It is recommended the cultivation mainly of small change, should be carried out, in the spring, in October, with low risk of water deficit throughout the region.

Considering the accumulation of 2.000 degrees day for the annual cycle of the species, it was identified that from October, the day degrees continue increasing until the month of March, being able to complete the cycle of the species, in good part before the winter (Graphics panel 2).

Graphics panel 2 - Monthly average of thermal sum in degree days for the lemon tree.



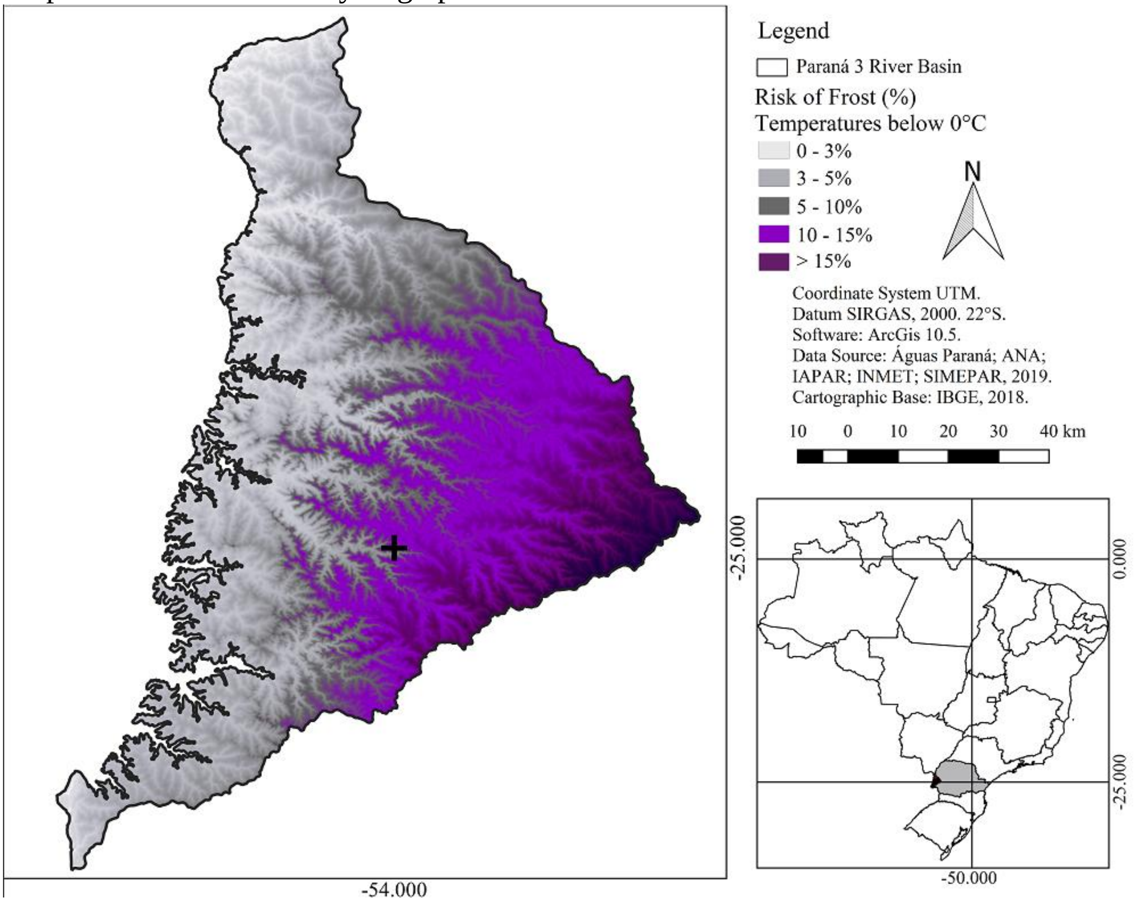
Source: INMET (2019), adapted and organized by the authors (2020).

In municipality of Assis Chateaubriand, for example, considering the time from

October to March, the accumulation of degrees day reaches, on average, the accumulation of 2,200. While in the colder region of Cascavel, the cycle would only be completed in April.

Citrus, in general, has good resistance to cold winds and frost, and those of low intensity do not cause severe damage (SANTOS FILHO et al., 2005). The risk of severe frost (below 0ºC) in the region (map 5) presented a distribution similar to the average temperature, with a greater risk in the eastern portion, close to the municipalities of Cascavel and Santa Tereza do Oeste, in the highest portion of the basin, and in some valley bottoms of the central portion. While the central portion of the basin presents a risk of 5 to 10 % while in the lower portions, close to the valley of the Paraná River III, mainly on the North-South axis from Guaíra / Terra Roxa to Foz do Iguaçu / Santa Terezinha de Itaipu the risk falls to 0 %.

Map 6 - Frost risk in the hydrographic basin of Paraná River III

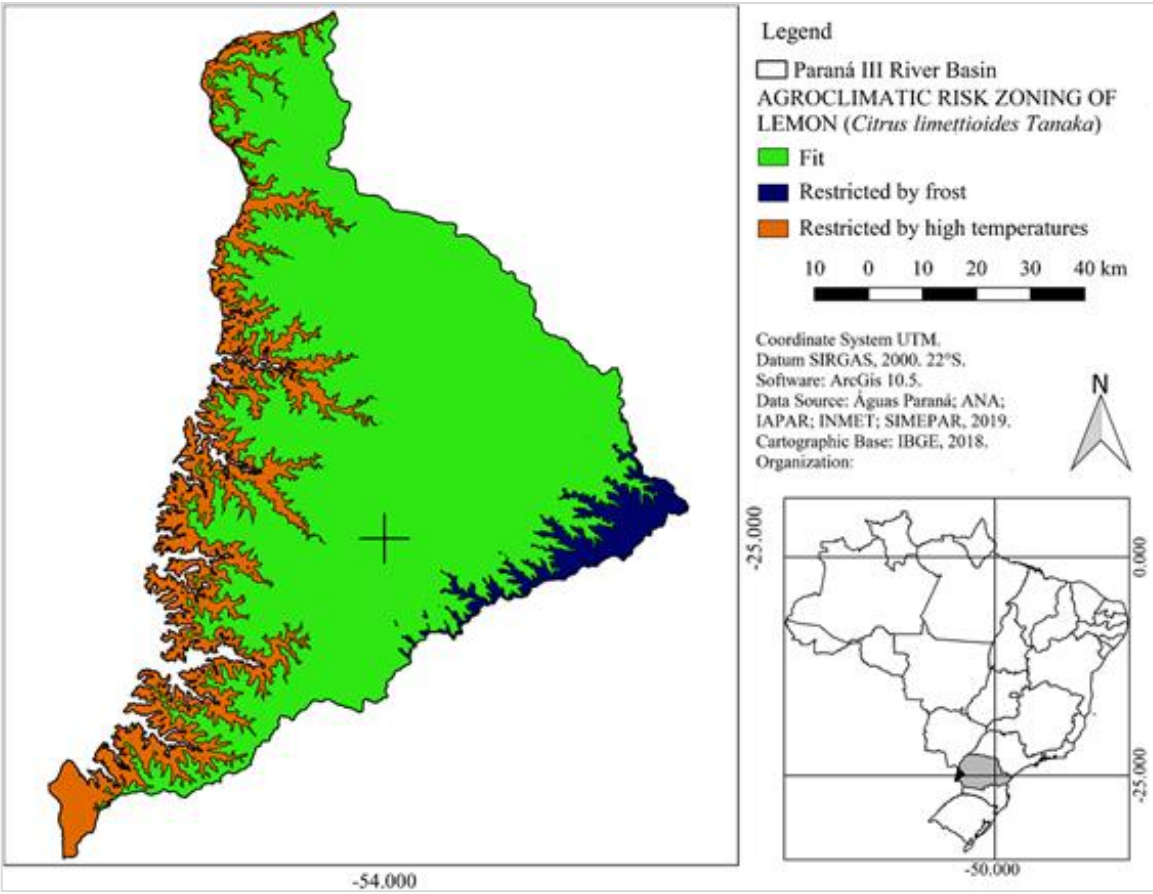


Source: Caldana et al. (2019), adapted and organized by the authors (2020).

The final climatic zoning map (map 7) was defined admitting restrictions of maximum temperature and severe frost, the former interfering in the complete development of the species and fruit quality, and the latter being able to lead to senescence of the species (COELHO et al., 1998).

Thus, the highest region in the basin (map 1) and, consequently, the coldest (Figure 03) exhibited restriction for cultivation of lemon tree. The entire central and eastern region of the basin was classified as inapt for cultivation. A small area located in the intermediate bands was classified as restricted, where the risk of frost is 10 %. In this case, the farmer must be careful of occurrences of frost.

Map 7 - Agroclimatic Risk Zoning of lemon (*Citrus latifolia*) in the basin of Paraná River III.



Source: Caldana et al. (2019), adapted and organized by the authors (2020).

Even in apt regions, the risk of frost remains. The farmer should avoid valley bottoms, at the end of the slopes, and give preference to cultivation in areas that are not considerable sloping, to facilitate the displacement of cold air. Preferably, the top of the spike and half slope should be used, mainly on the faces facing north, since, as highlighted, the cold front has preferential displacement in the south / southwest direction, northeast direction (CALDANA et al., 2018; CALDANA et al., 2019; CALDANA; MARTELÓCIO, 2019).

WREGE et al., (2005) zoned citrus cultivars for Rio Grande do Sul State, Brazil. They indicated that frost tolerance was studied at 2°C, as it has a wider range of species, in addition to ascertaining the thermal sum of the degrees day and precipitation. Only a small strip in the northwest of the state proved to be apt, other areas should use rootstocks for protection from extreme cold, or even, they had insufficient thermal sum. The latitudinal factor interferes with citrus production, since these adversities were not present in the basin of Paraná River III.

It should be noted that zoning does not eliminate the risks, but only presents more favorable conditions for the development of lemon tree orchards. As agriculture is a risky activity, all activities are susceptible to climate extreme events, which may or may not cause harm for the farmer. In the context of sustainable agriculture and climate change, agroclimatic zoning provides greater security in decision-making, agricultural planning, in the hydrographic basin of Paraná State III.

Conclusions

- The hydrographic basin of Paraná River III has a significant area with aptitude for cultivation and considerable perspectives through meteorological variables for the development of the lemon tree.
- Precipitation and water balance presented sufficient values in all scenarios studied for cultivation of lemon.
- No area was inapt for more than one meteorological variable. Only two bands were restricted, in the west by high temperatures and in the east by severe frosts.
- Agricultural management techniques can be taken to avoid the risk of severe frost and to mitigate the impacts of extreme temperatures and to avoid areas with a higher incidence of the phenomenon to ensure greater possibility of success in the cultivation of lemon in the basin of Paraná River III.

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