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AGROCLIMATIC RISK ZONING OF PINEAPPLE (*Ananas comosus*) IN THE HYDROGRAPHIC BASIN OF PARANÁ RIVER 3, BRAZIL

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ABSTRACT: Fruticulture is a prominent segment of Brazilian agriculture. It presents a continuous evolution of production, attending to the growing internal and external demand, besides being one of the main activities of family agriculture. Despite of recent technological and scientific advances, climate is still the most important variable in agricultural productivity. Studies that show the climatic variability and the impact on the physiological development of plant species are fundamental for the planning and agricultural calendar, aiming the conservation of resources and a sustainable management of the production. In this context, one of the first information to be considered when starting a crop is agro-climatic zoning, since it provides climate-related risk information and helps in decision-making and agricultural planning. Thus, the objective of this work was to carry out agroclimatic risk zoning for the Pineapple (Ananas comosus) in the Paraná River basin 3, Paraná state, Brazil. For this, meteorological data of 43 stations with series from 1976 to 2018 we used. The climatic risk analysis was based on the requirements of the species of precipitation, average annual temperature and in the coldest month, risk of frost and insolation. Statistical and geoprocessing techniques were applied to ensure full regional coverage of information and to contribute to decision-making. Favorable climatic conditions were identified for all climatic variables in the western portion of the river basin, while in the eastern portion the risk of frost restricted the aptitude.

KEYWORDS: Climate aptitude; Climate Variability; Agricultural Planning

ZONEAMENTO DE RISCO AGROCLIMÁTICO DO ABACAXIZEIRO (ANANAS COMOSUS) NA BACIA HIDROGRÁFICA DO RIO PARANÁ 3

RESUMO: A fruticultura é um segmento de destaque da agricultura brasileira. Apresenta evolução contínua de produção, atendendo a crescente demanda interna e externa, além de ser uma das principais atividades da agricultura familiar. Apesar dos recentes avanços tecnológicos e científicos, o clima é ainda a variável mais importante na produtividade agrícola. Estudos que evidenciem a variabilidade climática e o impacto no desenvolvimento fisiológico das espécies são fundamentais para o planejamento e calendário agrícola, visando a conservação de recursos e um manejo sustentável da produção. Nesse contexto, uma das primeiras informações a serem consideradas ao iniciar o cultivo de determinada cultura é o zoneamento agroclimático, visto que este fornece informações de risco relacionadas ao clima e auxiliam na tomada de decisão e planejamento agrícola. Dessa forma, o objetivo desse trabalho foi realizar o zoneamento de risco agroclimático para o Abacaxizeiro (Ananas comosus) na bacia do Rio Paraná 3, estado do Paraná. Para isso foram utilizados dados meteorológicos de 43 estações com recorte temporal de 1976-2018. A análise do risco climático foi pautada nas exigências climáticas da espécie, sendo estas, precipitação, temperatura média anual e do mês mais frio, risco de geada e insolação. Foram aplicadas técnicas estatísticas e de geoprocessamento para garantir uma plena cobertura regional de informações e contribuir para a tomada de decisão na agricultura da região. Identificou-se aptidão climática para todas as variáveis climáticas analisadas para o plantio na porção oeste da bacia hidrográfica, enquanto na porção leste o risco de geada restringiu a aptidão.

PALAVRAS-CHAVE: Aptidão climática; Variabilidade Climática; Planejamento Agrícola

1. INTRODUCTION

Despite of the agricultural technological advances, the climate is still the most important variable in crops production. The most significant natural variables in the production process come from the climate (AYOADE, 1986). Climate and the meteorological conditions are responsible for 80 % of the variability of crop production. Rainfall are the most important element and the most significant meteorological attribute in tropical and subtropical areas, where its variable distribution and occurrences of extreme periods between droughts and precipitations influence human activities, such as agriculture (CARAMORI et al., 2008; AGOVINO et al., 2019; GELCER et al., 2018; MICHLER et al., 2018).

Fruticulture is an activity that has a major contribution to the national economic development (FACHINELLO et al., 2011). Fruit species contribute to conservationist development when compared to soybean crops in succession conventional system, employed in the basin of Paraná river 3 (CAMBUI et al., 2017; DEY; CHAUDHURI, 2013; OLIVEIRA et al., 2018; AGOVINO et al., 2019).

The international scientific community has been demonstrating in several works the importance and impacts of meteorological variables for the different crops productions. This information suggest the importance of agricultural zoning, once with to plan all the cycle crops and avoid/minimize loses (MANCILLAS et al., 2015; CARVALHO et al., 2017; DAMASCENA et al., 2017; MACHADO et al., 2017; PANDOLFO et al., 2017; PASSOS et al., 2017; DOS REIS et al., 2017; ALBUQUERQUE et al., 2018; CONCEIÇÃO et al., 2018; GELCER et al., 2018; DE MATOS et al., 2018; JIANG et al., 2018; MEDEIROS et al., 2018; SANTI et al., 2018; DE SOUSA e DE OLIVEIRA, 2018; DE SOUZA et al., 2018; TAYT'SOHN et al., 2018; EZENNE et al., 2019; HASSANI et al., 2019; NOVOA et al., 2019; OGILVIE et al., 2019). Thus, agroclimatic risk zoning has a key relevance to reduce the agricultural risks of agricultural practice, assist in management and recommend planting times (RICCE et al., 2014; CALDANA et al., 2019b).

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The pineapple (*Ananas comosus*) is a tropical and perennial plant of the Bromeliad family. The origin center is, possibly, South America, more specific in Brazil (CRESTANI et al., 2010). The natural flowering of this species occurs in winter. Because the pineapple is a short day, the apical bud is induced to produce an inflorescence instead of emitting leaves. The duration of the natural cycle might vary from 12 to 36 months, once climatic conditions depends on the planting time, the type and weight of the seedlings used, and also the practices adopted (NASCENTE et al., 2005; RICCE et al., 2014).

Brazil is one of the three largest pineapple producers in the world, being the largest producer in South America. The main producers Brazilian states are Minas Gerais, Pará and Paraíba (IBGE, 2018), with potential for expansion of the productive area for the entire national territory. The Paraná state, south of Brazil, is located in a climate transition zone, presenting a great diversity of climates and soils, which favors the cultivation of a high species diversity, including pineapple. The precisely information from the environmental conditions prevailing in a region, the more apt it will be to select the most suitable crops, the best planting and sowing times, minimizing the crop risks and increasingly conservationist agriculture, in the context of climate change.

The purpose of this work was to perform agroclimatic risk zoning for pineapple in the basin of Paraná river 3, a drainage area on the left bank of the Itaipú reservoir, between the rivers Iguaçu and Piquiri.

2. MATERIAL AND METHODS

2.1 AREA OF STUDY

The basin of Paraná river 3 (Figure 01) has 28 municipalities in the western region of Paraná state, south of Brazil. In this area are concentrated the metropolitan regions of Cascavel (324,476 inhabitants) and Toledo (138,572 inhabitants) and has a large part are intended for agriculture, especially for soybean crops (IBGE, 2019). Authors whom identify and predict droughts periods, heavy rain, windstorms, hail and frost contribute to better planning, crop management and decision making, to obtain relevant results and less environmental damage with this economic activity (BERLATO et al., 2005; ANDERSON et al., 2017; MUSTAFA et al., 2018; PAILLER; TSANEVA, 2018; SOMBOONSUKE et al., 2018).

The region has a sloping relief (Figure 02) of the West-East feeling, ranging from 180 to 800 m, which provides climate variability and diversity in species that could be produced in the region. The “Cfa” climate classification (subtropical, without dry season and hot summer) predominates much of the region, covering the entire west, south, north and center of the basin. The “Cfb” climate classification (subtropical, without dry season and summer with mild temperatures) predominates in the eastern area of the region, with altitudes above 700 m, according to the Köppen climate classification (NITSCHE et al., 2019).

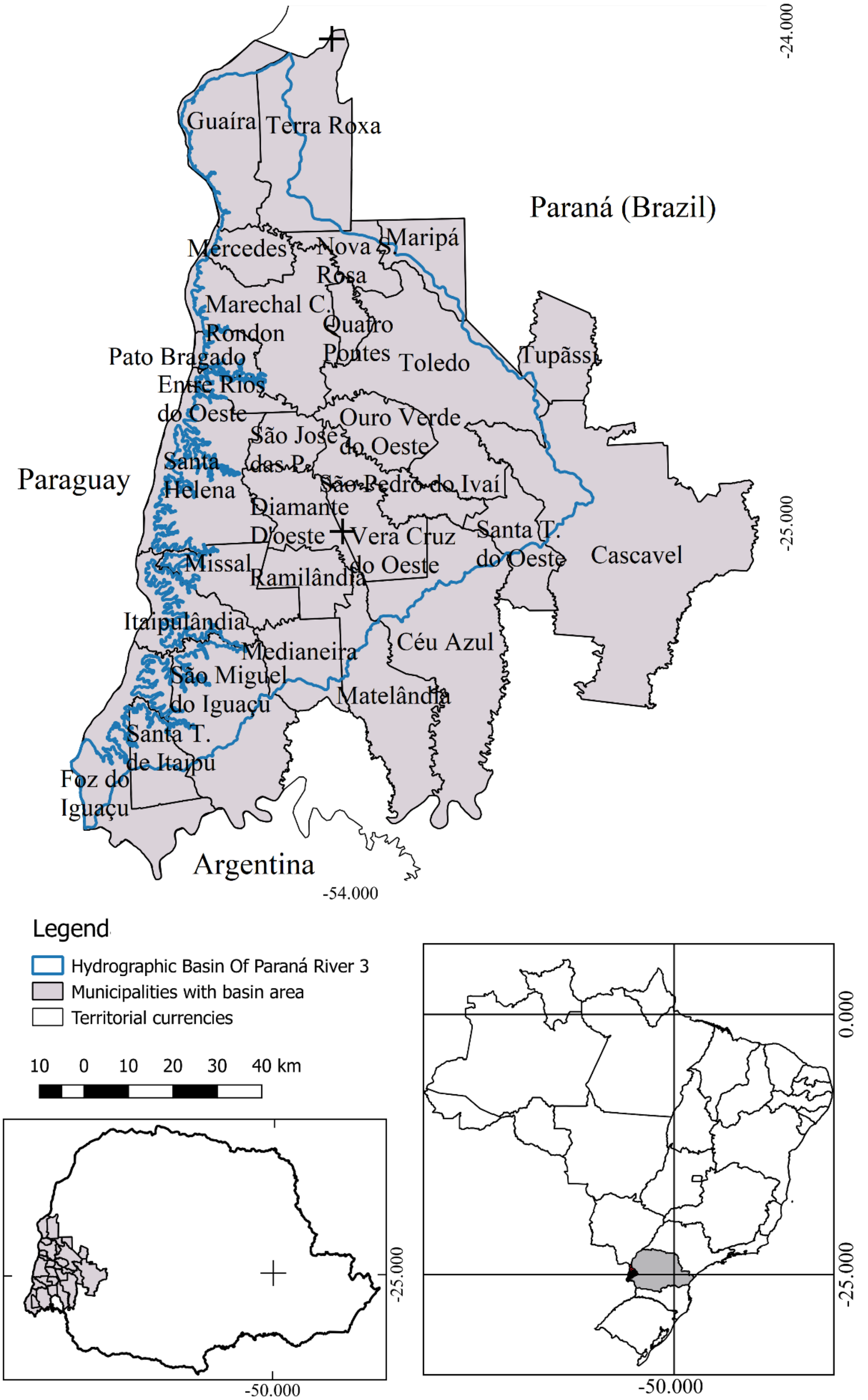

Figure 01 - Municipalities, with total or partial area, in the basin of Paraná river 3. Organized and adapted by the authors (2019).

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2.2 CLIMATE VARIABILITY

For the purpose of this study, we selected the specie hydro climatic requirements and meteorological data of annual, seasonal, monthly and daily time series from 1976 to 2018. To analyze climate variability and perform zoning of agroclimate risk, data from meteorological stations distributed around the basin were surveyed. This database comprises 3 weather stations from IAPAR – Instituto Agronomico do Paraná (1976-2018);6 weather stations from SIMEPAR – Sistema Meteorológico do Paraná (2000-2018) and 27 rain stations from Águas Paraná (1976-2018), according to the Figure 2.

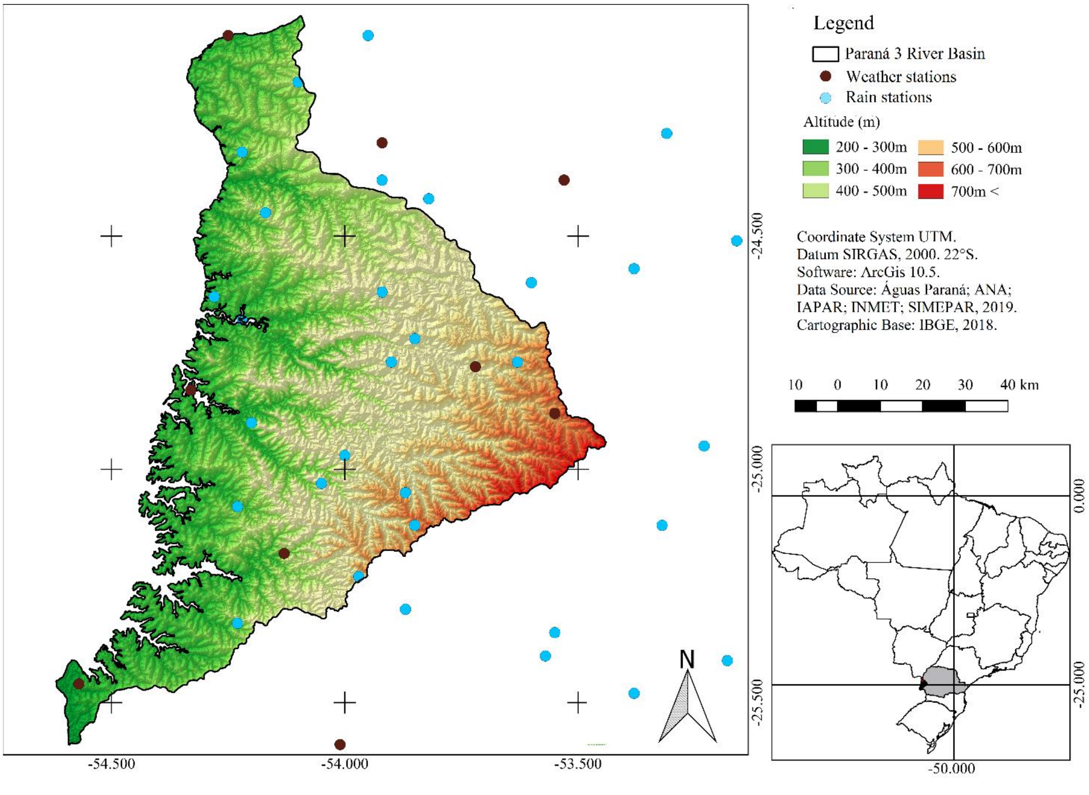

Figure 02 - Hypsometry and meteorological stations location, in the basin. Adapted and organized by the authors (2019).

For precipitation only data from pluviometric stations we used, because only these stations have long periods series (from 1976 to 2018). Spatialization of these data was performed through interpolation, which is an effective method for spatial visualization of climate data. This was done by isohyets and / or spatially filling the values through adjusted regression statistics and using the *Inverse Distance Weighted* (IDW) spatial interpolation algorithm (MUELER, 2004; LEM et al., 2013). The maps were created using Qgis *software*.

The chose of IDW for precipitation and insolation data were base in verification of data and for the quantity of weather stations available in the area of the study, once the estimator quality can be evaluated, across of crossed tab, this is, comparation between the real data and its respective estimative (XAVIER et al., 2010).

The historical series of insolation observed in the meteorological stations we used to calculate the average annual insolation for the photoperiod analysis.

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Annual average totals were interpolated by IDW for the entire hydrographic basin area.

Point data of the pluviometric stations were entered into the QGIS *oftware* and transformed into a raster file, using 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. Subsequently, we inserted isohyets and their values for a better visualization of areas with similar precipitation and / or insolation and to regionalize them.

The *Shuttle Radar Topography Mission* - SRTM base, at 30 m resolution, was used together positioning to correct the influence of the topography on temperature. This method is needed to spatialize and regionalize data to areas that do not have temperature data with greater accuracy.

For the spatialization of the average temperature and frost data the values measured in the meteorological stations were adjusted to multiple linear regression equations, linking the meteorological station values with the geographic factors altitude (alt), latitude (lat) and longitude (long). The applied equation is given by: $y = a + b.lat + c.long + d.alt$, where a, b, c, d are regression coefficients. This formula was applied in Arcgis geoprocessing *software* over the SRTM file, making it possible to generate maps.

We created three bases for apply the regression analysis, one from SRTM for altitude and add latitude and longitude, considering a resolution of scale of 30 m. Using the tool "Raster Calculator", the data were spatialization and established a value for each pixel for each metrological variable analysed.

The method used for the probability of frost was based on the historical minimum temperature series recorded within the meteorological shelter. Were determined the probabilities of values equal to or lower than 1.0 °C and then also adjusted to the equation $y = a + x.lat + y.long + z.alt$ (RICCE et al., 2014).

2.3 AGROCLIMATIC RISK ZONING

The risk factors selected for agroclimate risk zoning were:

a) *Annual precipitation*: Were selected monthly and annual data series from 27 meteorological stations. The obtained results were interpolated in a geographic information system for the maps generation with the regionalization of the data through the IDW. It was considered: High Risk: annual precipitation below 1,000 mm and low risk above 1,500 mm, and among these values it was considered as restricted by the precipitation’s variable (CUNHA et al., 2005; RICCE et al., 2014).

b) *Annual average sunshine* (Ia): We used data from the historical series of five sunshine insolation stations from IAPAR, measured by means of the heliograph to estimate the annual mean sunshine. Annual average totals were interpolated by IDW around the Hydrographic basin. Aptitude was determined by the following categories: Minimum Sunstroke: High Risk: Ia between 1,200 and 1,500 hours; Medium Risk: Ia between 1,500 and 2,500 hours and Great Sunstroke or low risk: Ia between 2,500 and 5,500 hours (CUNHA et al., 2005; RICCE et al., 2014).

c) *Average annual temperature* (Ta): Were used meteorological data from historical series of average temperatures of nine weather stations, to observed inside meteorological shelters and estimate the average annual temperature.

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Using the Ta value, regression was applied as a function of latitude, longitude and altitude for the whole Hydrographic basin. The following risk classes defined for Ta were: High Risk: below 19°C; Medium Risk: between 19°C and 22°C and Low Risk: greater than 22°C (CUNHA et al., 2005; RICCE et al., 2014).

d) *Average temperature of the coldest month* (Tmf): We used meteorological data from the historical series of nine weather stations of daily average temperatures observed inside meteorological shelters to calculate the average July temperature. Using these values, a regression equation of the mean temperature of the coldest month was adjusted as a function of latitude, longitude and altitude for the whole Hydrographic basin. The spatialization were realized using the regression formula, as already mentioned. Were defined the risk classes: High Risk: Tmf below 15.5°C and Low Risk: Tmf above 15.5°C (CUNHA et al., 2005; RICCE et al., 2014).

e) *Frost risk*: We used meteorological data of minimum temperature of the historical series from 13 stations, considering occurrences of values equal to or less than 1 ºC, observed inside the meteorological shelter to calculate the frost risks. Were calculated the probabilities of annual occurrence and correlated with altitude and latitude, obtaining a regression equation for the risk of frost. Using adjusted regressions, values greater than 40 % was estimated as high risk (CUNHA et al., 2005; RICCE et al., 2014).

For the thematic maps creation and the final zoning map in ArcGIS *softwar*e, first the numerical values of the weather and rain stations were transformed into points according to the geographical coordinates of the stations. After we used the edaphoclimatic requirements of the pineapple specie to make the data spatialization. A delimitation of the representative ranges of pineapple climate requirements were made. The station values are 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 highlighted. If the combination for a point is filled only with values "1" the region is classified as apt. If it has a value of "2" it will be restricted by a given variable. If two or more "2" values are assigned, the location is classified as unapt.

The standardization of the pixels by classifications is performed by dissolving the vector classes. In this way, the agroclimatic zoning classes are grouped, thus creating a regionalization of suitability for the species. The final map of the agroclimatic zoning of each crop will provide an estimate of the representative area of each risk class, ensuring its suitability or not for the site.

3. RESULTS AND DISCUSSION

Rainfall presented no risk for pineapple crop in the basin of Paraná River 3 (Figure 03). As noted, annual rainfall less than 1,000 mm would pose a risk, but in the region, the lowest average annual rainfall was 1,550 mm in the basin far north, in Guaíra region, while the highest average values are found in the Cascavel region and part of the southern basin with precipitation from 2,050 to 2,125 mm.

Rainfall in the Hydrographic basin area has three main formations that interfere with its regional distribution. First, the cold fronts, which are characterized by the encounter of the Polar Air Mass with the continental hot air mass; with the advent of humidity they generate strong atmospheric instability, which may lead to the formation of cumulonimbus and lead to the formation of severe storms, which may be accompanied by strong gusts of wind and hail, or even light to moderate rainfall, lasting days if this becomes stationary (BEREZUK; SANT'ANNA NETO, 2006; BEREZUK, 2017; PUNGE et al., 2017; CALDANA et al., 2018; CALDANA et al., 2019a).

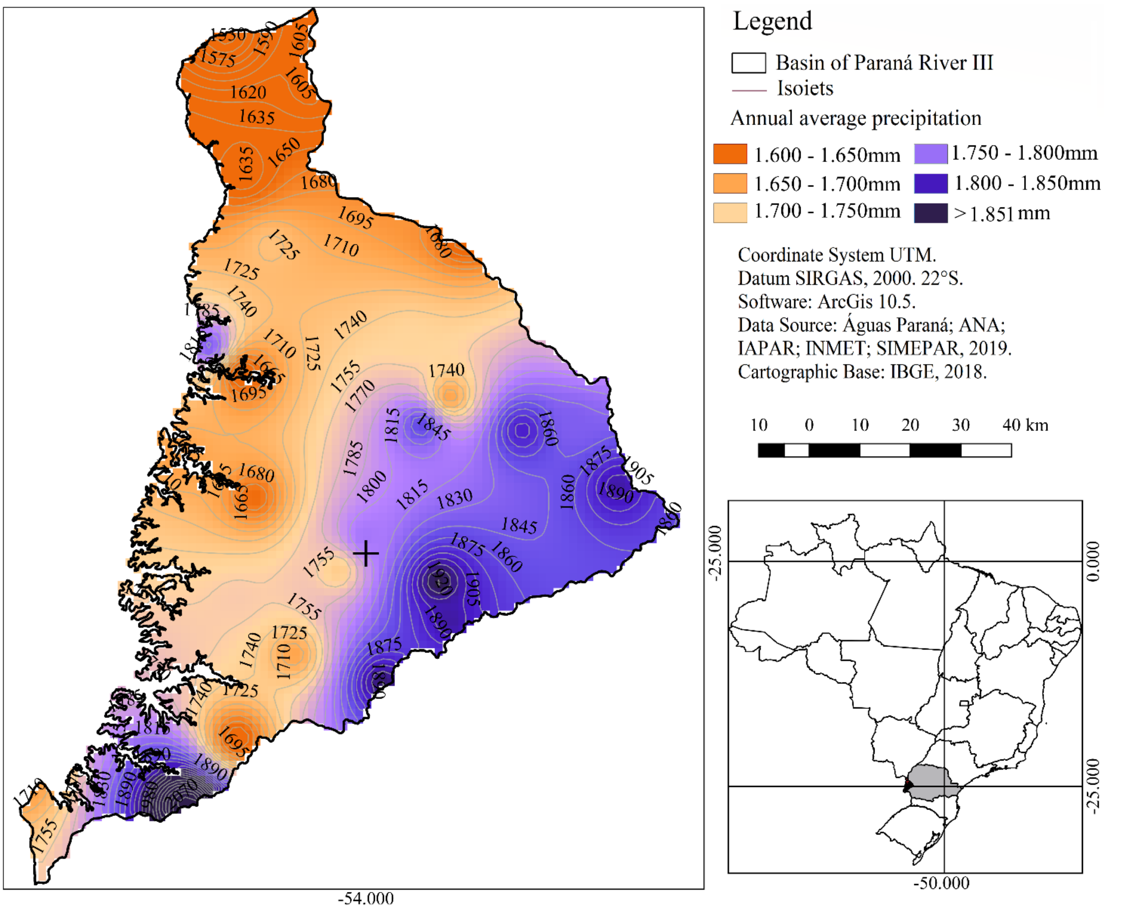

Figure 03 - Annual average rainfall in the basin of Paraná river 3. Adapted and organized by the authors (2019).

The Polar Air Mass has a trajectory favoured by the Paraná River and later Iguaçu River gutters, having a great impact on the local rainfall, mainly in the southern portion near the meeting of the two rivers in Foz do Iguaçu (MINUZZI e CARAMORI, 2011; CALDANA et al., 2018). The cold fronts are identified in satellite images by a large line of instability that advances in the Paraná state in the Southwest - Northeast direction (BEREZUK; SANT'ANNA NETO, 2006; BEREZUK, 2017; CALDANA et al., 2018; CALDANA et al., 2019b). As mentioned, the topography in the Southern area of the region has rapid rise from 200 to 800 m. This shock with the topography can causes rain to the upper area, near the municipality of Cascavel.

The other two main means of precipitation formation in the region are the Convective Systems and the Mesoscale Convective Complexes which operate throughout the year, but predominantly in the spring and summer seasons and are identified in satellite imagery by their roughly circular shape and wide storm coverage. They are defined as a cluster of cumulonimbus covered by a dense cirrus layer, as well as convective cloud systems with rapid vertical and horizontal growth over a period of 6 to 12 hours. Depending on their intensity, they can create various cores with storm formation and hail incidence. Their displacement through Paraná state is usually west-east from Paraguay (DAFIS et al., 2017; PUNGE et al., 2017; TREFAULT et al., 2018; CALDANA et al., 2018; CALDANA et al., 2019b). It is noteworthy that the region's elevations also rise in the west-east direction, which may contribute to the friction of the system with the relief.

Convective systems differ from MCC in their smaller spatial scope, forming by the conduction heat transfer process that occurs in intense vertical movements, thus leading to the rapid condensation process and the formation of Cumulonimbus. In both systems, friction with the relief can also contribute to the rise of warmer and wetter air and can form condensation and rain cores. This explains the highest average rainfall in the highest parts of the region (DAFIS et al., 2017; TREFAULT et al., 2018; CALDANA et al., 2019b). With the development and preferential trajectory in the same direction as the CCM, the relief of the region may also contribute to the higher rainfall heights being located in the highest area of the region.

The risk is also low by analyzing the variability and distribution of annual rainfall in the region (Figure 04). In the southern area of the region, located in Foz do Iguaçu, the lowest rainfall recorded was 1,105 mm in 1979, while the highest was 2,589 mm in 1983, none of which presented a risk for pineapple.

In the station of the northern area of the region of Terra Roxa, there were three precipitation values less than 1,200 mm, but none with a risk of precipitation less than 1.000 mm. While in the eastern area of the region of Cascavel, the highest rainfall of the series with 3.051mm was observed in 1983 and no risk to production, as well as in the Vera Cruz do Oeste and Missal stations, located in the Center and West regions, respectively.

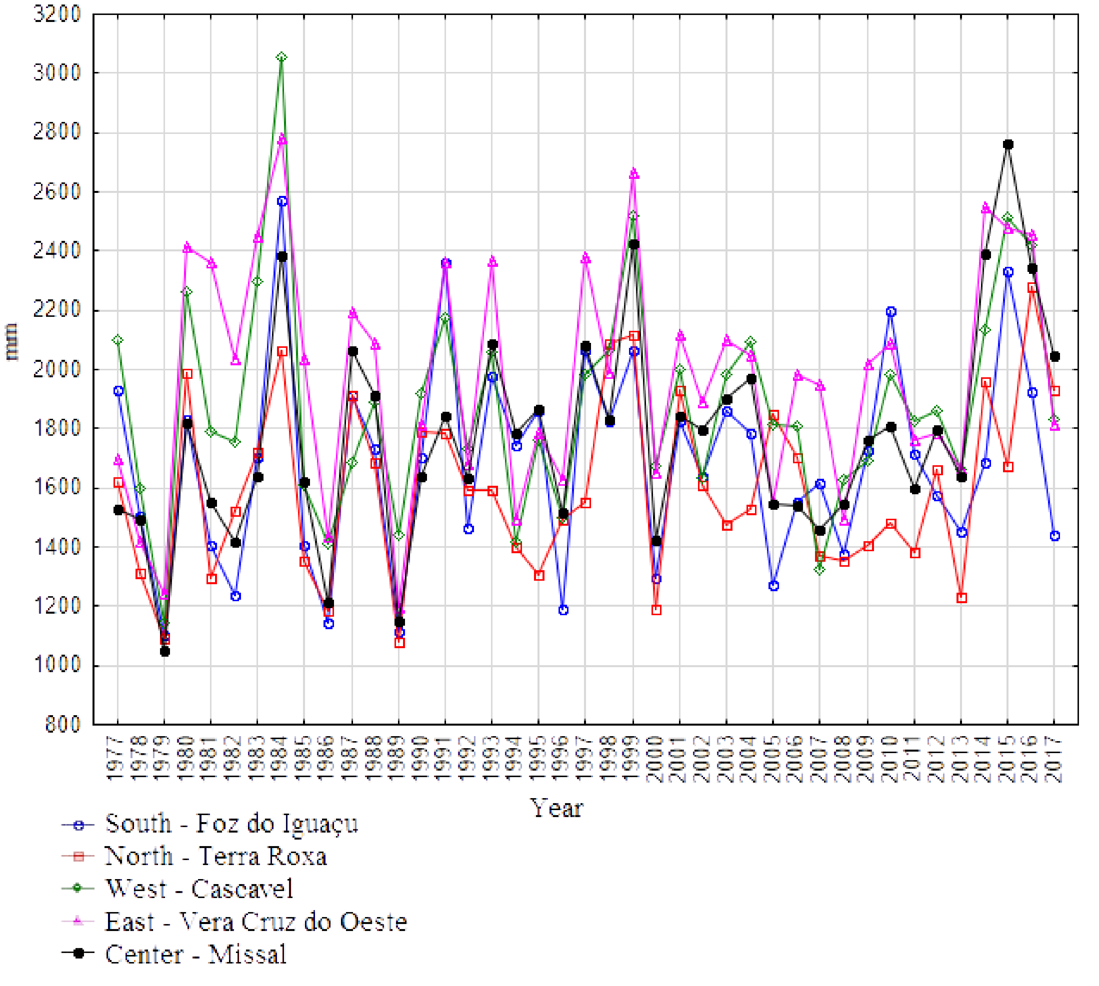

Figure 04 - Annual Rainfall Variability in the basin of Paraná River 3. Adapted and organized by the authors (2019).

Pineapple has a relatively long life cycle (about 18 months) so the crop will be exposed to various risks from rainfall distribution. As much as the region has sufficient rainfall, strategies have to be adopted when atypical situations occur. Excessive rainfall, depending on the phenological phase, can compromise the morphology and physiology of pineapple, such as incidence of diseases due to excess moisture, or the lack, which can compromise fruit formation and vegetative development, stages considered critical, even pineapple. having relatively low water requirements compared to annual crops (MONTEIRO et al., 2009).

Solar radiation is the primary source of energy for natural processes acting on the vegetative growth, yield and quality of pineapple. In the basin of Paraná River 3, a limiting factor for the full development of pineapple has been demonstrated (Figure 05), but with little difference to the time limit required by the species. As highlighted, the limit is 2,500 hours, this value is not only observed in the region of Cascavel, in the eastern area of the region, which presented average values of 2,450 hours of sunshine per year.

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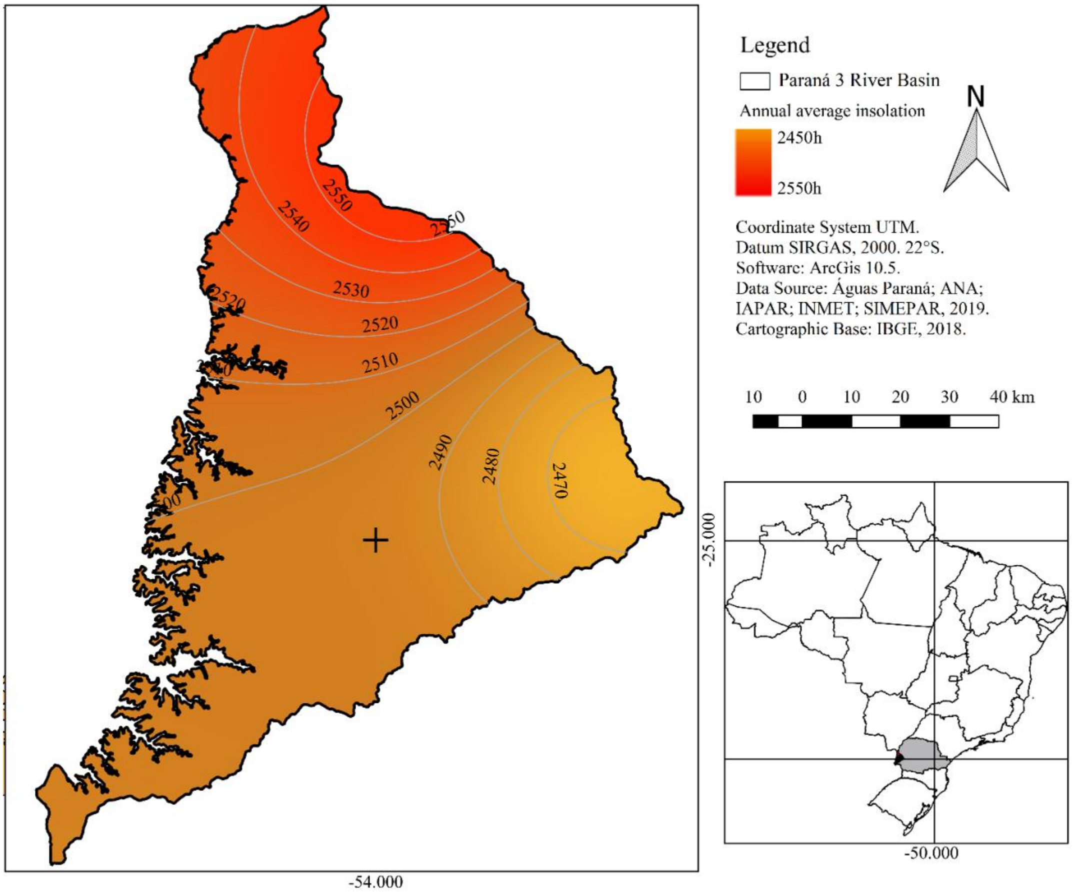

Figure 05 - Annual Average Insolation in the basin of Paraná River 3. adapted and organized by the authors (2019).

The northernmost area of the region had the highest amount of sunshine, with an average of 2,550 hours of sunshine per year. The latitudinal factor proves to be determinant in the insolation of the region, varying from 50 to 100 hours between the north and south portions. The only area of the region that does not respond to the latitude factor is to the east, which may be the discrepancy answered by rain, where in this region the average values are up to 400 mm more than in the northern area of the region.

Temperature is the most limiting factor for crop expansion and affects the plant cycle. Low temperatures and the risk of frost are the main parameters that limit pineapple cultivation in the basin of Paraná River 3 (PY et al., 1987).

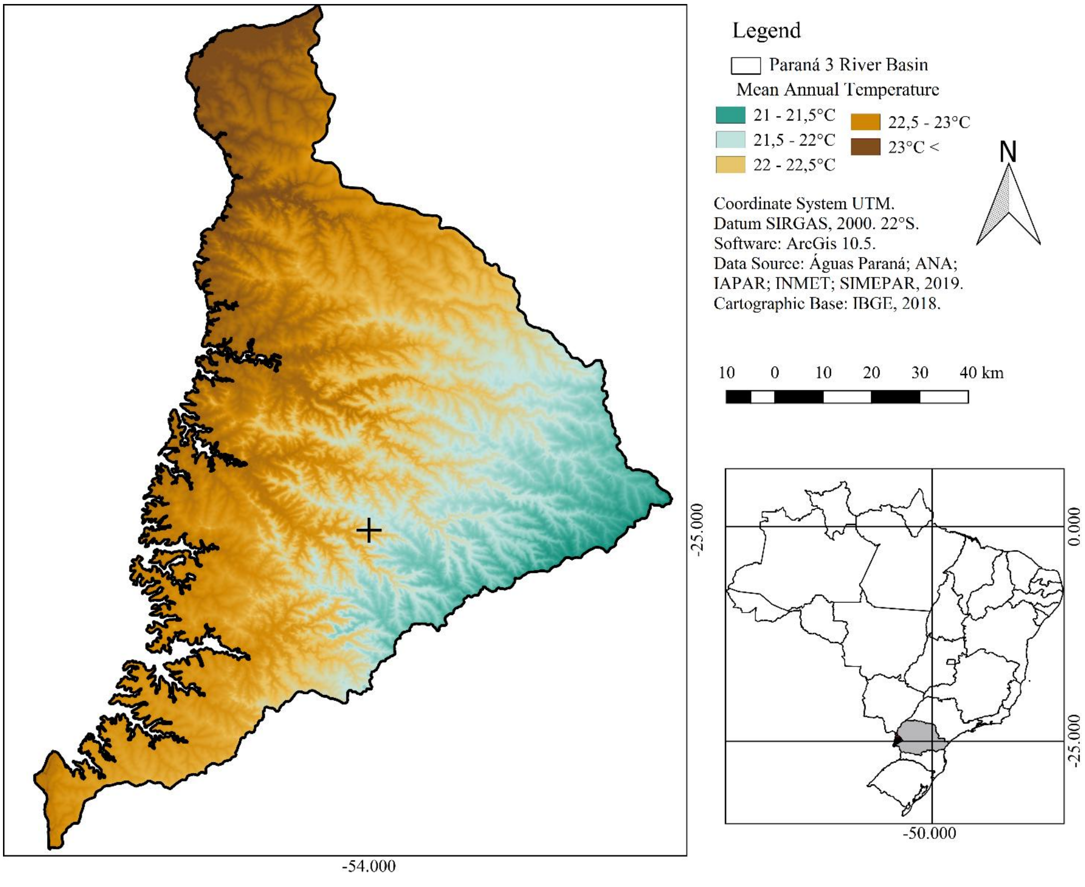

Figure 06 - Annual Average Temperature in the basin of Paraná River 3. Adapted and organized by the authors (2019).

As noted, the average annual temperature limit value for pineapple production is 22°C. And once again, the highest portion of the Cascavel region proved to be unsuitable for production, with values around 21°C. The edges of the valleys were also restricted, with average values of 21.5°C. The southern, western and northern portion, closest to the Paraná River channel, presented aptitude, with average values above 22°C. The highest average temperatures were observed in the Guairá region, in the extreme north of the basin, reaching over 23°C.

In this sense, the risk of annual frost in the region (Figure 07) was similar to the average temperature, with higher risk in the eastern, and in some valley in the most central portion of the basin. The altitudes of the western portion, near the Paraná River gutter, contribute to pineapple cultivation, reducing the risk of frost to about 5%.

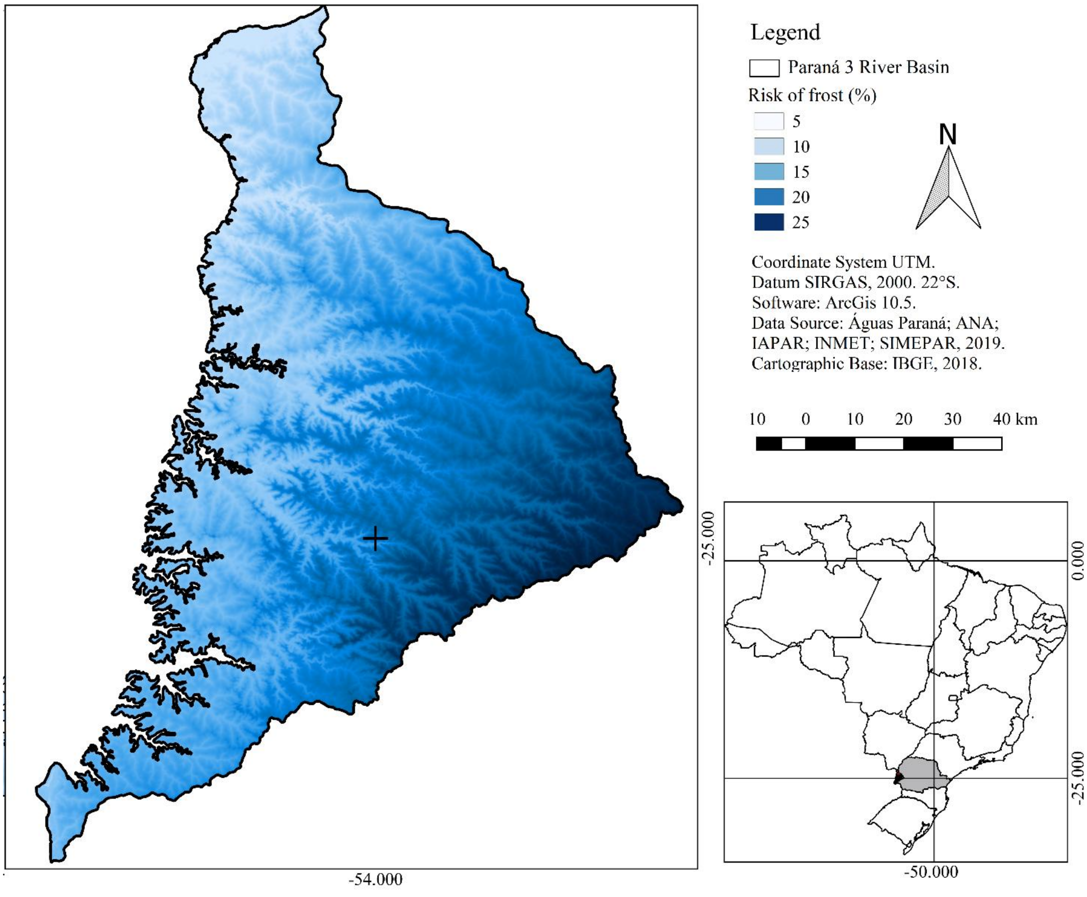

Figure 07 - Frost Risk in the basin of Paraná River 3. Adapted and organized by the authors (2019).

For the monthly average temperature (Figure 08), it was identified that the risk parameter is the occurrence of the coldest month with an average temperature below 15 °C. Thus, it was identified that the risk of this parameter is not present in the region. Cascavel station, located at the eastern end of the Hydrographic basin, was the only one to record the coldest month in June, with an average value of 15.2°C, very close to the risk level, but still higher than this one.

For the other five stations analyzed all occurrences of average temperature of the coldest month was in July. The highest average was observed at Santa Helena station, located in the western portion of the basin at 17.8°C.

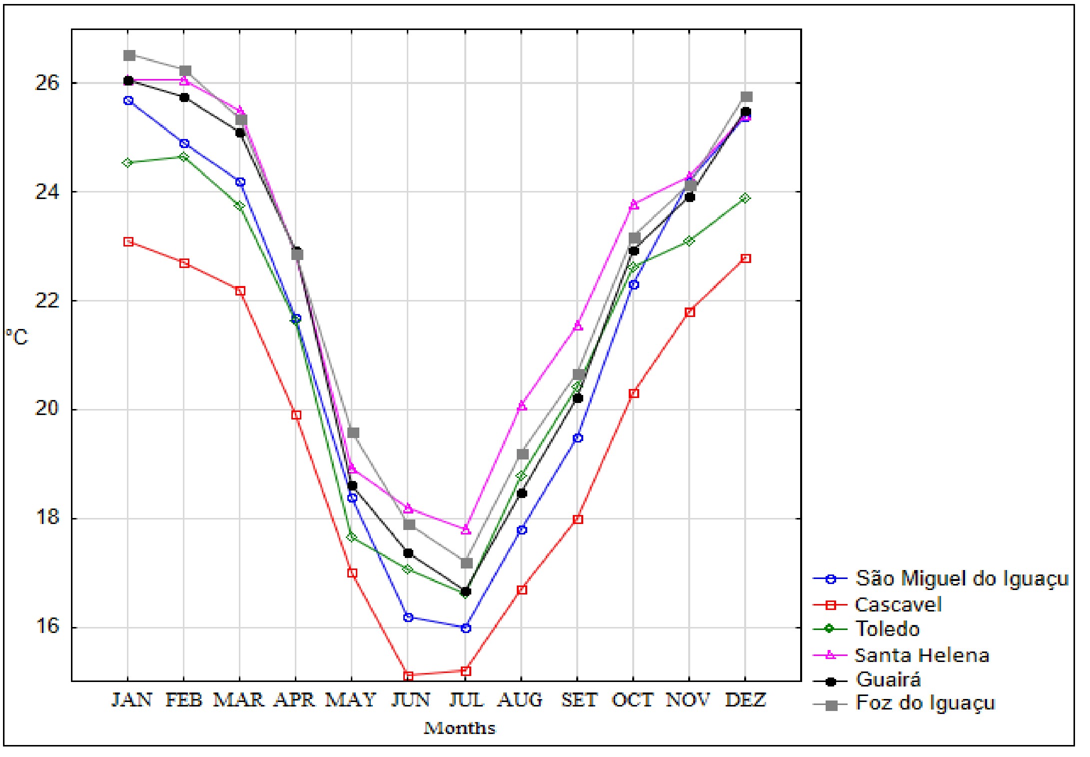

Figure 08 - Average monthly temperature (°C) in the basin of Paraná river 3. Adapted and organized by the authors (2019).

In the final map of pineapple agroclimatic risk zoning (Figure 09) it can be observed that the portion with lower altitudes in the north, west and south regions presented favourable conditions for pineapple production in all analyzed variables.

In the central portion, from north to south of the basin was identified a marginal region for production, with restriction by the factor of frost, since all other factors showed aptitude.

Pineapple could be cultivated in this area of the Hydrographic basin, but it is subject to greater risks. Thus, the producer should avoid the valley bottoms, end of the slope, and give preference to cultivation in areas not very steep, to facilitate the flow of cold air. Preferably the top of the spike and half slope should be used especially on the north facing areas, as, as already pointed out, the cold front has a preferential displacement in the south / southwest direction, northeast direction.

It is noteworthy that zoning does not eliminate the risks, but only presents more favourable conditions for the development of pineapple. As agriculture is a risky activity, all activities are susceptible to any extreme event, which may or may not cause harm. Zoning comes to provide greater security in decision making, agricultural planning and climate change scenarios, especially in the basin of Paraná river 3.

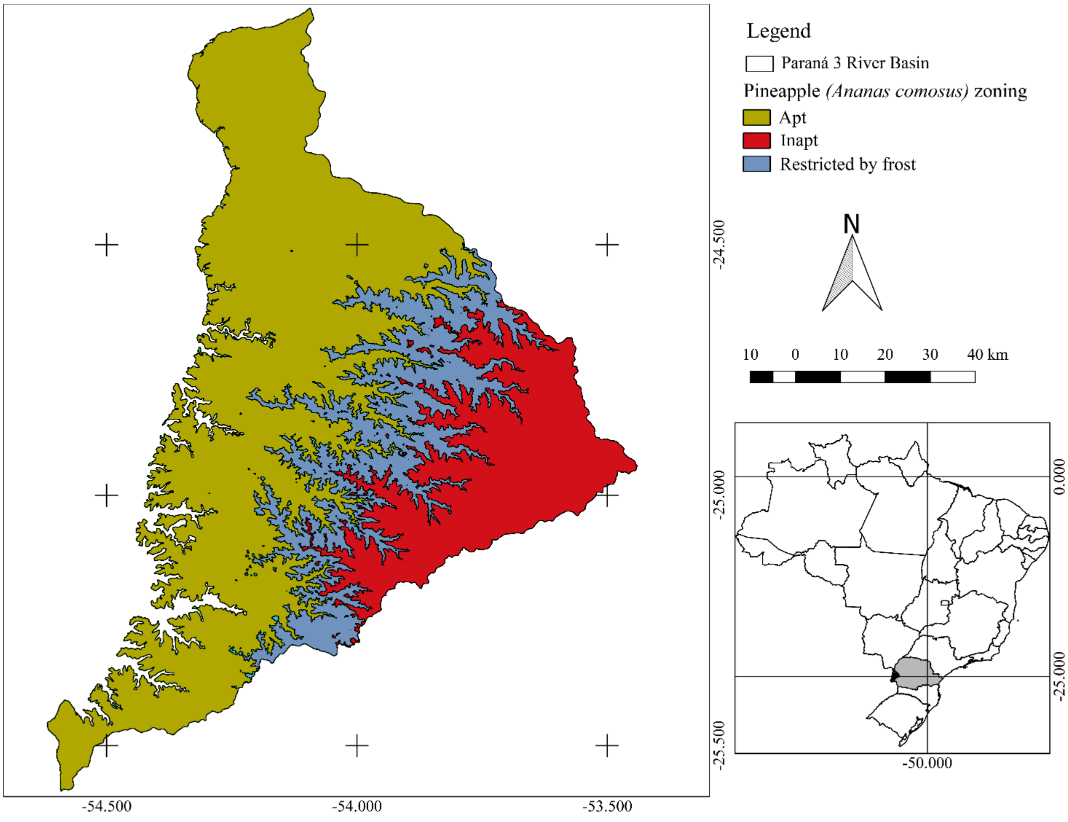

Figure 09 - Pineapple (*Ananas comosus*) Agroclimatic Risk Zoning, in basin of Paraná river 3. Adapted and organized by the authors (2019).

Ricce, et al., (2014) also analysed agroclimatic zoning for pineapple cultivation, this time for the entire state of Paraná. They used the appropriate limits of the climatic variables of average annual temperature, the temperature of the coldest month, the annual risk of frosts, the risk of water deficiency, the number of hours of annual sunshine and the photoperiod in the State. They identified that Paraná has regions with low climatic risk for pineapple cultivation. In addition to the West region, partially suitable, as highlighted in this work, the authors identified that the Northwest and North regions of the State are the most recommended for cultivation. While the Center, South and East regions are not recommended. The work cited, as it contains a larger area of analysis, the work cited hears greater generalization and little refinement in the delimitation of areas for cultivation.

The appropriate pineapple cultivation is in spring season to escape the frost and colder temperatures, where the next year he harvested in the winter at the end of the crop cycle, depending on the species used and the management employed on the property. This calendar favours development in the early stages when the temperature begins to rise, favouring root development and accelerated vegetative growth.

Pineapple is regarded as a plant with relatively reduced water requirements when compared to other ones. The use of irrigation is welcome to provide suitability for areas where frost restriction occurs. However, the economic feasibility of using frost-only irrigation systems should not be accepted, as they are costly acquisition and maintenance systems to be used only in extreme cases. Adjusting the calendar away from frost areas and seasons is still a more sustainable and better accepted technique in these situations.

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4. CONCLUSION

The basin of Paraná River 3 presents areas of low climate risk for pineapple crop. Rainfall has sufficient values in all scenarios evaluated. The most limiting factor for production in part of the basin is the occurrence of frost and ideal temperatures for the crop full development. The Western, Northwest, Northern and Southern regions of the basin are recommended for pineapple cultivation. For the marginal areas, as Eastern strip and altitudes areas, the cultivation has to be avoided.

Pineapple cultivation is an interesting crop for family farming, considering social and economic aspects and to minimize the effects of the global climate change.

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