ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

# ESTIAGENS EXTREMAS AFETAM A AGRICULTURA NO ESTADO DO PARANÁ, BRASIL

**LARISSA FERNANES DIAS PINTO[1]; PABLO RICARDO NITSCHE[2]; MARCELO AUGUSTO DE AGUIAR E SILVA[3]; DANIEL SOARES ALVES[4] E NATHAN FELIPE DA SILVA CALDANA[5]**

*[1] Mestranda em Agronomia, Universidade Estadual de Londrina - UEL, Rodovia Celso Garcia CID, Km 380, Campus Universitário, 86057-970, Londrina, Paraná, Brasil. E-mail: larissafernandesd.lf@gmail.com*
*[2] Pesquisador do IDR-Paraná, Instituto de Desenvolvimento Rural do Paraná – IDR/PR, Rodovia Celso Garcia Cid, km 375,86047-902, Londrina, Paraná, Brasil. E-mail: pablo@iapar.br*
*[3] Professor do curso de Bacharelado em Agronomia, Universidade Estadual de Londrina - UEL, Rodovia Celso Garcia CID, Km 380, Campus Universitário, 86057-970, Londrina, Paraná, Brasil. E-mail: aguiaresilva@uel.br*
*[4] Analista C&T do IDR-Paraná, Instituto de Desenvolvimento Rural do Paraná – IDR/PR, Rodovia Celso Garcia Cid, km 375,86047-902, Londrina, Paraná, Brasil. E-mail: danielsoares@iapar.br*
*[5] Doutorando em Agronomia, Universidade Estadual de Londrina - UEL, Rodovia Celso Garcia CID, Km 380, Campus Universitário, 86057-970, Londrina, Paraná, Brasil. E-mail: nathancaldana@gmail.com*

## 1 RESUMO

A estiagem é um fenômeno meteorológico causador de impactos relevantes para o setor agrícola, sendo considerado o principal frustrador de safras. Foi objetivo deste trabalho quantificar os riscos de ocorrência de estiagens extremas em diferentes macrorregiões no estado do Paraná nas quatro estações do ano. Foram utilizados dados diários de precipitação pluvial de 30 estações meteorológicas do Instituto de Desenvolvimento Rural do Paraná (IDR-Paraná) e do Sistema Meteorológico do Paraná (SIMEPAR), de 1976 a 2015. Para cada ano, determinou-se o número de dias sem precipitação pluvial para os trimestres de verão, outono, inverno e primavera. As estiagens foram identificadas utilizando-se a função de densidade de probabilidade de Gumbel, com os parâmetros α e β obtidos pelo Método de Lieblein a 20% de probabilidade. Concluiu-se que o estado do Paraná está sujeito a períodos de estiagem superiores a 60 dias, em qualquer época do ano. As regiões norte e noroeste estão sujeitas a maiores riscos de ocorrência de estiagens extremas, seguidas pelas regiões centrais, oeste e litorânea. A primavera e o verão são as estações do ano com os menores riscos de estiagem, enquanto que o outono e o inverno são as estações com maiores riscos.

**Palavras-chave:** anomalia climática, riscos climáticos, planejamento agrícola.

**PINTO, L. F. D.; NITSCHE, P. R.; SILVA, M. A. DE A. E; ALVES, D. S.; CALDANA, N. F. DA S.**
**EXTREME DROUGHTS AFFECT AGRICULTURE IN THE STATE OF PARANÁ, BRAZIL**

Recebido em 23/10/2020 e aprovado para publicação em 22/01/2021
DOI: http://dx.doi.org/10.15809/irriga.2021v1n2p297-307

## 2 ABSTRACT

The drought is a meteorological phenomenon that causes relevant impacts for the agricultural sector, being considered the main frustrating issue of harvests. This work aimed to quantify the risks of occurrence of extreme droughts in different macro-regions in the state of Paraná in the four seasons. Daily rainfall data from 30 weather stations from Rural Development Institute of Paraná (IDR-Paraná) and Meteorological System of Paraná (SIMEPAR) from 1976 to 2015 were used. For each year, the number of days without rainfall was determined for the summer, autumn, winter and spring quarters. The droughts were identified using the Gumbel probability density function, with the α and β parameters obtained from the Lieblein method at 20% probability. It was concluded that the state of Paraná is subject to periods of drought over 60 days, at any time of the year. The north and northwest regions are subject to greater risks of extreme droughts, followed by the central, western and coastal regions. Spring and summer are the seasons with the lowest risk of drought, while autumn and winter are the most risky.


**Keywords:** climate anomaly, climate risks, agricultural planning

## 3 INTRODUCTION

Drought is a complex meteorological phenomenon resulting from the interaction of several large-scale atmospheric anomalies. Its main causes are variations in ocean surface temperatures, atmospheric blocking formations, and the action of air masses (GRAYSON, 2013; TERASSI et al., 2018; GELCER et al., 2018). Its effects and consequences primarily affect agriculture but are also felt in economic, social, and environmental areas (DOUGLAS et al., 2015). It is considered one of the main factors of losses and damage in the agricultural sector, and its monitoring and monitoring are essential to mitigate its effects (BRAZ; PINTO; DE CAMPOS, 2017; CARMELLO, 2018).

The potential impacts of these events on Paraná's agriculture are significant, as the state's main economic activity is agribusiness. According to CONAB, in the 2019/2020 harvest, the state produced 40.8 million tons of grain, with approximately 41.4 million tons expected for 2020/2021, equivalent to 15.4% of the national production, estimated at 268.3 million tons (SOJA, 2021).

Furthermore, Paraná is located in the southern region of Brazil, with its largest extension below the Tropic of Capricorn, being a territory of climatic transition, which makes the action of meteorological elements in its territory extremely diverse (NITSCHE et al, 2019; SILVA et al, 2015; MELO et al, 2015; BERNARDES; AGUILAR; ABE, 1988). It is also subject to the effects of climatic events such as El Niño and La Niña, which are known for promoting intense rainfall and/or dry periods between seasons (TERASSI et al, 2018; JOZAMI; CONSTANZO; CORONEL, 2015). Thus, the origin of precipitation over Paraná is a result of this location and is strictly related to influential tropical and polar air masses derived from the Amazon and South Polar Ice Cap, respectively (ELY; DUBREUIL, 2017).

In regions at lower latitudes, in warmer months, in addition to the predominance of low-pressure systems, convective precipitation predominates. As latitude increases, the participation of high-pressure systems and frontal precipitation also increases (BORSATO; MENDONÇA, 2012). These same authors highlight that

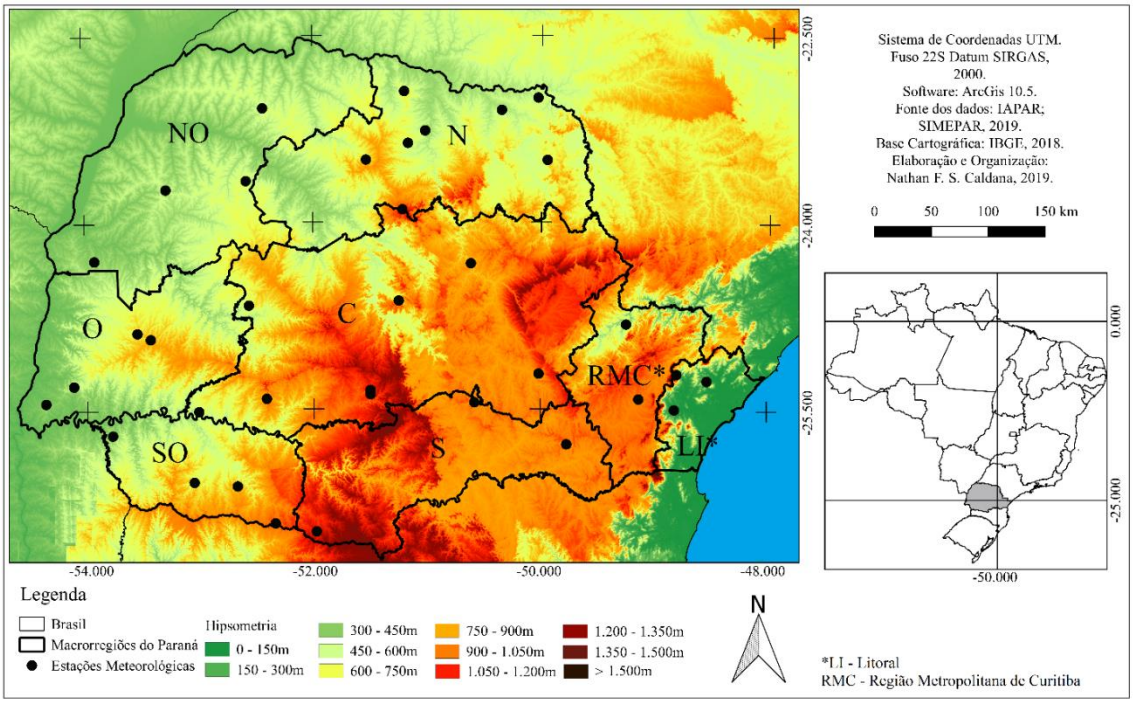
the state presents precipitation with high temporal, spatial, and volumetric variability. Bernardes, Aguilar, and Abe (1988) reported that, despite not having a defined dry season, in Paraná, the occurrence of long periods with no precipitation during the rainy months is common, which harms agriculture, especially during critical periods of crop development, such as flowering and grain filling (NASCIMENTO JÚNIOR; SANT'ANNA NETO, 2016).

In this context, the objective of this work was to quantify the risk of occurrence of extreme droughts in different macroregions in the state of Paraná during the four seasons of the year.

## 4 MATERIALS AND METHODS

The study was carried out in the state of Paraná, which is located in the southern region of Brazil, between 22° 30' S and 26° 43' S and meridians 48° 00' W and 54° 38' W. The climate is transitional between subtropical Cfa, with hot summers and concentrations of summer precipitation, without a defined dry season, and Cfb, which has a temperate climate with mild summers and without a defined dry season, with altitudes ranging from 0--1300 m (Figure 01).

**Figure 1.** Map with altitude (m), meteorological stations used and macroregions of the state of Paraná.




*North (N), northwest (NO), west (W), southwest (SW), central (C), southern (S), and metropolitan regions of Curitiba (RMC) and the coast (LI).
**Source:** Authors (2020)

Daily rainfall data from 1976--2015 were obtained from the network of meteorological stations of the Paraná Rural Development Institute IAPAR-EMATER (IDR-Paraná) and the Paraná Meteorological System (SIMEPAR), totaling 30 stations (Figure 1).

To identify extreme droughts, the maximum number of consecutive days without rainfall (NDS) for each year was calculated, considering only the days when

daily rainfall was less than or equal to 4 mm (TEIXEIRA et al., 2013).

Agronomically, during long periods of drought, these rainfall amounts alone are not sufficient to interrupt the water stress to which crops are subjected since they normally do not exceed potential evapotranspiration (ETP). For each year, the NDS was calculated for the quarters designated summer (December-January-February), autumn (March-April-May), winter (June-July August), and spring (September-October-November).

The Gumbel probability density function was used, which is defined as:

$$f(x) = \frac{1}{\beta} e^{-\frac{X-\alpha}{\beta} e^{-\frac{X-\alpha}{\beta}}} \quad (1)$$

where:

f(x)= Probability density function;

X = Number of days without rain;

β= position parameter or mode of the variable X;

α= scale parameter.

where the parameters α and β were obtained via the Lieblein method:

$$\alpha = \frac{a_j \sum X_j}{K} \quad (2)$$

$$\beta = \frac{b_j \sum X_j}{K} \quad (3)$$

where:

K = number of groups formed;

j = number of data used in the subset of group K.

The annual DNS data (40 years) were organized in chronological order and subdivided into ten groups (K) with four years in each (j). Within each group, the data were ordered in ascending order and weighted according to Lieblein's statistical weights (ASSIS; ARRUDA; PEREIRA, 1996).

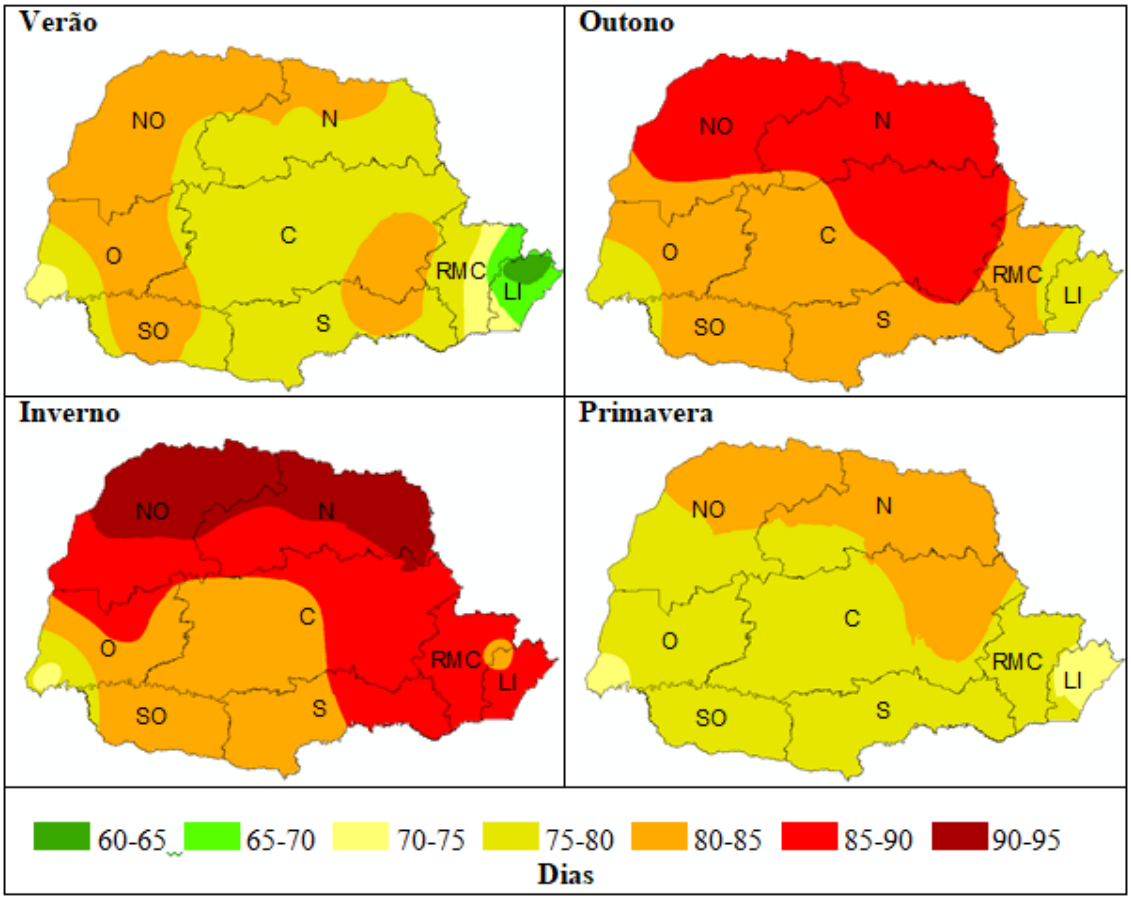
After sorting the data into groups, the probability function mentioned above (Equation (1)) was applied to obtain the frequency of NDS occurrence. A 20% probability value was adopted to estimate extreme drought, as this value is a reference for the climate risk zoning (ZARC) of the Ministry of Agriculture, Livestock and Food Supply (MAPA) (BRASIL, 2018a; BRASIL, 2018b).

On the basis of the georeferencing of meteorological stations and NDS probability values, ArcGIS ® 10.2 software was used for kriging interpolation, with a spatial resolution of 900 × 900 m, generating representative maps of extreme droughts for the quarters analyzed.

## 5 RESULTS AND DISCUSSION

The results show that extreme droughts in the state of Paraná can last between 60 and 95 days throughout the season (Figure 2). The longest dry period occurred in winter, lasting between 90 and 95 days, affecting the northern and northwestern regions of the state. This rainfall is likely dependent on the arrival of cold fronts, which naturally reduce the number of rainy days. The coast experiences the shortest dry periods, lasting between 60 and 65 days, in summer, possibly due to the direct influence of the Serra do Mar mountain range on the formation of orographic precipitation and the oceanic climate.

**Figure 2.** Duration, in days, of extreme droughts, with 20% probability, for the seasons of summer, autumn, winter and spring in the macroregions of Paraná in the period from 1976--2015.




*North (N), northwest (NO), west (W), southwest (SW), central (C), southern (S), and metropolitan regions of Curitiba (RMC) and the coast (LI)
**Source:** Authors (2020)

In general, the results of this work are consistent with those obtained by Fritzsons et al. (2011), whose climatic characterization for the state of Paraná presented periods of drought during the winter for the northern region, unlike the central and southern regions of the state, where they are considered regions of precipitation and intermediate drought.

During Paraná summer, periods of extreme drought typically range from 75--85 days (Figure 2). In the central and far western regions, there was a slight reduction, reaching between 75 and 80 days. In the north, northwest, a portion of the west and southwest, and a small portion of the center, the periods ranged between 80 and 85 days. Shorter periods, between 60 and 70 days, occur in the coastal region.

These differences in the duration of droughts across the state are explained by Wrege et al. (2016), who explain that the occurrence of intense and short-duration precipitation, but with great spatial variability, favors the occurrence of long periods of drought, especially in the summer. Furthermore, the formation of large masses of hot and dry air in the southwestern region of Brazil prevents the advance of frontal systems coming from the southern regions of the continent, making drought events more recurrent during the hottest seasons of the year (BORSATO; MENDONÇA, 2012; LEIVAS et al., 2014).

Considering that the state of Paraná is one of the largest grain producers in the country and that the summer harvest is the main growing season for soybeans and corn, long periods of drought, lasting between 75 and 85 days, can cause water stress and lead to productivity losses. Soybeans are more tolerant of short periods of drought, but a water deficit during the flowering and grain-filling periods represents the same level of loss as a deficit throughout the entire cycle (EMBRAPA, 2013). In other words, droughts during the reproductive period have greater impacts on crop yield than those during the growing season do (EMBRAPA, 2020). This is the opposite of what happens with corn crops, which are sensitive to water stress and short periods of drought in all stages of development. However, water deficit during the vegetative period directly affects the photosynthetic production of the plant and, consequently, the grain yield (JING et al., 2017; ZHANG et al., 2018).

During autumn in Paraná, periods of extreme drought range from 75--90 days, with three distinct regions (Figure 2). A large area in the north, northwest, and center, with droughts lasting 85--90 days; another area encompassing a central strip running from the west to the east of the state, with a dry period lasting between 80 and 85 days; and a third area with droughts lasting between 75 and 80 days located in the far west and on the coast of the state.

Winter crops are sown at this time of year: wheat, oats, rye, and others. For these crops, droughts during this period trigger problems with germination, initial development, and stand establishment (JAHAN et al., 2018; HUSSAIN et al., 2018). However, they can benefit some perennial crops, such as citrus and coffee, as their physiological cycle requires periods of water stress to break dormancy or achieve flowering uniformity (TOUNEKTI et al., 2018; MIRANDA et al. 2018; BALFAGÓN et al., 2018).

In Paraná's winter, the longest periods of extreme drought are observed, ranging from 75--95 days (Figure 2). The northern region stands out, with droughts lasting 90--95 days. Shorter periods are observed in the far west, lasting 75--80 days. In the other regions, extreme droughts range from 80--90 days.

With long periods of drought in winter, especially in the far north of the state, some winter crops, such as wheat, despite tolerating low temperatures and water deficits, suffer from decreased yield and production due to decreased soil moisture, especially during the germination and booting periods. This can cause flower sterility, resulting in incompletely filled grains (MONTEIRO, 2009). On the other hand, wheat crops respond positively when subjected to water deficit within 10 days prior to harvest (physiological maturity point). However, after this period, a decline in biomass accumulation and distribution may occur, contributing to loss of quality and devaluation of the grain (TRICKER et al., 2018; DELL'AMICO et al., 2016).

In the spring, the duration of drought in the state of Paraná ranged from 70--85 days (Figure 2). The highest values are recorded in the northern, northwestern, and northeastern regions of the state, with values between 80 and 85 days, and lower values are recorded for the coastal and far west regions, with values between 70 and 75 days. However, extreme values between 75 and 80 days without precipitation predominated in the other regions of the state.

Because it is a season affected by cold fronts and air masses, spring is characterized as a transition period, with greater variability in drought levels. This variability directly affects the agricultural sector, as it hinders the initial development of summer crops, such as corn and soybeans, and delays the crop cycle, directly affecting the planting of the following year's winter crops (KULMAN et

al., 2014; MARINS; MASSOQUIM; BORSATO, 2016; NÓIA JÚNIOR; SENTELHAS, 2019).

In general, the different regions of the state exhibit distinct behaviors regarding the number of days without rain, making quantifying the risk of extreme events crucial in current climate change scenarios, as an increase in the frequency and occurrence of these events has been observed (CAI et al., 2012; ZHANG; HU, 2018). Thus, the results obtained in this study allow for a better quantification of risks associated with droughts for the state of Paraná, serving as a tool for improving strategic planning in the agricultural sector, particularly with a view to achieving resilience to possible changes in climate risk.

## 6 CONCLUSIONS

The state of Paraná is subject to dry periods lasting more than 60 days in any season of the year, with differences between regions.

The northern and northwestern macroregions of the state of Paraná are subject to greater risks of extreme droughts, followed by the central, western and coastal regions.

The spring and summer seasons present the lowest risk of extreme drought, whereas the autumn and winter seasons present the highest risk of extreme drought.

## 7 REFERENCES

ASSIS, FN; ARRUDA, HV; PEREIRA, AR **Applications of statistics to climatology** . UFPel , Pelotas: Publisher University , 1996.

BALFAGÓN, D.; ZANDALINAS, SI; BALIÑO, P.; MURIACH, M.; GÓMEZ-CADENAS, A. Involvement of ascorbate peroxidase and heat shock proteins on citrus tolerance to combined conditions of drought and high temperatures. **Plant Physiology And Biochemistry** , Paris, vol. 127, n. 1, p. 194-199, jun. 2018.

BERNARDES, LRM; AGUILAR, AP; ABE, S. Frequency of occurrence of dry spells in the State of Paraná. **Geography Bulletin** , Maringá, v. 6, n. 1, p. 83-83, 1988.

BORSATO, V.; MENDONÇA, F.A. The Participation of the Atlantic Tropical Mass in the Weather State in South-Central Brazil. **Geonorte Magazine** , Manaus, v. 3, n. 8, p. 293-304, 2012.

BRAZIL. Ministry of Agriculture, Livestock and Supply. Secretariat of Agricultural Policy. Ordinance No. 257, of November 8, 2018. Agricultural Zoning of Climatic Risk for corn crops in the state of Paraná. **Official Gazette of the Union** : section 1, Brasília, DF, year 2018, no. 215, p. 4-69, November 8, 2018a

BRAZIL. Ministry of Agriculture, Livestock and Supply. Secretariat of Agricultural Policy. Ordinance no. 152, of July 20, 2018. Agricultural Zoning of Climatic Risk for soybean crops in the State of Paraná, crop year 2018/2019. **Official Gazette of the Union** : section 1, Brasília, DF, year 2018, no. 141 p. 4-159, July 20, 2018b.

BRAZ, DF; PINTO, LB; CAMPOS, CRJ Occurrence of severe events in agricultural regions of Rio Grande do Sul. **Geosciences** , Rio Claro, v. 36, n. 1, p. 89-99, 2017.

CAI, W.; LENGAIGNE, M.; BORLACE, S.; COLLINS, M.; COWAN, T.; MCPHADEN, MJ; TIMMERMANN, A.; POWER, S.; BROWN, J.; MENKES, C. More extreme swings of the South Pacific convergence zone due to greenhouse warming. **Nature** , London, vol. 488, no. 7411, p. 365-369, Aug. 2012.

CARMELLO, V. Soybean trend and yield variation in association with economic and social characterization in Paraná State, Southern Brazil. **Science and Nature** , Santa Maria, v. 40, p. e34, 2018.

SOYBEAN. **Monitoring the Brazilian Grain Harvest** : grains, Brasília, DF, v. 8, n. 5, p. 1-94, Feb. 2021. 2020/21 Harvest, Fifth survey. Available at: https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos. Accessed on: Feb. 25, 2021.

DELL'AMICO, JM; MARTIN, RM; MOMPIE, EIJ; GUEVARA, DM; LLERENA, RP Physiological response of wheat (*Triticum aestivum* L.) cultivar INCA TH 4 al water deficit. **Crops Tropicales** , La Habana, v. 37, no. 3, p. 94-102, 2016.

DOUGLAS, PMJ; PAGANI, M.; CANUTO, MA; BRENNER, M.; HODELL, DA; EGLINTON, TI; CURTIS, JH Drought, agricultural adaptation, and sociopolitical collapse in the Maya Lowlands. **The National Academy of Sciences** , Washington, DC, vol. 112, no. 18, p. 5607-5612, apr. 2015.

ELY, D.; DUBREUIL, V. Analysis of spatiotemporal trends of annual precipitation for the state of Paraná, Brazil. **Brazilian Journal of Climatology** , Curitiba, v. 21, n. 13, p. 553-569, 2017.

EMBRAPA. **Soybean Production Technologies** . Londrina: Embrapa Soja, 2013. (Production Systems, n. 16)

EMBRAPA. **Soybean Production Technologies** . Londrina: Embrapa Soja, 2020. (Production Systems, n. 17)

FRITZSONS, E.; MANTOVANI, LE ; WREGE, MS; CHAVES NETO, A. Analysis of rainfall to define homogeneous zones in the State of Paraná. **Raega -** Geographic Space in Analysis, Curitiba, v. 23, n. 16, p. 555-572, 2011.

GELCER, E.; FRAISSE, CW; ZOTARELLI, L.; STEVENS, FR; PERONDI, D.; BARRETO, DD; MALIA, HA; ECOLE, CC; MONTONE, V.; SOUTHWORTH, J. Influence of El Niño-Southern oscillation (ENSO) on agroclimatic zoning for tomatoes in Mozambique. **Agricultural and forest meteorology** , Amsterdam, v. 248, no. 1, p. 316-328, 2018.

GRAYSON, M. Agriculture and drought. **Nature** , London, vol. 501, no. 7468, p. S1, 2013.

HUSSAIN, J.; KHALIQ, T.; AHMAD, A.; AKHTAR, J. Performance of four crop models for simulations of wheat phenology, leaf growth, biomass and yield across planting dates. **PloS one** , San Francisco, v. 13, no. 6, p. e0197546, 2018.

JAHAN, MAHS; SEN, R.; ISHTIAQUE, S.; CHOUDHURY, AK; AKHTER, S.; AHMED, F.; BISWAS, JC; MANIRRUZAMAN, M.; MIAH, MM; RAHMAN, MM Optimizing sowing window for wheat cultivation in Bangladesh using CERES-wheat crop simulation model. **Agriculture, Ecosystems & Environment** , Amsterdam, vol. 258, no. 8, p. 23-29, 2018.

JING, Q.; SHANG, J.; HUFFMAN, T.; QIAN, B.; PATTEY, E.; LIU, J.; DONG, T.; DRURY, CF; TREMBLAY, N. Using the CSM-CERES-Maize model to assess the gap between actual and potential yields of grain maize. **The Journal of Agricultural Science** , Cambridge, vol. 155, no. 2, p. 239, 2017.

JOZAMI, E.; CONSTANZO, M.; CORONEL, A. Influence of "El Niño - Oscillation Sur " sobre las precipitations in Paraná and Lucas González (Entre Ríos , Argentina). **Revista de Climatology** , Spain , v. 15, no. 15, p. 85-92, 2015.

KULMAN, D.; REIS, JT; SOUZA, AC; SAUCERS, COFFEE; SAUSEN, TM Occurrence of Drought in Rio Grande do Sul in the period 1981 to 2011. **Science and Nature** , Santa Maria, v. 36, n. 3, p. 441-449, 2014.

LEIVAS, JF; ANDRADE, RG; VICTORIA, DC; TORRESAN, FH; VICENTE, LE; TEIXEIRA, AHC; BOLFE, EL; BARROS, TR Evaluation of the standardized vegetation index in the indicative monitoring of droughts in critical periods for soybean in Southern Brazil. **Brazilian Journal of Cartography** , Rio de Janeiro, v. 66, n. 5, p. 1145-1155, 2014.

MARINS, JAL; MASSOQUIM, NG; BORSATO, VA The influence of climate on the dynamics of the agricultural landscape in the Campo Mourão region/PR between 2005 and 2014. *In* : BRAZILIAN SYMPOSIUM ON GEOGRAPHIC CLIMATOLOGY, 12., 2016, Goiânia. **Proceedings** [...]. Goiânia: Abcclima , 2016. p. 1772-1782. Available at: http://www.abclima.ggf.br/sbcg2016/anais/arquivos/eixo_4/trabalho%20(2).pdf. Accessed on: February 25, 2019.

MELO, LC; SANQUETTA, CR; CORTE, APD; VIRGENS FILHO, JS Future climate scenarios for Paraná: opportunities for the forestry sector. **Brazilian Journal of Climatology** , Curitiba, v. 16, n. 11, p. 120-131, 2015.

MIRANDA, MT; SILVA, SF; MOURA, BB; HAYASHI, AH; MACHADO, EC; RIBEIRO, RV Hydraulic Redistribution in Citrus rootstocks under drought . **Theoretical and Experimental Plant Physiology** , Heidelberg, vol. 30, no. 3, p. 165-172, 2018.

MONTEIRO, JEBA (org.). **Agrometeorology of crops** : the meteorological factor in agricultural production. Brasília, DF: INMET, 2009.

NASCIMENTO JÚNIOR, L.; SANT'ANNA NETO, JL Contribution to precipitation studies in the state of Paraná: the Pacific decadal oscillation-PDO. **Raega -** Geographic Space in Analysis , Curitiba, v. 35, n. 3, p. 314-343, 2016.

NITSCHE, PR ; CARAMORI, PH; RICCE, WS; PINTO, LFD **Climate atlas of the state of Paraná** . Londrina: Instituto Agronomic of Paraná, 2019.

NÓIA JÚNIOR, RS; SENTELHAS, PC Soybean–maize off-season double crop system in Brazil as affected by El Niño Southern Oscillation phases. **Agricultural Systems** , Essex , vol. 173, no. 6, p. 254-267, 2019.

SILVA, WL; DERECZYNSKI, C.; CHANG, M.; FREITAS, M.; MACHADO, BJ; TRISTÃO, L.; RUGGERI, J. Observed trends in indicators of climate extremes of temperature and precipitation in the state of Paraná. **Brazilian Journal of Meteorology** , São José dos Campos, v. 30, n. 2, p. 181-194, 2015.

TEIXEIRA, CFA; DAMÉ, RCF; BACELAR, LCS; SILVA, GM; COUTO, RS Drought intensity using precipitation indices. **Environment & Water Journal** , Taubaté, v. 8, n. 3, p. 203-213, 2013.

TERASSI, PMB; OLIVEIRA-JÚNIOR, JF; GÓIS, G.; GALVANI, E. Variability of the Standardized Precipitation Index in the Northern Region of Paraná State Associated with El Niño -Southern Oscillation Events. **Brazilian Journal of Meteorology** , São José dos Campos, v. 33, n. 1, p. 11-25, Mar. 2018.

TOUNEKTI, T.; MAHDHI, M.; AL-TURKI, TA; KHEMIRA, H. Water relations and photoprotection mechanisms during drought stress in four coffee (Coffea arabica) cultivars from southwestern Saudi Arabia. **South African journal of botany** , Pretoria, v. 117, no. 4, p. 17-25, 2018.

TRICKER, PJ; ELHABTI, A.; SCHMIDT, J.; FLEURY, D. The physiological and genetic basis of combined drought and heat tolerance in wheat. **Journal of experimental botany** , Oxford, vol. 69, no. 13, p. 3195-3210, 2018.

WREGE, MS; FRITZSONS, E.; CARAMORI, PH; RICCE, WS; RADIN, B.; STEINMETZ, S.; REISSER JUNIOR, C. Regions with similar water behavior in Southern Brazil. **Raega** - Geographical Space in Analysis , Curitiba, v. 38, n. 3, p. 365-384, 2016.

ZHANG, O.; HU, Z. Assessment of drought during corn growing season in Northeast China. **Theoretical and Applied Climatology** , Wien, v. 133, no. 3, p. 1315-1321, 2018.

ZHANG, Y.; LOREAU, M.; HE, N.; WANG, J.; PAN, Q.; BAI, Y.; HAN, X. Climate variability decreases species richness and community stability in a temperate grassland. **Oecologia** , Berlin, v. 188, n. 1, p. 183-192, 2018.