Revista Brasileira de Climatologia
Brazilian Journal of Climatology

AGROCLIMATIC APTITUDE FOR CULTIVATION OF CASSAVA CROP (*MANIHOT ESCULENTA*) IN NORTHWEST MESOREGION OF PARANÁ STATE, BRAZIL

Aptidão Agroclimática para a Produção de Mandioca (Manihot Esculenta) na Mesorregião Noroeste do Estado do Paraná, Brasil

Aptitud Agroclimática para la Producción de Yuca (Manihot Esculenta) en la Mesoregión Noroeste del Estado de Paraná, Brasil

Nathan Felipe da Silva Caldana
Programa de Pós-graduação em Agronomia, Universidade Estadual de Londrina - UEL
nathancaldana@gmail.com

Alan Carlos Martelócio
Pós-Graduação em Fertilidade do Solo e Nutrição Mineral de Plantas, Unicesumar
amartelocio@agronomo.eng.br

Luiz Gustavo Batista Ferreira
Programa de Pós-Graduação em Agronomia, Universidade Estadual de Ponta Grossa
luiz.gustavo@agronomo.eng.br

Ana Paula Ferreira Dominoni
Programa de Pós-graduação em Agronomia, Universidade Estadual de Londrina - UEL
ana.dominoni@hotmail.com

Marcelo Augusto de Aguiar e Silva
Programa de Pós-graduação em Agronomia, Universidade Estadual de Londrina - UEL
aguiaresilva@uel.br

Abstract: Cassava is one of the most important crops in tropical countries, due to its relative tolerance to drought and adverse climate, in addition to being an important food base. Rainfed agriculture is extremely dependent on atmospheric conditions since, among the factors that influence production, this is the only one that the producer cannot control. Thus, the objective of this

work was to identify the agroclimatic suitability for the cultivation of cassava in the Mesoregion Northwest of Parana state, Brazil, through the agroclimatic risk zoning based on the ecophysiological requirements of cassava. Data were from 44 meteorological stations distributed throughout the mesoregion, with a time frame from 1976 to 2019. The agroclimatic risk for cassava was evaluated through the variables: temperature, rain, water deficit and frost. Aptitude for cultivation was identified throughout the mesoregion, with greater potential in relation to the rest of the state, mainly due to its sandy soil and more suitable temperatures. Precipitation was sufficient for cultivation, and the limiting factors for production throughout the year were the occurrence of low temperatures and frost. Planting was recommended from September to December, depending on the occurrence of temperatures below 10°C.
Keywords: Agroclimatology. Agricultural production. Variability. Temperature; Zoning.

Resumo: A mandioca é uma das culturas mais importantes nos países tropicais, devido a sua relativa tolerância a seca e clima adverso, além de ser uma importante base alimentar. A agricultura de sequeiro é extremamente dependente das condições atmosféricas, uma vez que, que das etapas e variáveis da produção, essa é a única que o produtor não pode controlar. Dessa forma, o objetivo desse trabalho foi identificar a aptidão agroclimática para o cultivo da mandioca na Mesorregião Noroeste Paranaense por meio do zoneamento de risco agroclimático, da variabilidade climática e das exigências fisiológicas do cultivar. Foram utilizados dados de 44 estações meteorológicas distribuídas pela mesorregião com recorte temporal de 1976 a 2019. O risco agroclimático para a mandioca foi avaliado por meio das variáveis: temperatura, chuva, déficit hídrico e geada. Foi identificada aptidão para o cultivo em toda a mesorregião, mostrando maior potencialidade perante o resto do Estado principalmente pelo solo arenoso e por ser mais quente. A precipitação se mostrou suficiente para o cultivo, o fator limitante para a produção durante todo o ano foram a ocorrência de temperaturas frias e geada. O plantio foi recomendado de setembro a dezembro, conforme a ocorrências de temperaturas a baixo de 10°C.
Palavras-chave: Agroclimatologia; Produção agrícola; Variabilidade; Temperatura; Zoneamento.

Resumen: La yuca es uno de los cultivos más importantes en los países tropicales, debido a su relativa tolerancia a la sequía y al clima adverso, además de ser una importante base alimentaria. La agricultura de secano es extremadamente dependiente de las condiciones atmosféricas ya que, entre los factores que influyen en la producción, este es el único que el productor no puede controlar.El propósito de este estudio fue identificar la aptitud agroclimática para el cultivo de yuca en la Mesorregión Noroeste del estado de Paraná, Brasil, considerando la zonificación de riesgo agroclimático, variabilidad climática y requerimientos fisiológicos de los cultivos. Se utilizaron datos de 44 estaciones meteorológicas repartidas por la Mesorregión, con un período de tiempo de 1976 a 2019. Se investigó el riesgo agroclimático de la yuca utilizando las variables: temperatura, lluvia, déficit hídrico y heladas. Se identificó aptitud para el cultivo, presentando un potencial agrícola significativo, en comparación con el resto del estado de Paraná, principalmente debido al suelo arenoso y más cálido. La precipitación resultó ser suficiente para el cultivo, el factor limitante para la producción durante todo el año fue la ocurrencia de temperaturas frías y heladas. Se recomendó la siembra de septiembre a diciembre, según la ocurrencia de temperaturas inferiores a 10 ° C.
Palabras clave: Agroclimatología; Producción de agricultura; Variabilidad; Temperatura; Zonificación.

Submetido em: 27/06/2021
Aceito para publicação em: 09/04/2022
Publicado em: 11/04/2022

1. INTRODUCTION

During the last century and especially in the beginning of the 21st century, climate change has caused atypical events worldwide, such as the occurrence of extreme temperatures, heat waves, drought events, an increase in the height of daily precipitation, culminating in higher climate risks (IPCC, 2013). Its impacts on society and human activities are uncertain and increasingly perceptive, making it one of the greatest challenges for humanity from now to the future (MEIRA et al., 2019; FÉLIX et al., 2020). Rainfed agriculture is extremely dependent on atmospheric conditions, once the farmer cannot control de meteorological conditions (CARAMORI et al., 2008; AGOVINO et al., 2019; CALDANA et al., 2019). Thus, studies of the relations soil-plant-atmosphere are key for the expansion of this segment (FERREIRA et al., 2019; DA SILVA et al., 2020), contributing to agricultural planning with lower risks, decision making, and the search for better quality and market value for agricultural production.

In order to maximize productivity and reduce risks, agrometeorological studies have been applied in different parts of the world. Agroclimatic risk zoning helps to improve crops management, decision making, agricultural planning and to subsidize agricultural policies (RICCE et al. 2013), aiming for higher productivity with lower losses. The studies that focus on climatic risk for agriculture are fundamental, since events of frost, snow, extreme heat, drought, excessive rain, windstorm and hail can cause significant damages to the phenological development of different crops (MEZHER et al., 2012; RICCE et al., 2013; MORAIS and CARBONIERI, 2015; MARTINS et al., 2017; CALDANA et al., 2020).

Cassava (*Manihot esculenta*) is a heliophile, perennial, shrubby plant, belonging to the Euphorbiaceae family. Has a relative tolerance to drought and wide adaptation to the most varied conditions of climate and soil. Nowadays, cassava is grown in many countries over an extensive range of the globe, ranging from 30 degrees North to South of latitude (MATTOS et al., 2004). In most countries in the Americas, cassava is consumed as nature form, except for Brazil, which has table flour as its main derivative. The most important part of the plant is the tuberous root, rich in starch, used in human and animal food or as a raw material for several industries (OTSUBO et al., 2002). Starch represents a great source of carbohydrates. It is the sixth main food product of humanity, gaining even more importance in the food security scenario (LORENZI et al., 1996; OTSUBO et al., 2002).

The purpose of this study was to identify the agroclimatic aptitude for the cultivation of cassava in the Northwest Mesoregion of the Paraná state (NMPR), Brazil, through the agroclimatic risk analyses based on the ecophysiological requirements of this crop.

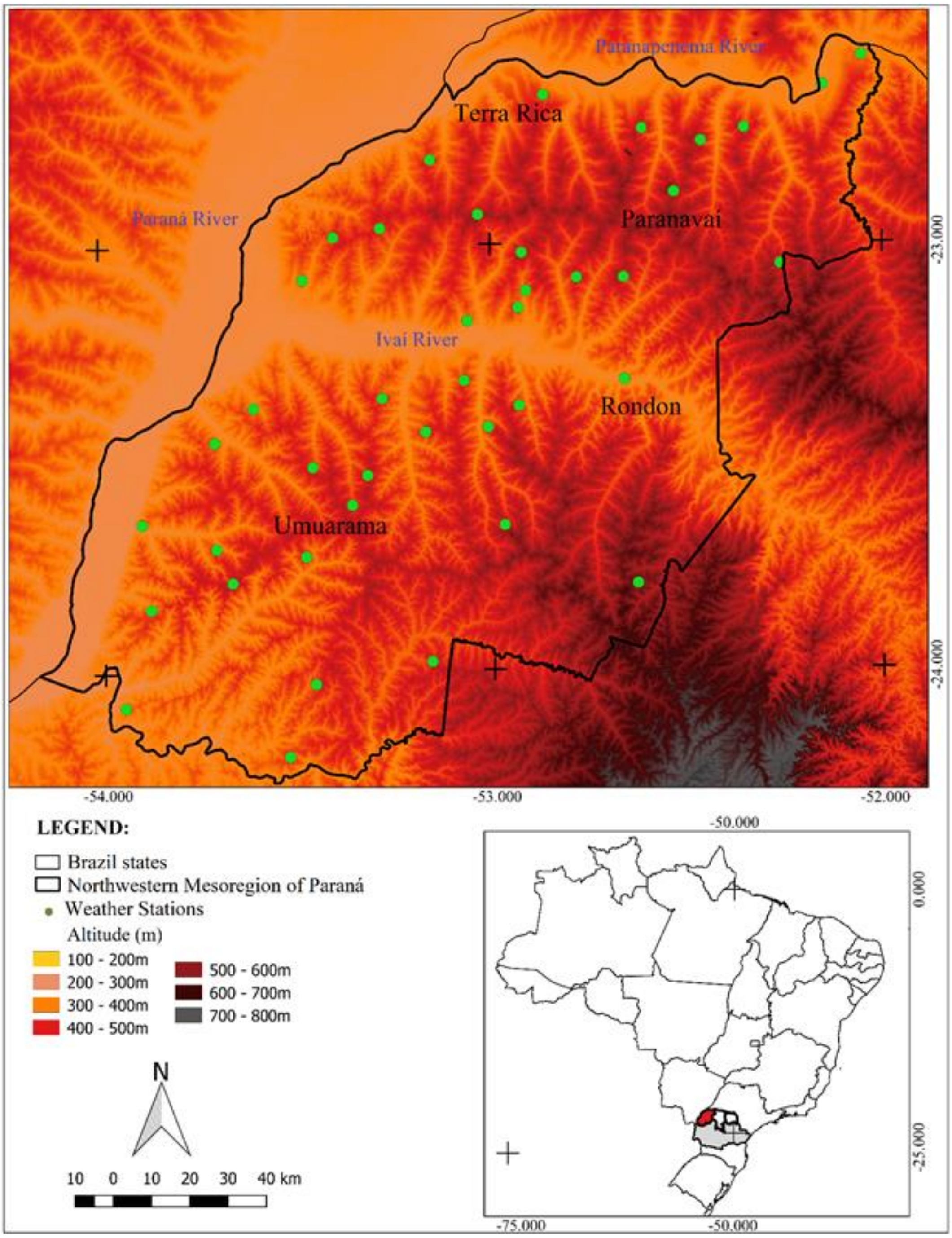
2. MATERIAL AND METHODS

2.1. Area of study

The NMPR (Figure 01) has approximately 700 thousand inhabitants (IBGE, 2019). It is an important agricultural production area in the Paraná state (DE LIMA et al., 2006), exhibiting the key importance of studies on meteorological variables for this area. The region has the entire extension of its area with a “Cfa” climate (subtropical, without dry season and hot summer). It has also the highest temperatures and the lowest annual rainfall in the Paraná state (NITSCHE et al., 2019). The NMPR soil is predominantly sandy (BHERING et al., 2007).

For the purpose of this study, we selected the hydroclimatic requirements of the studied species and daily, annual and seasonal time series from 1976 to 2019 of the Northwest Mesoregion (Figure 2). In order to analyze climate variability and to produce the climate risk zoning, we surveyed data from meteorological stations distributed across the area of the study. The database comprises data several meteorological stations, including six from IAPAR—Instituto Agronômico do Paraná, and 27 from Instituto das Águas do Paraná. Other ten stations from SIMEPAR—Sistema Meteorológico do Paraná, with data from 2000 to 2019 were included to contribute to analyses, despite of the short period of collection.

Figure 1 - Meteorological stations and topography of the Northwest Mesoregion of the Paraná state, Brazil.



Fonte: Topodata (2020). **org:** authors (2020).

2.2. Statistical analysis

Cassava, as a tropical plant, prefers warm climates for an appropriate physiological development and growth. The ideal average temperature is above 24°C. Frosts are not tolerated and temperatures below 10ºC inhibit growth, causing harmful consequences to the crop productivity. These climatic requirements explain why the largest areas cultivated with cassava are in warm regions (MATOS et al., 2006).

Thus, the free period of low temperatures (below 10°C) was estimated to identify the best period to develop cassava in the region. The method consists of identifying the occurrence of temperatures below 10°C by analyzing the data series. Whenever the temperature of one day was less than or equal to this threshold, the value "1" was associated and otherwise, the value "0" was assigned. Then, we calculated the probabilities of occurring at least one temperature below 10°C per decade (WREGE et al., 2005).

Adopting this procedure, if within a given decade there were one or more temperatures below the critical value, that decade was computed as "1", regardless of the number of times the temperature occurred, otherwise, it was computed as "0". Based on the "0" and "1" sequences of the entire historical series for each season, the cumulative frequency of low temperatures throughout the year was calculated for each station. The date on which the 5 % probability accumulated in each of the stations was assumed to be the first critical temperature, considering from the beginning to the end of the year. The last critical Spring temperature was also determined for an accumulated frequency of 5 % probability, but calculations were carried out starting from the end to the beginning of the year (WREGE et al., 2005). If the period between the first and the last critical temperature of the year was shorter than the crop cycle, the locality was classified as inapt for cultivation.

As for the pluviometric regime, the crop produces well in regions / places with an annual average of 750 to 1000 mm of rain. During the biological developing phase, the crop requires about 500 to 600 mm (OTSUBO et al., 2002; MATTOS et al., 2006).

2.3. Agroclimatic aptitude

Based on the crop requirements, we estimated the selected risk factors for climate risk zoning. In order of requirement and importance for development, and based on the characteristics of NMPR, those were the following:

Annual average rainfall: For the area of the study, we used data from 27 stations; data from 1976 to 2019 of the annual and monthly climate series. The results obtained were interpolated in a geographic information system for the generation of the rain map, using the Inverse distance weighted (IDW). The risk was assessed using a moving average grouped by semester, according to the mentioned crop cycle. The risk was considered high when annual rainfall was less than 1,000 mm, with less than 500m during the cycle of six months; low risk corresponded to rainfall greater than 1,000 mm (OTSUBO et al., 2002; MATOS et al., 2006).

Annual average temperature (Ta): Mean Ta from all the stations in the NMPR were used to adjust Ta as a function of latitude, longitude and altitude. The following risk classes for Ta were defined: High Risk: less than 20°C or greater than 27°C; Low Risk: between 20 and 27°C (OTSUBO et al., 2002; MATOS et al., 2006).

Frost risk: We used minimum screen temperature data from the historical series of 10 stations. The minimum temperatures of 1°C, observed inside the meteorological shelter, were considered critical to calculate the risk of frost. The probabilities of annual occurrence were calculated and correlated with altitude and latitude, obtaining a regression equation for the risk of frosts. Using adjusted regressions, probabilities greater than 20 % were considered as high risk (OTSUBO et al., 2002; MATTOS et al., 2006).

To characterize the rainfall variability and extremes, Box Plot graphs or box diagrams were used. The graphics were created using the Statistica® software. Box plots represent five classifications of values. Outliers are divided into outliers (values above what is considered maximum, but which are not extreme) and extremes, with are values greater than Q3 + 1.5 (Q3 - Q1) or less than Q1 - 1.5 (Q3 - Q1). The highs and lows are considered the highest values in the series, but they are not extreme or outliers. Inside the box, three quartiles are classified with 25% of the data each, in addition to the median value, equivalent to the second quartile, or 50% of the data (LEM et al., 2013; SCHNEIDER and DA SILVA, 2014). For the analysis using Box plot, data from Paranavaí, Rondon, Terra Rica and Umuarama stations were used (Figure 01).

For precipitation analyses, we used only data from rainfall stations, once these have long data series (1976-2019). The Spatialization of these data was performed through interpolation, which is an effective method for spatial visualization of climate data. This was done through isohyet and/or spatially filling the values adjusted by regression statistics and using the IDW spatial interpolation algorithm (MUELER, 2004; LEM et al., 2013). The maps were created with aid of Qgis software.

The punctual data of the rainfall stations were entered into the Qgis software and transformed into a raster file, with aid of 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, isohyet and their values were inserted for a better visualization of areas with similar precipitations and/or insolation and to regionalize them. We also evaluated the distribution of annual precipitations using one weather station by region.

The Shuttle Radar Topography Mission - SRTM base, at 30 m resolution, was used 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 high spatial coverage.

Multiple linear regression equations were applied for the spatialization of the average temperature and frost data measured at the meteorological stations. The equations are given by: y = a + b.lat + c.long + d.alt, where a, b, c, d are regression coefficients, and lat, long, and alt represent the latitude, longitude and altitude, respectively. This mathematic formula was applied in Arcgis geoprocessing software over the SRTM file to generate maps with spatial resolution of 30 m.

The method used for the probability of frost was based on the historical minimum temperature series recorded within the meteorological shelter. We 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.

The Climatological Water Balance was obtained through Thornthwaite and Mather methods (1955), using the equation with the values of several meteorological variables and the available soil water capacity proportional to the effective depth of the roots of the analyzed species. We considered the monthly average rainfall data (extracted from the monthly totals of each year) and the monthly average temperature (extracted from the monthly averages of the daily values of each year). Then, the potential evapotranspiration (PET) was calculated, according to the Thornthwaite method. First, the standard potential evapotranspiration (PET, mm/month) was calculated through the empirical formula:

(1) $\text{For: } 0 < Tn < 26.5\ °C$

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

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

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

Where: Tn - average temperature of month n (n = 1 is January, n = 2 is February, etc), in ºC; 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, being calculated by the formula:

$I = 12(0{,}2\ Ta)^{1{,}514}$

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

(5) $a = 0{,}49239 + 1{,}7912x10^{-2}\,I - 7{,}71x10^{-5}\,I^2 + 6{,}75x10^{-7}\,I^3$

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

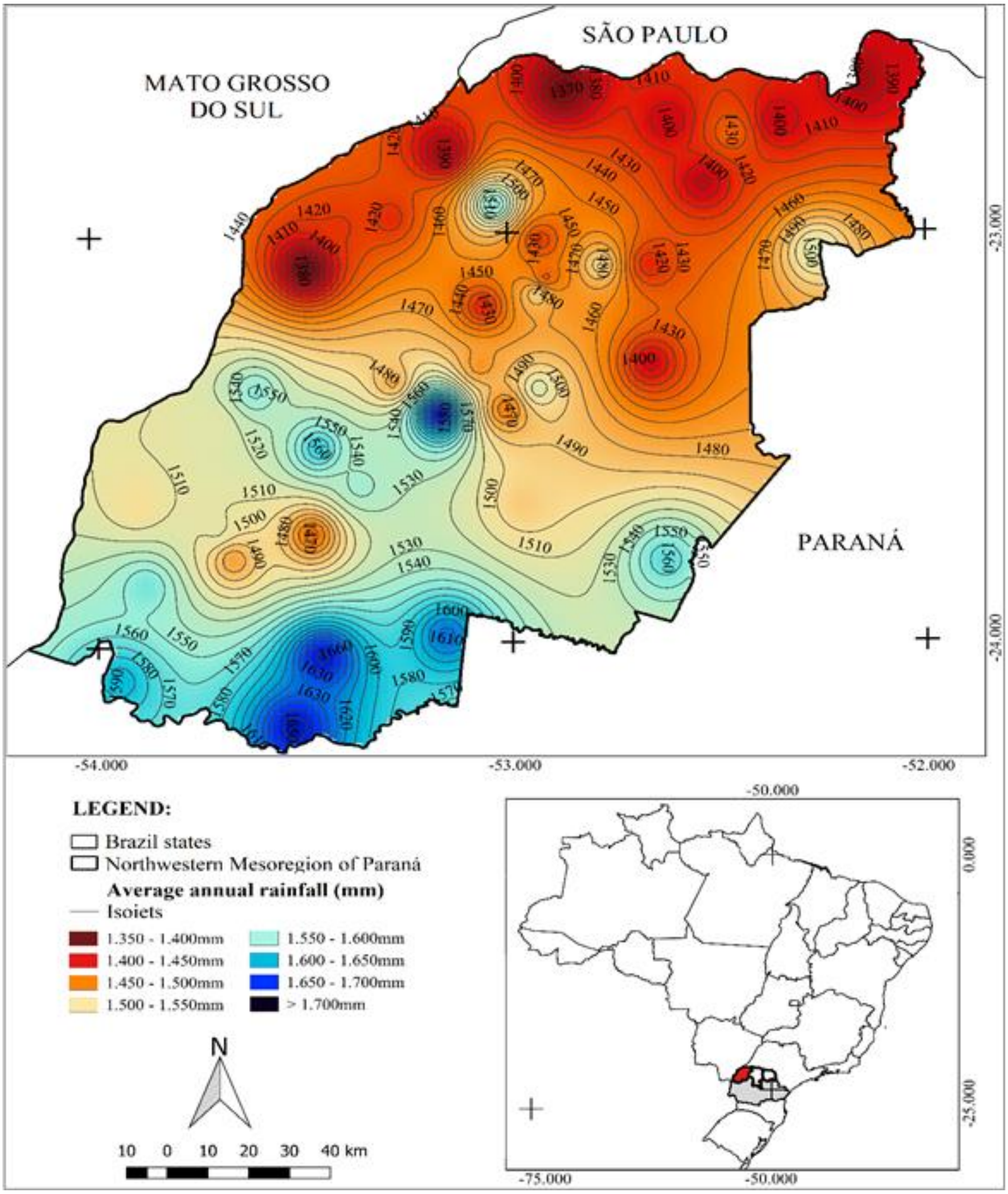
(6) $COR = \left(\frac{N}{12}\right)\left(\frac{NDP}{31}\right)$

3. RESULTS AND DISCUSSION

The NMPR exhibits discrepancies in the average annual precipitation (Pa) in almost all its extension (Figure 02). The Southern area has the highest heights, with Pa of up to 1,650 mm. At the other end of the region, near to the Paraná River channel occurred the lowest Pa, reaching 1,370 mm, near the municipality of Terra Rica.

These differences in the Pa regime of the Mesoregion match with the oscillations of the topography (Figure 01). The highest concentrations of rain are located in conditions of higher altitudes. In the Central-Eastern area, with an altitude higher than 700 m, variability ranged from 1,600 to 1,650 mm.

Figure 2 - Average annual accumulated precipitation in the North Central Mesoregion of Paraná



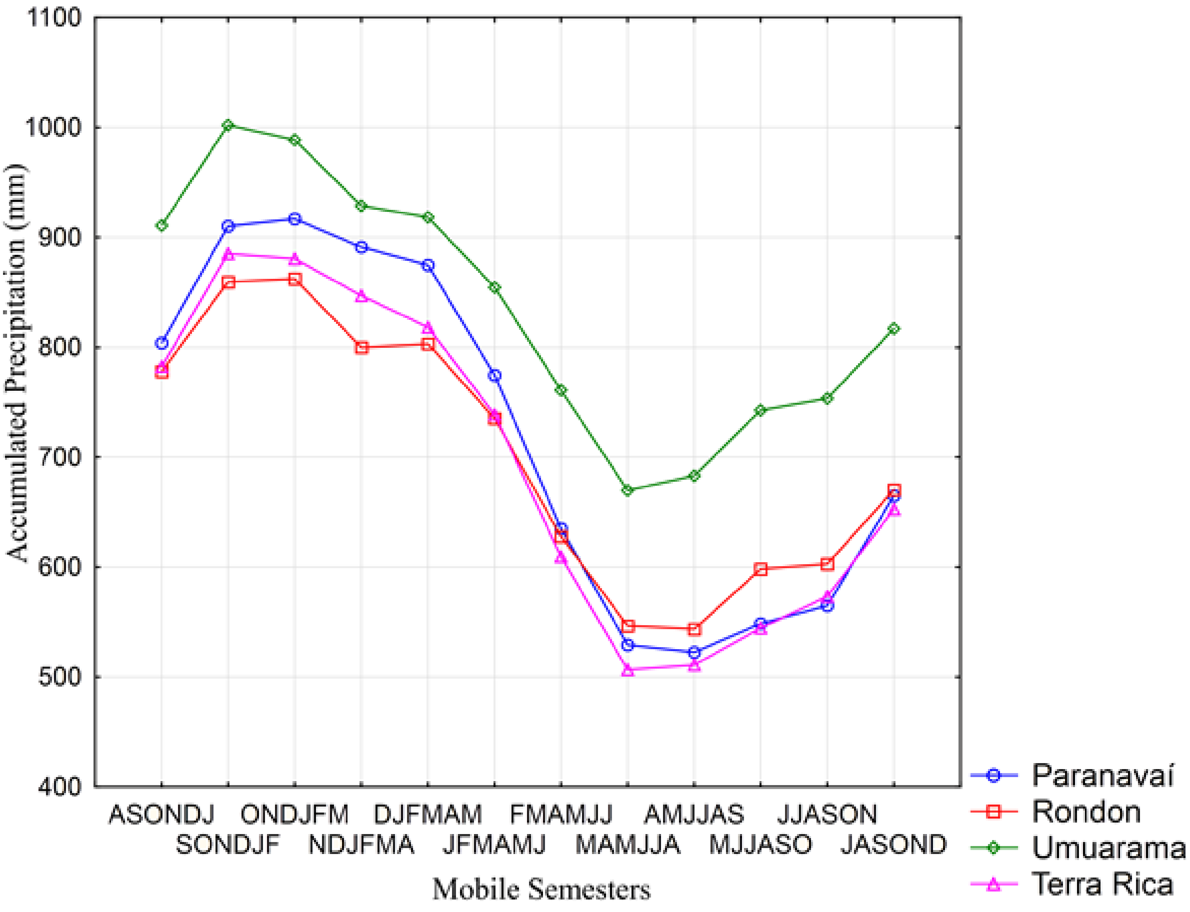
Source: Elaborated by the authors (2020).

Rainfall is one of the most important elements for the cultivation of cassava, a crop grown almost exclusively without irrigation. The most appropriate rainfall regime is the occurrence of Pa of at least 1,000 mm, with good distribution during 6 to 8 months of the vegetative cycle. Our analyses identified that no station exhibited restriction for this element, with the lowest Pa of 1,370 mm.

The accumulated monthly rainfall separated by mobile semesters (Figure 03) o indicate the best growing season based on the rainfall required by the crop during the cycle of cassava. This crop has a relatively short cycle, producing satisfactorily up to 180 days after planting (OTSUBO et al., 2002; MATOS et al., 2006).

The step 01 was from August to January, ending from July to December (Figure 03). It was possible to identify that all semesters have enough precipitation to grow cassava. The lowest average was identified in Terra Rica, from March to August, with an average rainfall of 506 mm.

Figure 3 - Average precipitation for mobile semesters in Northeast Mesoregion of Paraná state, Brazil.



Source: Elaborated by the authors (2020).

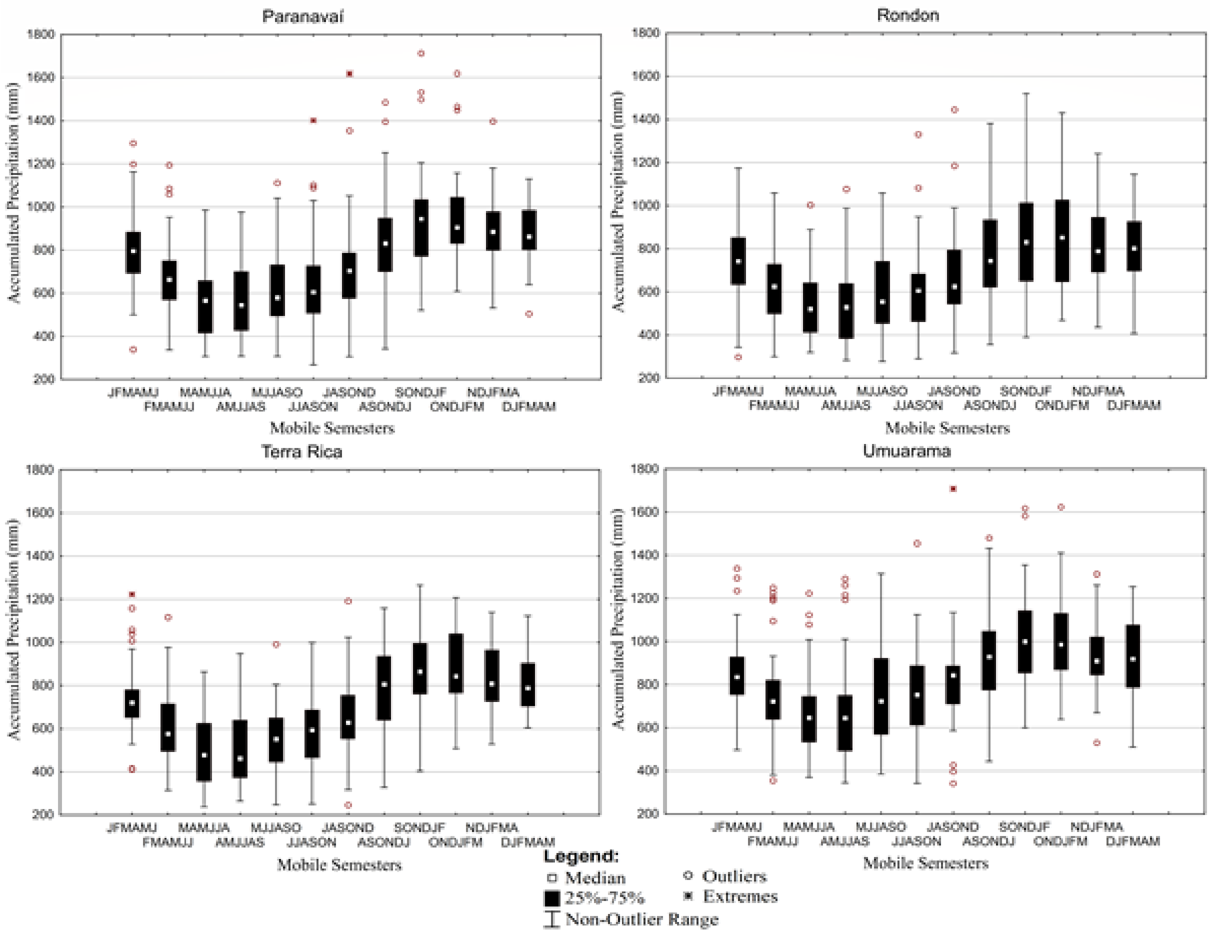
The lowest pluviometric heights were identified in two stations, in the first six mobile semesters analyzed the smallest records were in municipality of Rondon, in the following six were in municipality of Terra Rica, while the highest were all in municipality of Umuarama.

The most favorable semester for cropping was from September to February, with an average range from 870 to 988 mm.

As identified by Mattos et al. (2006), cassava is produced even in semi-arid regions in Brazil with annual precipitation of 500 to 700 mm, however, using varieties improved or selected for these regions and planting time as recommended by the agroclimatic zoning.

For a detailed analysis of the rain in the crop cycle, the annual variability was analyzed using box plots (Figure 04). The stations showed great variability across mobile semesters, exhibiting the importance of planning for the time of sowing and management of the crop in the region. In the municipality of Umuarama, for example, in the semester from July to December there were precipitations from 322 to 1,780 mm in the historical series.

Figure 4 - Variability of the pluviometric precipitation for mobile semesters in Northwest Mesoregion of Paraná state, Brazil.



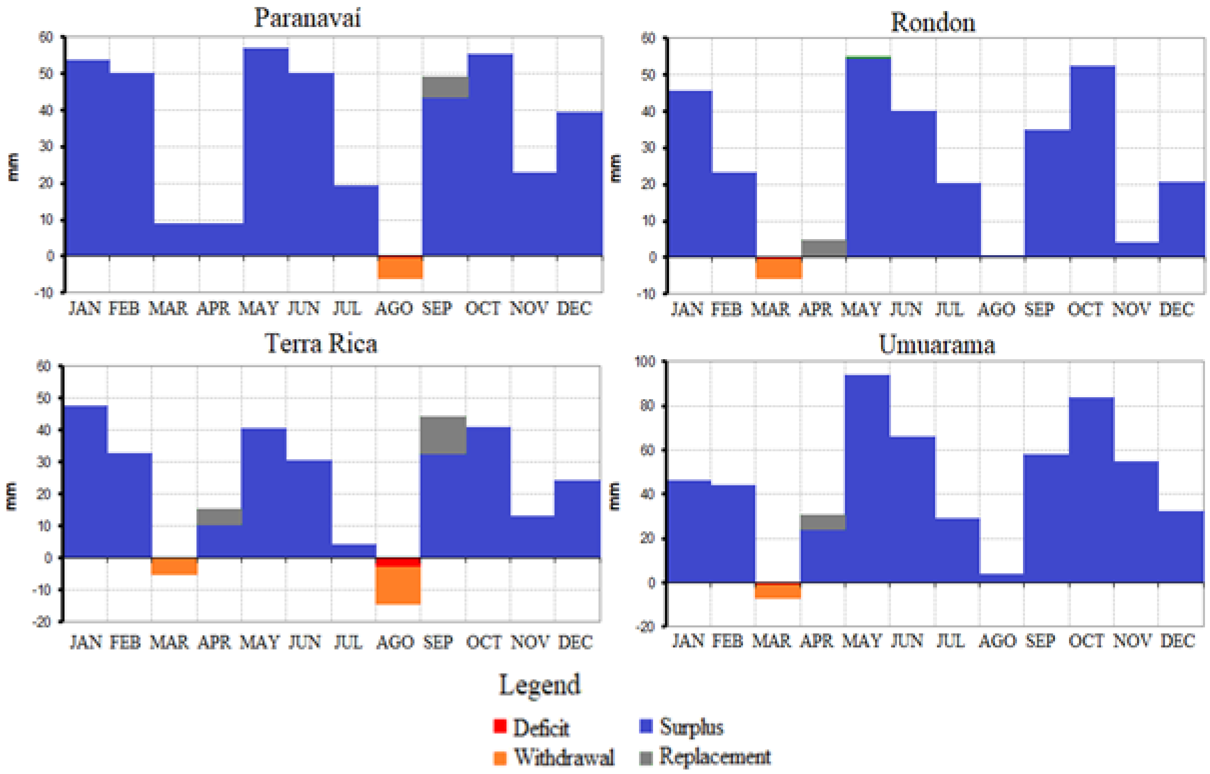
Source: Elaborated by the authors (2020).

Differently of the averages, some semesters had a median of less than 500 mm, which is considered enough for cassava production. In Terra Rica, the April-September and May-October semesters had 50% of the years with insufficient rainfall, making planting in those semesters inapt.

Precipitation events of less than 500 mm occurred in most of the semesters and in all stations. In Umuarama, which had the highest average rainfall, the only semester that did not have any precipitation below this critical limit in the 44 years analyzed was October-March, while for September-February it was observed only at the station of Terra Rica.

The water deficiency evidenced by the water balance (Figure 05), in addition to causing affect the production of roots, in the first five months of cassava cultivation can cause even the death of the plants. Therefore, it is fundamental to analyze this risk before planting the crop anywhere in the globe. It should also be noted that, as mentioned, the soil of the region of this study is predominantly sandy, with lower water retention in the root zone (BHERING et al., 2007), but with physical properties suitable for cassava cultivation.

Figure 5 - Water balance for cassava crops in Northwest Mesoregion of Paraná state, Brazil.



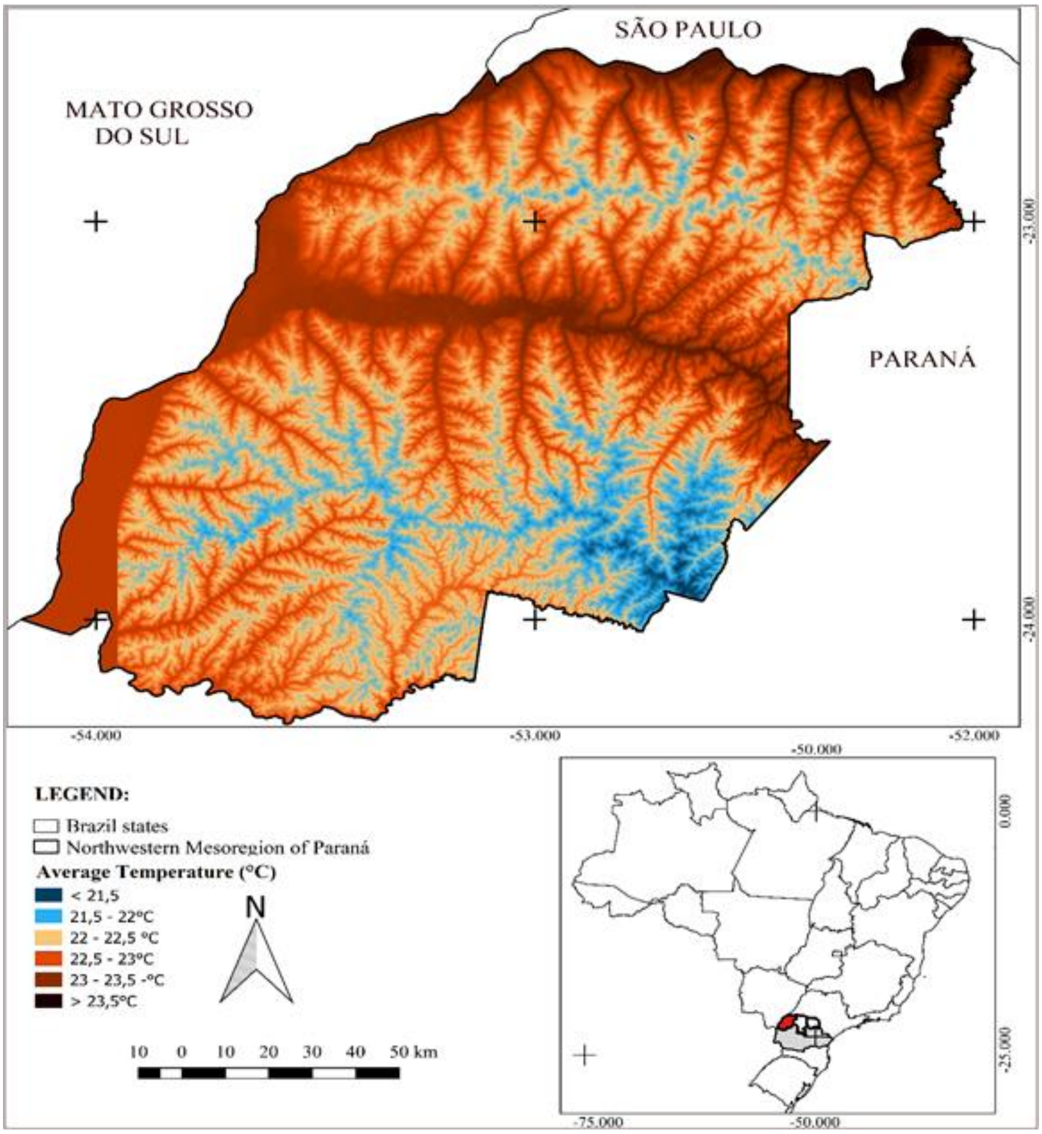
Source: Elaborated by the authors (2020).

The average risk of a deficit of 100 mm per year was not observed in any station. The only months to show small withdrawal and deficit values were March and August, but they were replaced in the following month. Once again, the semester of September-February and October-March were the most favorable for the cultivation of cassava in the region, demonstrating the low risk due to this variable.

Temperature is one of the most important and restrictive elements for the cultivation of cassava. The ideal temperature range for cassava cultivation is between 20°C and 27°C (annual average), with optimum of 24°C to 25°C.

The entire Mesoregion (Figure 6) has conditions for the production of cassava, with mean annual temperatures within the ideal range. The lowest temperatures observed were in the areas of higher altitudes, located in the extreme Southeast of the region, with average temperatures between 21 and 21.5°C. While the largest records were identified near to the Paraná River channel, with values above 23.5°C.

Figure 6 - Annual average temperature in Northwest Mesoregion of Paraná state, Brazil.

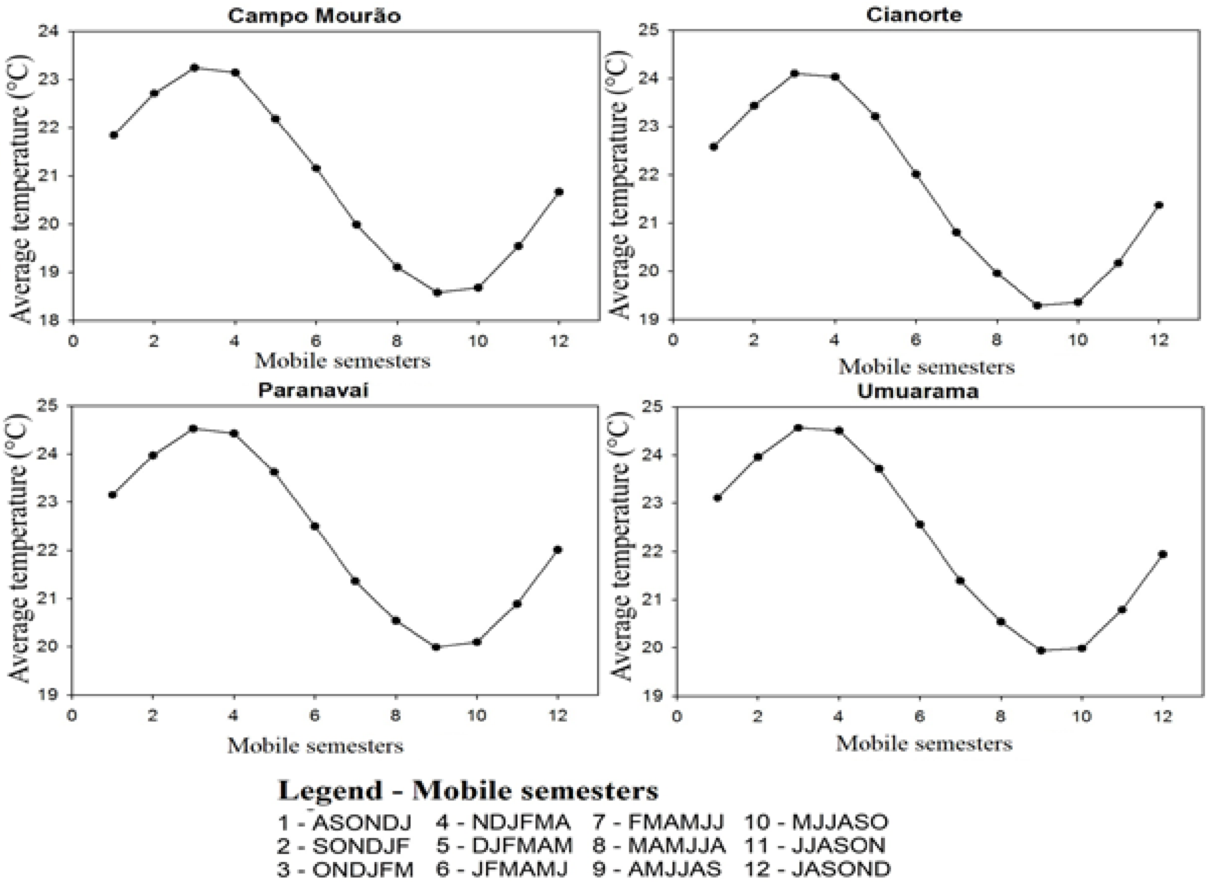


Source: Elaborated by the authors (2020).

It should be noted that the Northwest Mesoregion is the warmest of Paraná state (NITSCHE et al., 2019), an advantageous condition for cassava cultivation.

The monthly average temperatures were grouped in mobile semesters to establish the best growing seasons for the Northwest Mesoregion (Figure 07). It is observed that, in all semesters and seasons, the temperatures had similar oscillations. The Mobile Semester 9 (A-M-J-J-A-S), which covers the months from April to September, presented the same behavior in all the analyzed stations, proving to be inapt for the implantation of the cassava crop. The temperatures were well below the recommended, getting close to 19.8°C.

Figure 7 - Average temperature per mobile semester in four places of the Mesoregion Northwest of Paraná state, Brazil.

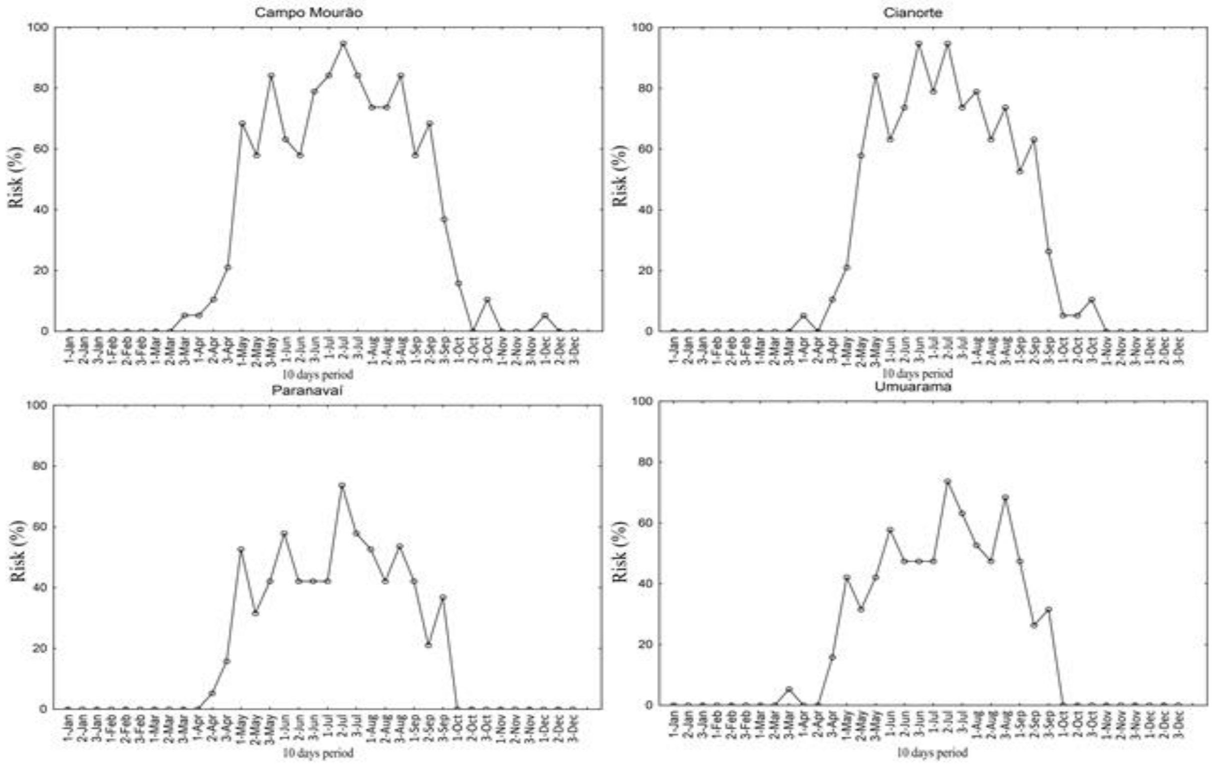


Source: Elaborated by the authors (2020).

The municipality of Campo Mourão was inapt in five mobile semesters (7, 8, 9. 10 and 11) with temperatures below 20°C, with all these semesters fully or including the autumn and winter seasons. The months of June, July and August should be avoided during the cycle, since they are the coldest of the year.

As mentioned, the species was adapted to high temperatures, and its grow stops when the average monthly temperature is below 15°C. Under such conditions the plants starts a resting phase, when it usually loses its leaves and prolongs its cycle. If the temperatures reach values below 10°C daily production is not viable, so it becomes necessary to assess the frequency of occurrences of these temperatures (Figure 08).

Figure 8 - Risk of low temperature occurrences (<10°C) per 10-day series in Northwest Mesoregion of Paraná state, Brazil

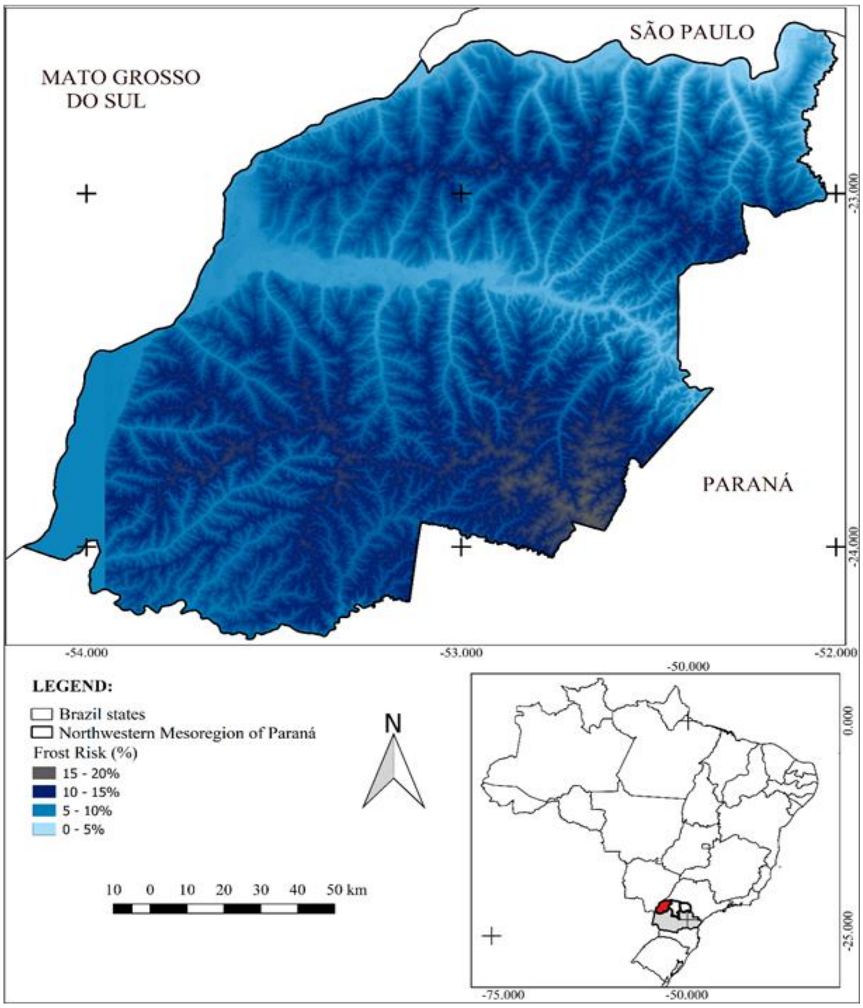


Source: Elaborated by the authors (2020).

Campo Mourão and Cianorte, located in the highest areas of the region, presented a risk of more than 50% of occurrences of temperatures below 10°C for a long period from the 10-day series from 10th of April to the 3rd of September.Planting with lower risk in these areas is recommended between the months of October and November, so that it is possible to avoid cold temperatures in late April.

The risk of frost occurring in the mesoregion varies regionally (Figure 9). The Southern areas and part of the east have the greatest risks. In these areas, the chance of frost varies from 10 to 20% a year, the highest risks occur in the Winter.

Figure 9 - Risk of frost occurrences in Northwest Mesoregion of Paraná state, Brazil

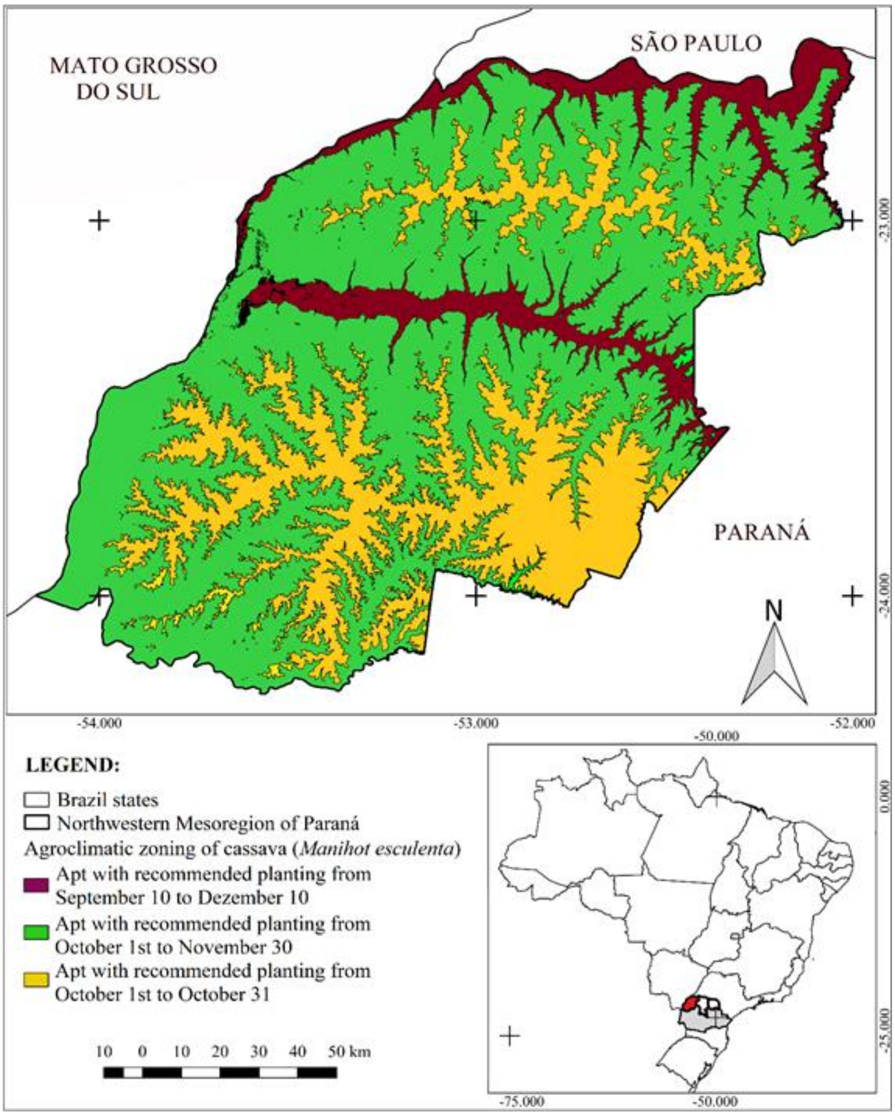


Source: Elaborated by the authors (2020).

The regions and areas that presented risks between 0 % and 10 % are more apt for cultivation. Such condition is seen in the North, West and a fraction of the East, mainly in the vicinity of the Paraná, Paranapanema and Ivaí rivers.

From these analyzes, it is possible to verify that the risks for the cultivation of cassava (Figure 10) are mainly linked to temperature and frost. In the mesoregion, risks begin to reduce in September and disappear in October, when planting is recommended.

Figure 10 - Risk of frost occurrences in Northwest Mesoregion of Paraná state



Source: Elaborated by the authors (2020).

In low altitude locations, near to the Paranapanema and Ivaí River, planting can start in the beginning of September, until the beginning of December, the largest window available for implementing the culture and decision making.

In the green areas on the map, classified as an intermediate area, planting can be carried out for two months, still guaranteeing effectiveness due to the agrometeorological factors in the region. In the coldest area, only one month is available for planting, due to the cold temperatures that occur in September and April, thus leaving only seven months free for cultivation.

It is important to emphasize that the cassava crop is highly resistant and an with adaptation not seen in other crops grown in the Paraná state, as is the case of soybean, corn and wheat. Even in regions where the frequency of frosts is higher, reaching 20%, which is the case in the South and East, the crop has a prospect for expansion, provided it is planted at the right time. It is possible that given the same conditions, other crops may not behave the same. Even in adversities, it is possible to verify its persistence in environments inappropriate for its cultivation, being, therefore, a resilient crop.

The Northwest Mesoregion, in this way, exhibited significant aptitude throughout its territory for the cultivation of cassava. In general, the crop will respond satisfactorily to the climatic conditions of the spring and summer months, where there is a better distribution of rainfall and higher temperatures, less risk of frost and low temperatures. The rainfall is sufficient for the crop in all RMNP, being one of the elements that most favored the climate aptitude of the cassava crop in the area of this study.

4. CONCLUSION

Northwest Mesoregion of Paraná state has a large area with aptitude and considerable perspectives through the meteorological variables for the development of cassava. Precipitation and water balance showed sufficient values in all scenarios tested for production, in addition to the advantage, compared to a great part of the state, of having sandy soil. No area was completely inapt for any meteorological variable; only in restricted periods of the year there were restrictions, mainly in the autumn and winter seasons. The limiting factor for production throughout the year was the occurrence of cold temperatures and frost. Planting was recommended from September to December, according to the occurrence of temperatures below 10°C.

ACKNOWLEDGMENTS

The authors would like to thank the research funding agencies CAPES and FAPERGS for the scholarships granted to the first author of the article.

REFERENCES

AGOVINO, M. et al. Agriculture, climate change and sustainability: The case of EU-28. **Ecological Indicators**, v. 105, p. 525-543, 2019.

ASSAD, E. D. et al. Impacto das mudanças climáticas no zoneamento agroclimático do café no Brasil. **Pesquisa Agropecuária Brasileira**, v. 39, n. 11, p. 1057-1064, 2004.

BHERING, S. B. et al. **Mapa de Solos do Estado do Paraná**. Embrapa Solos-Documentos (INFOTECA-E), 2007.

CALDANA, N. F. S. et al., Agroclimatic Risk Zoning of Avocado (*Persea americana*) in the Hydrographic Basin of Paraná River III, Brazil. **Agriculture**, v. 9, n. 263, p. 1-11, 2019.

CALDANA, N. F. S. et al., Caracterização das ocorrências de precipitação de granizo e seus impactos socioeconômicos no estado do Paraná. **Agrometeoros**, v. 27, p. 271-284, 2020.

CARAMORI, P. H. et al. Zoneamento agroclimático para o pessegueiro e a nectarineira no Estado do Paraná. **Revista Brasileira de Fruticultura**, v. 30, n. 4, p. 1040- 1044, 2008.

FÉLIX, A. da S. et al. Análise exploratória dos impactos das mudanças climáticas na produção vegetal no Brasil. **Revista em Agronegócio e Meio Ambiente**, v. 13, n. 1, p. 397-409, 2020.

FERREIRA, B. G. et al. Análise da variabilidade do poder evaporante do ar em um cultivo de açaizeiro (*Euterpe oleracea Mart*.), Castanhal-PA. **Revista Sustinere**, v. 7, n. 2, p. 362-373, 2019.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Pesquisa Agropecuária.** Disponível em: <https://sidra.ibge.gov.br/Tabela/1613>. Acesso em 19 de Março de 2019

IPCC. Technical Summary. In: Climate Change 2013: The Physical Science Basis. **Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.** Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013.

LEM, S. et al. The heuristic interpretation of box plots. **Learning and Instruction,** v. 26, p. 22-35, 2013.

DE LIMA, J. F. et al. Análise regional das mesorregiões do estado do Paraná no final do século XX. **Análise Econômica**, v. 24, n. 46, 2006.

MARTINS, J. A. et al. Climatology of destructive hailstorms in Brazil. **Atmospheric Research**, v. 184, p. 126-138, 2017.

MEIRA, R. L.; MOREIRA, B. L.; VIEIRA, M. F. O aquecimento global e sua influência sobre a Mata Atlântica: algumas considerações. **Cadernos UniFOA**, v. 3, n. 1 Esp, p. 65, 2019.

MEZHER, R. N. et al. Climatology of hail in Argentina. **Atmospheric research**, v. 114, p. 70-82, 2012.

MORAIS, H.; CARBONIERI, J. Horas e unidades de frio em pomares de maçã com diferentes microclimas. **Revista Brasileira de Fruticultura**, v. 37, p. 001-012, 2015.

MÜLLER, N. L. Contribuição ao estudo do Norte do Paraná. **Boletim Paulista de Geografia**, n. 22, p. 55-97, 2017.

NITSCHE, P. R. et al. **Atlas Climático do Estado do Paraná.** Londrina, PR: IAPAR, 2019. Disponível em: http://www.iapar.br/modules/conteudo/conteudo.php?conteudo=677

OTSUBO, A. A. et al., **Aspectos do cultivo da mandioca em Mato Grosso do Sul**. Embrapa Agropecuária Oeste-Livro técnico (INFOTECA-E), 2002.

RICCE, W. da S. et al. Zoneamento agroclimático da cultura do abacaxizeiro no Estado do Paraná. **Semina: Ciências Agrárias**, v. 35, n. 4, p. 2337-2346, 2014.

SCHNEIDER, H.; DA SILVA, C. A. O uso do modelo box plot na identificação de anos-padrão secos, chuvosos e habituais na microrregião de Dourados, Mato Grosso do Sul. **Revista do Departamento de Geografia**, v. 27, p. 131-146, 2014.

SENTELHAS, P. C. Temperatura letal de diferentes plantas frutíferas tropicais. **Bragantia**, v. 55, n. 2, p. 231-235, 1996.

DA SILVA, T. T. F. Félix et al. Estimativa da temperatura do solo e comparação de variáveis meteorológicas em anos extremos de pluviosidade em Mossoró-RN. **Brazilian Journal of Agroecology and Sustainability**, v. 1, n. 2, 2020.

WREGE, M. S. et al. Regiões potenciais para cultivo da cana-de-açúcar no Paraná, com base na análise do risco de geadas. **Revista Brasileira de Agrometeorologia**, v. 13, n. 1, p. 113-122, 2005.