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DISTRIBUTION OF WEATHER ELEMENTS AND ITS INFLUENCE ON CROPS IN THE NORTH REGION OF RIO GRANDE DO SUL STATE AND THE EXTREME WEST OF THE SANTA CATARINA STATE, BRAZIL

Distribuição dos elementos meteorológicos e sua influência nas culturas da região norte do estado do Rio Grande do Sul e extremo oeste do estado de Santa Catarina, Brasil

Distribución de los elementos meteorológicos y su influencia en las culturas en la región norte del estado de Rio Grande del Sul y el extremo oeste del estado de Santa Catarina, Brasil

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Abstract: Knowledge on the behavior of the meteorological elements of a region is of great importance for decision making, especially in agricultural cultivation, as they will directly influence the growth and development of crops. Therefore, the objective of this work was to know the distribution of meteorological elements by the nonparametric Kernel distribution and to analyze their influence on the cultivation of crops. The study was conducted using data obtained from the Automatic Weather Station A854-Frederico Westphalen. The station is located in the municipality of Frederico Westphalen, Rio Grande do Sul, Brazil. The meteorological elements used in the study were the incident global solar radiation, rainfall and average air temperature. The data were organized as overall, per year and per month. Nonparametric kernel density estimation method was used. The application of nonparametric Kernel density estimation method to the meteorological elements allowed us to observe the distribution

over the 10 years of record overall, in the year and in the month. Furthermore, the distribution made it possible to identify the highest peaks that are related to higher densities. The observation of 10 years of records of solar radiation, rainfall and air temperature data from the weather station by the nonparametric Kernel distribution method gives an indication of how the elements are presenting themselves in the period. Despite specific restrictions, the weather/climate is suitable for the cultivation of species that have been used in the region, following their zoning.
Keywords: Weather data. Growing plants. Agricultural zoning.

Resumo: O conhecimento do comportamento dos elementos meteorológicos de uma região é de grande importância para a tomada de decisões, principalmente no cultivo agrícola, pois influenciarão diretamente no crescimento e desenvolvimento das lavouras. Portanto, o objetivo deste trabalho foi conhecer a distribuição dos elementos meteorológicos pela distribuição não paramétrica de Kernel e analisar sua influência no cultivo de culturas. O estudo foi realizado com dados obtidos da Estação Meteorológica Automática A854-Frederico Westphalen. A estação está localizada no município de Frederico Westphalen, Rio Grande do Sul, Brasil. Os elementos meteorológicos utilizados no estudo foram a radiação solar global incidente, precipitação e temperatura média do ar. Os dados foram organizados em geral, por ano e por mês. Foi utilizado o método não paramétrico de estimativa da densidade do kernel. A aplicação do método não paramétrico de estimativa de densidade Kernel aos elementos meteorológicos permitiu observar a distribuição ao longo dos 10 anos de registo globalmente, no ano e no mês. Além disso, a distribuição possibilitou identificar os picos mais altos que estão relacionados a densidades mais altas. A observação de 10 anos de registros de dados de radiação solar, precipitação e temperatura do ar da estação meteorológica pelo método não paramétrico de distribuição de Kernel dá uma indicação de como os elementos estão se apresentando no período. Apesar de restrições específicas, o clima/tempo é adequado para o cultivo de espécies que vêm sendo utilizadas na região, seguindo seu zoneamento.
Palavras-chave: Dados meteorológicos. Crescimento de plantas. Zoneamento agrícola.

Resumen: El conocimiento del comportamiento de los elementos meteorológicos en una región es de gran importancia para la toma de decisiones, especialmente en el cultivo agrícola, ya que influirán directamente en el crecimiento y desarrollo vegetal. Así, el objetivo del trabajo fue conocer la distribución de elementos meteorológicos por la distribución no paramétrica de Kernel y analizar su influencia en el cultivo. El estudio se realizó con datos obtenidos de la Estación Meteorológica Automática A854-Frederico Westphalen. La estación está ubicada en la ciudad de Frederico Westphalen, Rio Grande do Sul, Brasil. Los elementos meteorológicos utilizados en el estudio fueron la radiación solar global incidente, la precipitación y la temperatura media del aire. Los datos se organizaron en general, por año y por mes. Se utilizó el método no paramétrico de estimación de la densidad de grano. La aplicación del método no paramétrico de estimación de densidad Kernel a los elementos meteorológicos permitió observar la distribución a lo largo de los 10 años de registro, en el año y en el mes. Además, la distribución permitió identificar los picos más altos que se relacionan con densidades más altas. La observación de 10 años de registros de datos de radiación solar, precipitación y temperatura del aire de la estación meteorológica mediante el método no paramétrico de distribución de Kernel da una indicación de cómo se comportan los elementos en el período. A pesar de restricciones específicas, el clima es propicio para el cultivo de especies que han sido utilizadas en la región, siguiendo su zonificación.
Palabras clave: Datos climatológicos. Crecimiento vegetal. Zonificación agroclimática.

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1. INTRODUCTION

Climate is an essential factor in decision-making in agriculture, civil construction, transport and especially in the configuration of native vegetation, distribution of fauna and river flows. All these points are of utmost importance for the functionality of the economy and life on earth (MARTÍN, 1999). In this context, there are conventional or automatic weather stations, or remote orbital sensors present in all regions for the generation of meteorological data (LUCAS et al. 2014; CAMERA et al. 2014; VIANNA et al. 2017).

The recommendation for the density of each weather station is an area of 9,000 km² per station in coastal locations, 5,750 km² per station in flat and gently rolling areas and 2,500 km² per station in mountainous regions (WMO, 1994). However, in Brazil, the density of weather stations is very low, with locations where it is not possible to cover the entire territorial area (HAMADA et al. 2008; ALVARES et al. 2013). The weather station in the municipality of Frederico Westphalen is in the extension of the Federal University of Santa Maria, which has been in operation since December 13, 2007. The automatic weather station A854-Frederico Westphalen assists in civil construction, studies in the region and in the zoning of agricultural and forestry crops.

Meteorological databases are designed to receive, store, process and make available information on meteorological elements (solar radiation, rainfall, air temperature) (VIANNA et al. 2017). These elements allow the definition of zoning of potential areas for agriculture, analysis of areas subject to climatic risks (SANTOS and MARTINS 2016) and conduction of climate studies (VIANNA et al. 2017). Meteorological variability between and within the years is considered to have direct and indirect effects on the availability of natural resources such as solar radiation, water and nutrients for plants, directly impacting their growth and development (BINKLEY et al. 2004).

The critical meteorological elements associated with agricultural production, according to Hoogenboom et al. (2000), are rainfall, air temperature and solar radiation. The influence of these elements on the plant is enhanced when two of them act simultaneously. Air temperature and solar radiation are crucial elements for photosynthesis, contributing to the development and thermal control of the plant and to the production of photoassimilates destined for the accumulation of biomass, in addition to influencing the evapotranspiration processes (SILVA et al. 2021).

Rainfall is considered a modifying element, which indirectly affects many processes of plant growth and development. Plant stress influenced by low rainfall is a result of a combination of factors such as potential evapotranspiration, soil moisture in the rooting zone, root distribution, canopy size etc. (GONÇALVES et al. 2017). In many cases, the response to water stress can affect plants differently during vegetative and reproductive growth. Plant cells when subjected to water deficit become dehydrated, adversely affecting several basic physiological processes, for instance causing reduction in carbon assimilation through stomata, and directly affecting photosynthetic processes and biomass production (TAIZ et al. 2017).

The variation of climatic conditions can change throughout the year and day, especially in relation to solar radiation, as well as the alternation of hot and cold periods, which influence the phenology of plants (BERGAMASCHI, 2007). Therefore, for farmers to benefit from weather conditions, information must be presented in the form of results on a scale relevant to their decisions (BAETHGEN et al. 2009). Thus, according to Apipattanavis et al. (2010), it becomes necessary to demonstrate raw climatic information in distributions of results relevant to agricultural management and cultivation. This, the study sought to use the nonparametric kernel distribution in the meteorological elements (incident global solar radiation, rainfall and air temperature) recorded by an automatic station located in the municipality of Frederico Westphalen, Rio Grande do Sul, in the period from 2008 to 2017, since they have different distributions. Therefore, the objective of this study was to know the distribution of meteorological elements by the nonparametric kernel distribution and to analyze their influence on the cultivation of crops.

2. MATERIAL AND METHODS

2.1. Location

The study was conducted using data obtained at the Automatic Weather Station A854-Frederico Westphalen from the National Institute of Meteorology (Figure 1). The station is located on the campus of the Federal University of Santa Maria in the municipality of Frederico Westphalen, Rio Grande do Sul, Brazil, at the geographic coordinates 27º 23’ 44”S and 53º 25’ 46”W. According to Köppen’s climate classification, the climate of the region is Cfa type, characterized by an average air temperature of 19.1 °C, ranging from 0 to 38 °C, and an average annual precipitation of 2,040 mm (ALVARES et al. 2013).

Figure 1 - Automatic weather station in Frederico Westphalen, Rio Grande do Sul, Brazil (a), central storage panel called datalogger (b), pyranometer and tipping rain gauge (c) and the place where the sensor that records the air temperature is located (d).

Source: Prepared by the authors.

2.2. Meteorological elements

The meteorological elements used for the study were the incident global solar radiation, rainfall and maximum, minimum and average air temperature, recorded by the automatic weather station in the period from 2008 to 2017, totaling ten years of record (Figure 1a).

Incident global solar radiation was recorded by a Pyranometer, which is installed next to the station tower at a height of 1.5 m (Figure 1b). In the same place there is a rain gauge, which measures rainfall in millimeters (Figure 1c). The average air temperature is recorded by a sensor that is located inside a metal protection fixed to the main tower of the station at a height of 3 m, as shown in Figure 1d.

These sensors and meters need energy to perform the record, which comes from a photovoltaic panel also present in the station. The record is performed every hour, totaling 24 daily values. The recorded data are stored in the central panel present in the station, called *Datalogger*, which is also used to control the transmission of data via satellite to the website of the National Institute of Meteorology.

The data were downloaded from the National Institute of Meteorology website, in the station data table. In the case of the study in question, data from the Automatic Weather Station A854-Frederico Westphalen were used (https://tempo.inmet.gov.br/TabelaEstacoes/A854). The interval between performing the search and downloading the data must not exceed six months. Thus, over the 10 years of recording meteorological elements, data were downloaded every month. The folder generated by the download is in Excel.csv format.

Data were organized into three different sets:

i. **Overall:** all values of each element were recorded over the 10 years in order to evaluate the overall distribution;

ii. **Per year:** each element was analyzed in the year, making it possible to evaluate the distribution between the years;

iii. **Per month:** the data are analyzed by month, making it possible to evaluate the distribution in the coldest and hottest months of the year and the weather characteristics during the 12 months.

2.3. Kernel density estimation – KDE

Nonparametric density estimation is an important tool in statistical analysis. Kernel density estimation, which is a nonparametric method of estimating density functions, was used to observe the distributions of the meteorological elements in question over the 10 years. For a set of observations X1, X2 X3, ..., Xn (X can be a scale or vector), the Kernel estimator is given by the following equation:

(1) $$\hat{f}(x)=\frac{1}{nh}\sum_{i=1}^{n}K\left(\frac{x-X1}{h}\right)$$

Where: h is the bandwidth, X1, X2 X3, ..., Xn are independent and identically distributed random variables and K is the kernel function (Gaussian Kernel) proposed by Silverman (1986).

The bandwidth (h) parameter that defines the smoothness of the estimated kernel density function was optimized using the best-known method, the rule of thumb of Silverman (1986), which refers to a family of distributions and is given by:

(2) $$h_0x=1.06\cdot \sigma x \cdot n^{-1/5}$$

Where: σx is the standard deviation of the values of x at the locations of presence.

The bandwidth of a Kernel is determined by the amount of smoothing applied to a dot pattern. A very small bandwidth can smooth the dot patterns, but a larger bandwidth can have the opposite effect. Thus, algorithms are commonly used to find optimal bandwidths (DOWNS and HORNER, 2012). The advantage of the rule of thumb of Silverman (1986) is that it provides a practical method of bandwidth selection.

2.4. Data processing

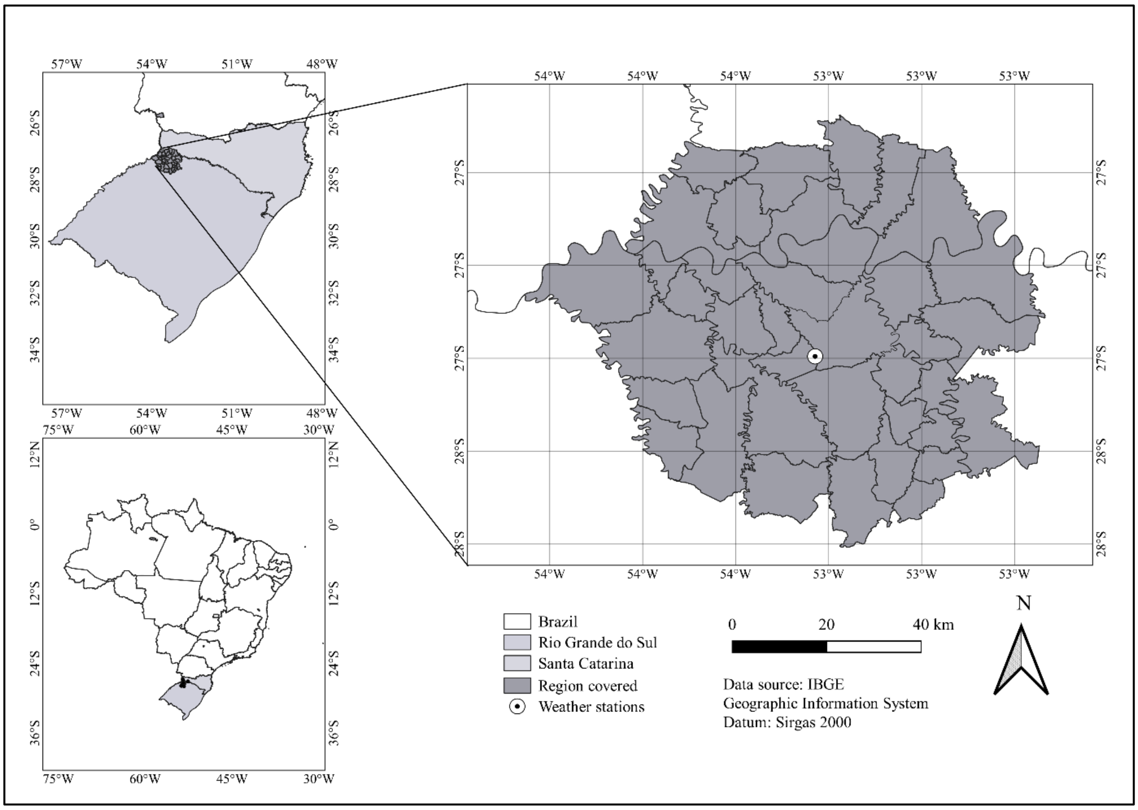
Data were analyzed using Julia programming language version v.1.5. In this language, the following packages were used: DataFrames.jl, responsible for the manipulation and tabulation of the data; Distributions.jl, helping in the probabilistic distribution; KernelDensity.jl, used to perform the nonparametric kernel density estimation; and PyPlot.jl, used to plot the results.

3. RESULTS AND DISCUSSION

3.1. Coverage area of the weather station

The meteorological station covers a radius that can cover 39 cities in the northern regions of the state of Rio Grande do Sul and the extreme west of the state of Santa Catarina, serving as support for decision-making, especially in agricultural production in these regions (Figure 2).

Figure 2 - Location of municipalities covered by the Frederico Westphalen weather station, Rio Grande do Sul, Brazil.



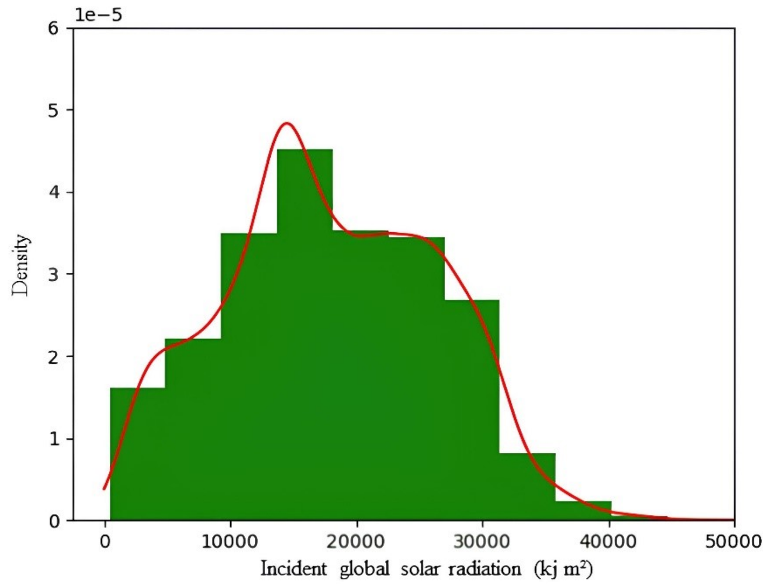
Source: Prepared by the authors.

The closest weather stations to the Frederico Westphalen station are those located in the municipalities of Palmeira das Missões and Santo Augusto in the state of Rio Grande do Sul, at distances of 59.3 and 62.1 km, respectively, and those located in the municipalities of São Miguel do Oeste and Chapecó in the state of Santa Catarina, at distances of 69.1 and 85.8 km, respectively, considering a straight line. Considering that all of them are located at a distance of more than 50 km, the Frederico Westphalen weather station is of great importance for the region, as it is located in a large agricultural center and its records become fundamental for crop management.

3.2. Solar radiation

The values of daily solar radiation in the period of 10 years by the fit of the Kernel density estimate (KDE) showed a positive skewed distribution. The peak with the highest density was recorded close to 18,000 $KJ.m^{-2}.day^{-1}$, with other smaller peaks concentrated at 27,000 $KJ.m^{-2}.day^{-1}$ and 5,000 $KJ.m^{-2}.day^{-1}$. These solar radiation values ranged from 450 $KJ.m^{-2}.day^{-1}$ to 45,000 $KJ.m^{-2}.day^{-1}$ (Figure 3).

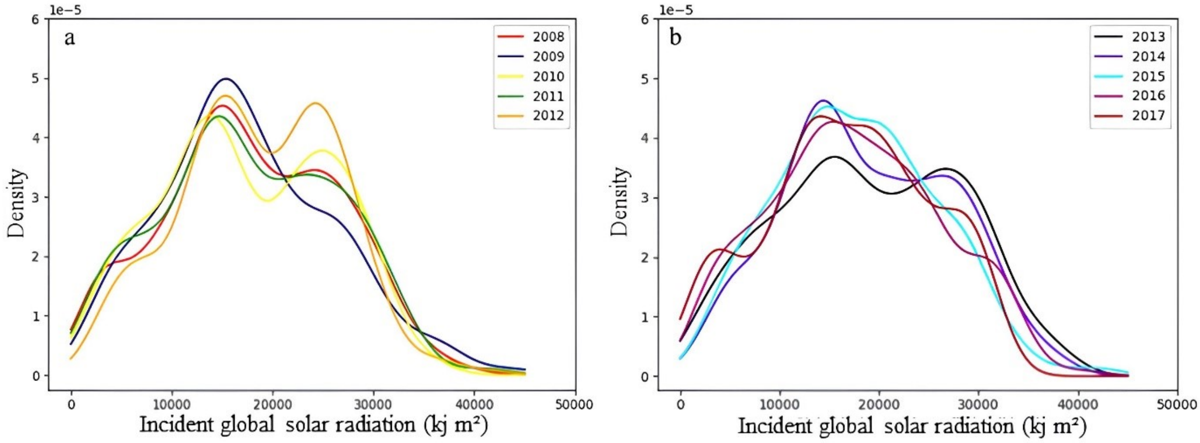
Figure 3 - Incident global solar radiation recorded between the years 2008 to 2017, adjusted by the Kernel density estimation function.



Source: Prepared by the authors.

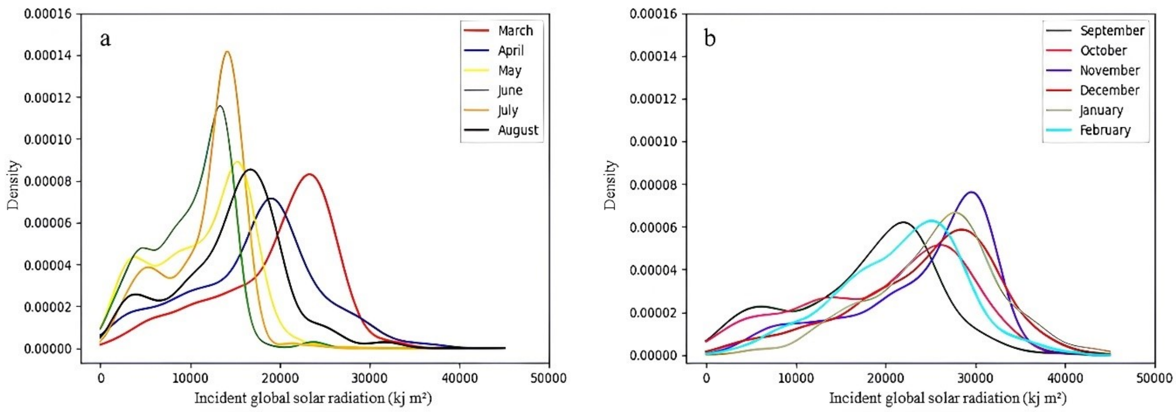
The number of peaks found when the data are presented as overall may be related to the differences in the incidence of solar radiation throughout each year (Figure 4) and each month (Figure 5).

Figure 4 - Incident global solar radiation per year recorded over ten years, adjusted by the Kernel density estimation function. Between 2008-2012 (a) and 2013-2017 (b).



Source: Prepared by the authors.

Figure 5 - Incident global solar radiation per month recorded between 2008 to 2017, adjusted by the Kernel density estimation function. Between March and August (a) and September to February (b).



Source: Prepared by the authors.

Over the years, the data also tended towards the same distribution, that is, in a positive skewed way. All years except 2009 and 2015 showed a well-defined bimodality, with large density peaks, the first occurring around 13,000 KJ.m^{-2}.day^{-1} and the second peak in the years 2008, 2010, 2011 and 2012, around 25,000 KJ.m^{-2}.day^{-1}, and for the years 2013, 2014, 2016 and 2017 close to 29,000 KJ.m^{-2}.day^{-1}. The year with the highest incidence of solar radiation was 2013, with an annual average of 19,104.06 KJ.m^{-2}.day^{-1}, whereas 2017 had the lowest incidence of annual solar radiation, equal to 16,946.83 KJ.m^{-2}.day^{-1} (Table 1).

Table 1 - Descriptive statistics of incident global solar radiation per year recorded over ten years.

Year	Incident global solar radiation (KJ m². day^{-1})			Band width
	Average	Standard deviation	Coefficient of variation	
2008	17,763.86	8,533.70	48.04	0.84
2009	17,482.05	8,521.30	48.74	1.42
2010	17,495.78	8,432.53	48.20	1.64
2011	17,735.68	8,698.08	49.04	1.71
2012	18,562.71	7,750.94	41.76	1.60
2013	19,104.06	9,197.39	48.14	2.47
2014	18,947.43	8,400.48	44.34	1.55
2015	17,850.61	8,020.69	44.93	3.59
2016	17,604.24	8,572.94	48.70	1.49
2017	16946.83	8235.34	48.60	1.38

Source: Prepared by the authors.

Regarding the incident global solar radiation in the months, it was observed that in most months of the autumn and winter seasons (Figure 5b) a positive skewed distribution still prevailed, with the highest density of peaks occurring between 13,000 KJ.m^{-2}.day^{-1} and 23,000 KJ.m^{-2}.day^{-1}. In the months of June, July and August there was a second peak close to 5,000 KJ.m^{-2}.day^{-1}. In most months of the spring and summer seasons, the data distribution tended towards a negative skewness, with peaks of higher density between 22,000 KJ.m^{-2}.day^{-1} and 29,000 KJ.m^{-2}.day^{-1}; the highest incidence of solar radiation was recorded in January, with an average of 25,512.13 KJ.m^{-2}.day^{-1}, and the lowest value was recorded in June, an average of 10,035.39 KJ.m^{-2}.day^{-1} (Table 2).

Table 2 - Descriptive statistics of incident global solar radiation per month, recorded between 2008 to 2017.

Month	Incident global solar radiation (KJ m². day^{-1})			Band width
	Average	Standard deviation	Coefficient of variation	
January	25,512.13	7,032.12	27.56	1.81
February	21,724.32	6,836.00	31.47	1.79
March	19,460.25	6,463.51	33.21	1.18
April	16,977.58	7,229.78	42.58	1.20
May	11,269.71	5,224.14	46.36	0.81
June	10,035.40	4,297.50	42.82	0.59
July	11,656.05	4,218.75	36.19	0.66
August	14,395.45	5,994.41	41.64	0.99
September	17,822.96	7,678.06	43.08	0.56
October	20,062.47	8,779.38	43.76	1.44
November	24,019.11	7,742.93	32.24	0.69
December	24213.63	7982.16	32.97	1.89

Source: Prepared by the authors.

The distributions of solar radiation in the studied period bring the possibility of knowing their variations over time and according to the seasons. The values recorded are within the ideal range for agricultural and forestry crops, and this meteorological element is not limiting for the exploitation of agricultural systems covered by the data.

Among the most cultivated crops in the region covered by the weather station are corn (*Zea mays*), soybean (*Glycine max*) and wheat (*Triticum aestivum* L.) and, as a more frequent perennial crop, eucalyptus (*Eucalyptus* spp.). Among these crops, only corn has C4 metabolism, which produces a high concentration of CO_2, supplying its activities and eliminating photorespiration, allowing corn plants to be more efficient in capturing solar radiation. Unlike corn, soybean, wheat and eucalyptus have C3 metabolism and, unlike C4, are less efficient in capturing solar radiation, thus requiring greater availability. However, all these crops can be grown in this region, as there is no extreme radiation deficit, even in winter, when cloudy days are more frequent.

According to Monteiro (2009), for the cultivation of eucalyptus, care must be taken in places with undulating relief because, for a certain part of the day, the slopes facing the plantation may not have an incidence of direct solar radiation, which may affect yield.

Larcher (2003) also mentions that on the slopes of mountains, the incidence of radiation can be reduced by up to 60%, when they are positioned in the north-south direction, consequently decreasing the period of direct light.

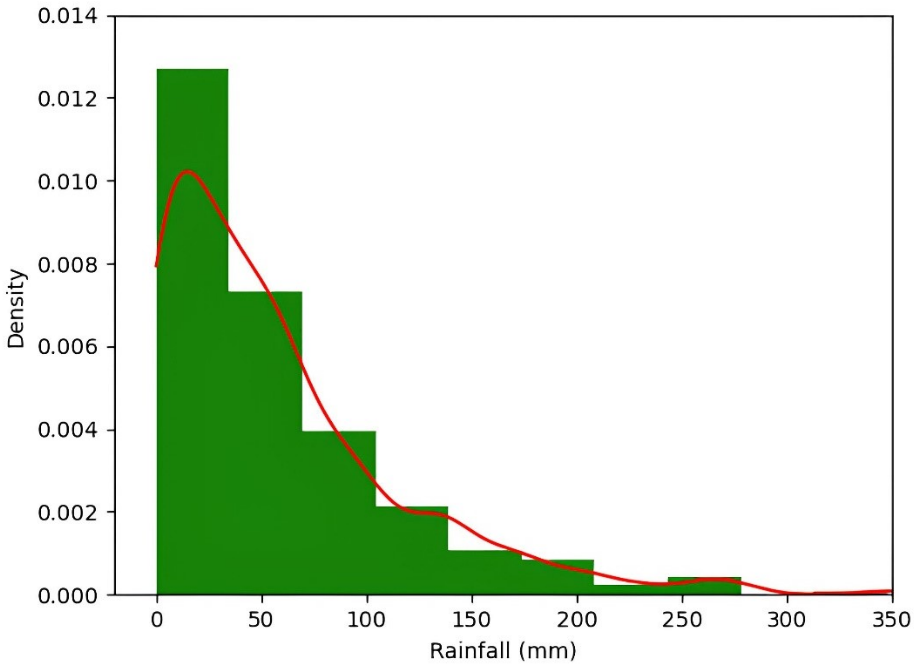
The cultivation of plants in protected environments also deserves attention, as the incidence of solar radiation is lower than outside due to the reflectance and absorbance of the covering material (plastic). According to Buriol et al. (1995), Frisina and Escobedo (1999) and Beckmann et al. (2006), the transmittance of plastic is on average 77%, other authors such as Reis et al. 2012 found transmittance around 62%, but for the northeast region of Brazil. In these environments, there is a large production of vegetables and forest seedlings. For these vegetables, the incidence of daily available solar radiation of 8,400 $KJ.m^{-2}.day^{-1}$ is taken as a reference (FAO, 1990). For the month of June, which has the lowest incidence of solar radiation (10,035.39 $KJ.m^{-2}.day^{-1}$), and after correcting the transmissivity of the plastic present, an average daily value of 7,727.26 $KJ.m^{-2}.day^{-1}$ is obtained, below the trophic limit of plants.

Buriol et al. (2005), when evaluating the availability of solar radiation for vegetables grown in a protected environment in the state of Rio Grande do Sul, found lower values of solar radiation in the month of June, through data collected at the Iraí station, located near Frederico Westphalen and belonging to the same region of study. The authors highlight in their work that crops in Rio Grande do Sul are concentrated in two periods. In the first, flowering must occur by the end of May, so that the harvest is carried out until June. The second crop can be started in July, for fruiting to occur after the levels of incidence of solar radiation are below the trophic limit (8,400 $KJ.m^{-2}.day^{-1}$). However, the solar radiation requirement varies according to species and cultivars.

3.3. Rainfall

Rainfall through KDE over the 10-year period showed a negative exponential distribution (Figure 6). Along the distribution it can be observed that there were three peaks with different densities. The highest peak occurred near 20 mm, and the others occurred at 140 mm and 270 mm, consequently, the peak density for precipitation accumulated is every 10 days. In general, the average precipitation accumulated every ten days was 5.80 mm, ranging from 0 to 350 mm.

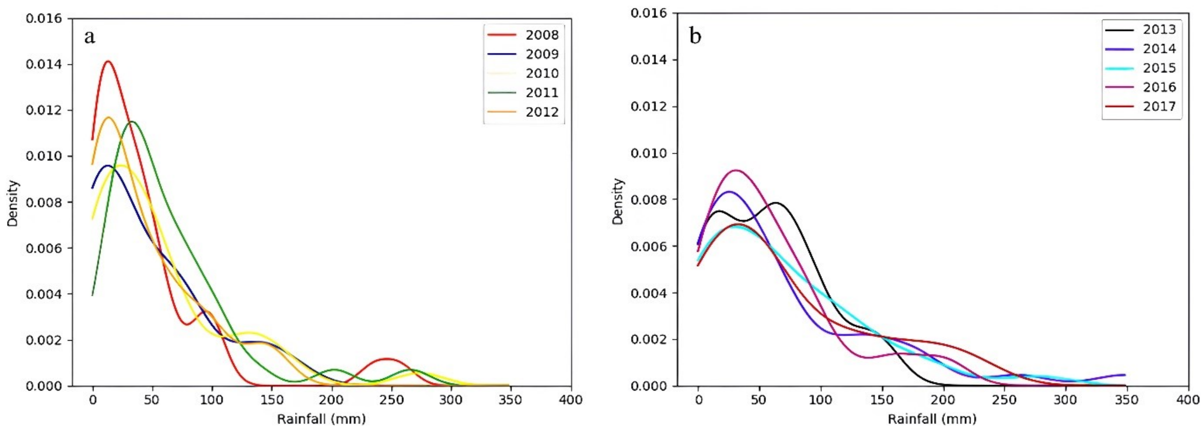
Figure 6 - Precipitation recorded, between the years 2008 to 2017, adjusted by the Kernel density estimation function.



Source: Prepared by the authors.

The negative exponential behavior of the precipitation distribution was also found when observed throughout each year in a 10-day accumulation (Figure 7). Most years had their peak with the highest density close to 40 mm of rainfall, except for 2008, 2009, 2012 and 2013, when the peak was concentrated around 10 mm.

Figure 7 - Precipitation per year recorded over ten years, adjusted by the Kernel density estimation function. Between 2008-2012 (a) and 2013-2017 (b).



Source: Prepared by the authors.

Every year the rainfall showed a distinct bimodality, especially in 2008, 2011 and 2013, which had more than one defined peak. For 2008, they were found at 40, 100 and 250 mm. In 2011, the first peak was close to 40 mm, in addition to one around 200 mm and another at approximately 270 mm. For the year 2013, the peaks were concentrated at 40 and 70 mm. In addition, the annual average of rainfall considering the ten-day accumulation was 2,103.16 mm, ranging from 1,578.66 mm (2012) to 2,627.78 mm (2017), years with lowest and highest rainfall, respectively (Table 3).

Table 3 - Descriptive statistics of accumulated precipitation every ten days recorded over ten years.

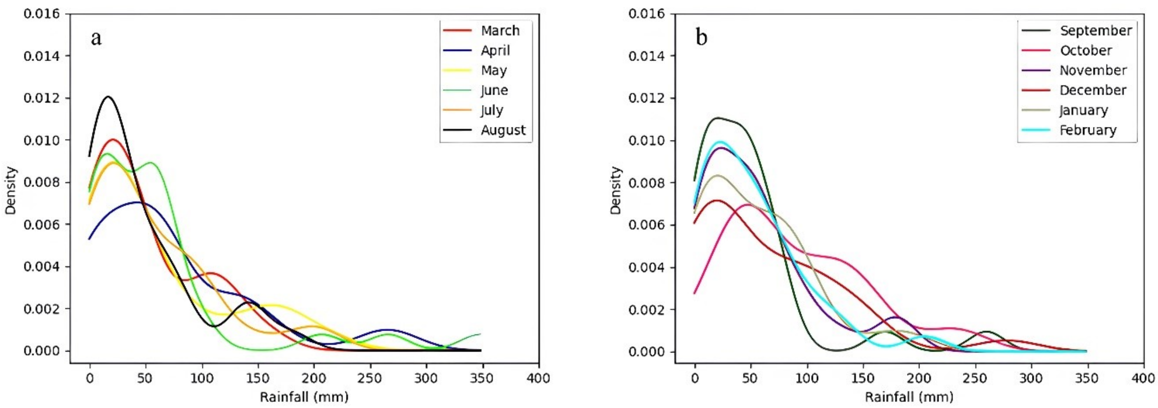
Year	Rainfall (mm)			Band width
	Average	Standard deviation	Coefficient of variation	
2008	44.23	9.35	25.27	8.48
2009	44.52	9.87	24.11	5.13
2010	54.96	9.91	34.85	18.78
2011	61.93	8.88	43.90	17.08
2012	43.25	7.34	28.36	9.92
2013	57.25	7.34	42.34	3.38
2014	70.89	13.08	44.34	2.93
2015	67.66	10.81	45.71	7.55
2016	59.52	8.86	41.53	22.82
2017	71.99	11.34	48.96	8.91

Source: Prepared by the authors.

When comparing the first five years of record (Figure 7a) with the last five years (Figure 7b), coincidentally, a tendency was observed in the distribution of rainfall in the evaluated years. Between the years 2008 and 2012, the peaks show a more concentrated distribution in a smaller range, that is, between 10 and 150 mm. Between the years 2013 and 2017, the distribution of values is concentrated between 10 and 200 mm. The distribution of rainfall is correlated with the events of El Niño and La Niña. For the years 2008 and 2012, according to NOAA (2022) El Niño predominated and, for the years 2015 to mid-2016, the predominance was La Niña.

There is an exponential distribution of rainfall data per month (Figure 8), the same one found in rainfall considering the 10 years and per year, except for the month of October, which showed a positive skewed distribution. October was also the month with the highest volume of rainfall, unlike August, which had the lowest volume of precipitation (Table 4).

Figure 8 - Precipitation per month recorded, between the years 2008 to 2017, adjusted by the Kernel density estimation function. Between March and August (a) and September to February (b).



Source: Prepared by the authors.

Table 4 - Descriptive statistics for accumulated precipitation every ten days considering per month recorded between the years 2008 to 2017.

Month	Rainfall (mm)			Band width
	Average	Standard deviation	Coefficient of variation	
January	54.75	48.87	89.26	15.73
February	50.61	46.21	91.31	19.80
March	48.67	46.47	95.48	16.07
April	70.61	70.95	100.47	5.78
May	58.09	62.52	107.61	14.13
June	61.55	79.17	128.61	7.10
July	54.37	54.68	100.58	5.24
August	45.57	48.98	107.50	13.32
September	47.79	55.20	115.50	18.51
October	89.32	60.89	68.17	15.01
November	53.68	49.05	91.37	22.06
December	63.74	65.54	102.82	14.04

Source: Prepared by the authors.

For the distribution analyzed in the months, accumulated every 10 days, the peaks with the highest density were also approximately between 10 and 50 mm. All months showed bimodality with well-defined peaks, except December, which had a single peak close to 20 mm. The month of August had the peak with the highest density, close to 10 mm accumulated weekly; on the other hand, the values tend to show better distribution throughout the month.

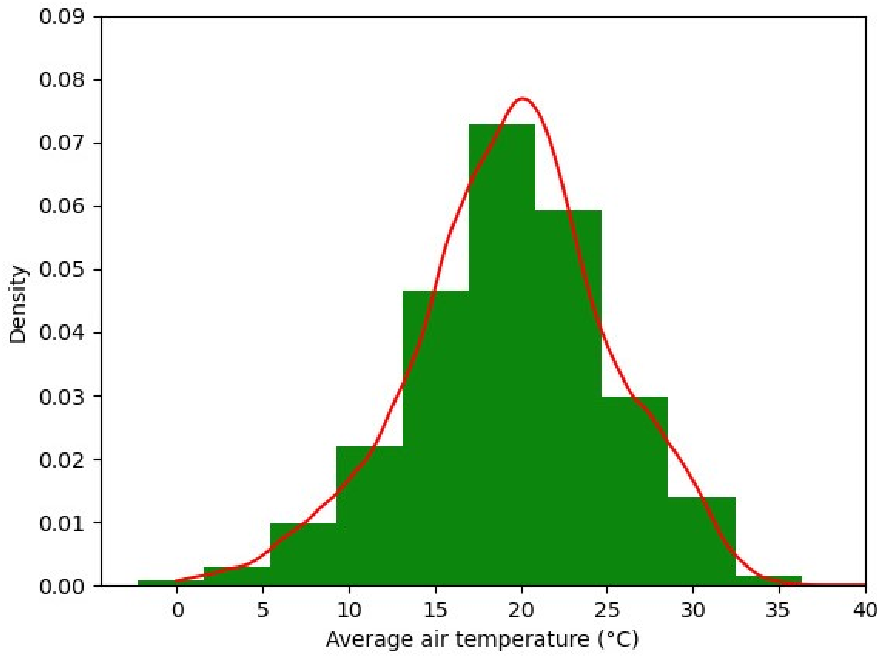
Summer crops tend to be planted from August in the study region. This month was the one with the lowest rainfall in the studied period, but in the months of September and October there is a maintenance of rainfall, with its highest peaks at 40 and 50 mm and average rainfall accumulated every 10 days of 47.8 and 89.3 mm, consequently promoting growth and development within the recommended range for summer crops grown in the region, which have a water requirement of 600 to 700 mm throughout their cycle (MONTEIRO, 2009).

This information must be accompanied by a study of the water balance of the region, especially regarding the variation of water storage in the soil, as well as the loss through evapotranspiration of crops and the recharge of water in the soil, which are related to its availability to crops. In the region, due to the predominant type of soil (deep Neossolo Litólico eutrófico típico - Entisol) (CUNHA, 2011), the water storage capacity in the soil is between 100 and 150 mm. Therefore, rainfall between 20 and 50 mm is well desired for water infiltration into the soil and its recharge, considering that the soil water balance is positive.

3.4. Air temperature

The average daily air temperature values by the KDE method, over the years, tended to a normal distribution curve (Figure 9). Over the 10 years, the temperature varied from -2.3 to 36.3 °C, with an overall average temperature of 19.4 °C. The same average temperature was recorded where the single peak with the highest data density occurred.

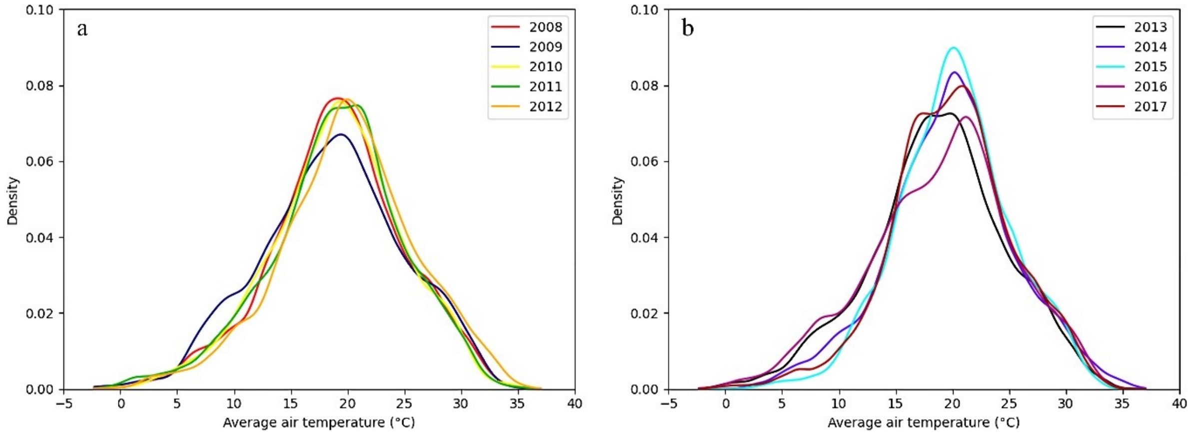
Figure 9 - Average air temperature recorded between 2008 to 2017, adjusted by the kernel density estimation function.



Source: Prepared by the authors.

The average air temperature over the years had the same normal distribution trend of the data, except for 2016 and 2017, which tended to be bimodal, with two peaks close to 17 and 21 °C (Figure 10). The other years showed only one peak with higher density in the range of 18 to 22 °C. This difference of 5 °C in the density of the peak found was observed throughout each year. However, the highest average temperature was 19.5 °C, recorded in 2015, and the lowest was 17.9 °C, for the year 2009 (Table 5).

Figure 10 - Average air temperature per year recorded over ten years, adjusted by the Kernel density estimation function. Between 2008-2012 (a) and 2013-2017 (b).



Source: Prepared by the authors.

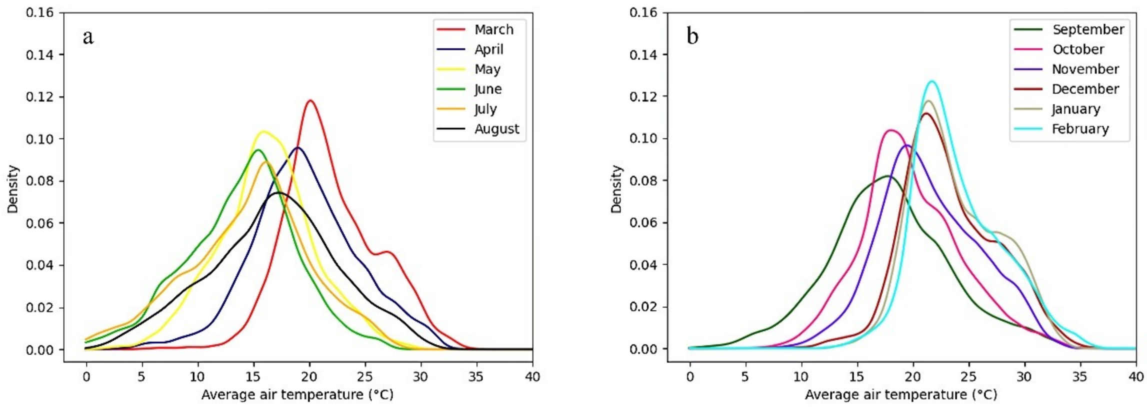
Table 5 - Descriptive statistics of the average air temperature per year recorded over ten years.

Year	Average air temperature (°C)			Band width
	Average	Standard deviation	Coefficient of variation	
2008	19.16	5.80	30.27	0.78
2009	18.66	6.29	33.69	0.83
2010	19.05	5.78	30.34	0.88
2011	19.05	5.90	30.97	0.72
2012	20.02	6.00	29.98	0.81
2013	18.78	5.95	31.66	0.56
2014	19.84	5.60	28.23	0.51
2015	20.13	5.00	24.82	0.51
2016	18.98	6.30	33.20	0.53
2017	19.91	5.34	26.83	0.64

Source: Prepared by the authors.

The air temperature when observed throughout each month is visible a variation between them. This fact is considered normal, because the occurrence of well-defined seasons throughout the year, with hotter and colder months, directly influences the average temperature (Figure 11). The data distribution followed the same temperature trend over the 10 years and each year, approaching a normal distribution, showing peaks with higher density ranging from 15 to 23 °C.

Figure 11 - Average air temperature per month recorded between 2008 to 2017, adjusted by the Kernel density estimation function. Between March and August (a) and September to February (b).



Source: Prepared by the authors.

The months of March, December and January had a bimodality by the fit. March had its highest density peak near 21 °C and its lowest at 27 °C. For the months of December and January, the peak with the highest density was approximately 23 °C and the peak with the second highest density was near 29 °C.

The highest average air temperature was obtained in January, 23.7 °C, considered the peak of the summer season, and the lowest average was found in June, 13.9 °C, the month in which winter begins (Table 6).

Table 6 - Descriptive statistics of the average air temperature per month recorded between 2008 to 2017.

Month	Average air temperature (°C)			Band width
	Average	Standard deviation	Coefficient of variation	
January	23.74	3.89	16.38	0.47
February	23.98	3.92	16.33	0.37
March	21.95	4.15	18.89	0.33
April	19.60	4.74	24.20	0.47
May	16.19	4.35	26.87	0.49
June	13.91	4.92	35.36	0.32
July	14.57	5.55	38.06	0.49
August	16.80	5.81	34.59	0.20
September	17.90	5.40	30.15	0.79
October	19.80	4.51	22.76	0.43
November	21.50	4.48	20.82	0.69
December	23.31	4.17	17.91	0.56

Source: Prepared by the authors.

Temperature is considered an important meteorological element to take into account in plant production, as it is a determinant in the phenology of species as well as in the spatial and temporal distribution. For corn, studies reveal that the ideal temperature for growth and development is between 24 °C and 30 °C (CRUZ et al. 2006). However, it has maximum and minimum base temperatures of 8 °C and 40 °C, so it can vary according to the hybrid, being early, medium or late, promoting cultivation at the end of winter and between summer and autumn (MONTEIRO, 2009).

Soybeans are better adapted to environments with temperatures ranging from 20 °C to 30 °C and are not suitable for cultivation in environments with temperatures lower than or equal to 10 °C and temperatures above 40 °C (FARIAS et al. 2007; MONTEIRO, 2009), similar to corn. With temperatures above 40 °C, the soybean crop experiences effects on its growth rates, flowering and consequently on the formation of its grains. The crop also needs base temperatures below 10 °C to induce these processes.

Wheat is grown in Frederico Westphalen in the winter and autumn seasons, as it needs milder temperatures. Elevated temperatures during the cultivation cycle can cause a reduction in growth and development, especially in the development of the root system, tillering, flowering and spikelet formation (PIMENTEL et al. 2015). The optimal temperature for growing wheat is within the range from 18 °C to 24 °C (STONE and NICOLAS, 1994). However, currently, with genetic improvement, new cultivars adapted to regions such as the Midwest, which have higher temperatures, are emerging.

For Eucalyptus, a perennial crop, high temperatures can favor cultivation. In winter, they can go into dormancy only if the average daily temperature is below 10 ºC, considered the minimum base temperature of Eucalyptus. It has an optimal average temperature of 25 °C and an upper base limit of 36 °C (MONTEIRO, 2009). However, there are species that are more susceptible to cold (*E. maculata*, *E. saligna*, *E. urophylla*), as well as others that are better acclimatized (*E. grandis*, *E. camaldulensis* and *E. viminalis*) (FERREIRA, 1979).

One of the main precautions that must be taken in the cultivation of eucalyptus in the region of Frederico Westphalen and throughout Rio Grande do Sul is the occurrence of frosts, especially in the seedling phase right after transplanting to the field, which occurs in mid-September. At this time, the formation of so-called late and/or spring frosts occurs, which can compromise not only the newly transplanted seedlings but also trees younger than two years old (FLORES et al. 2009). On the other hand, Elli et al. (2020), when studying the impacts of climate change on Eucalyptus productivity in Brazil, making future projections, found an increase in average temperatures. It is important to note that in southern Brazil temperatures are milder, this increase would not affect the productivity of eucalyptus forests in that region. However, in regions with higher temperatures, this increase can cause thermal stress.

The application of nonparametric Kernel density estimation method to the meteorological elements allowed us to observe the distribution over the 10 years of record overall, in the year and in the month. Furthermore, the distribution made it possible to identify the highest peaks that are related to higher densities. It provided assistance in identifying the correct times for sowing, harvesting and care that farmers should take when managing crops.

Considering the most cultivated crops in the region, corn, soybean, wheat and eucalyptus, all tend to have some restriction regarding the meteorological element air temperature. However, all of them can be planted, as the average temperature overall, per year and per month is within the acceptable range for cultivation, according to the sowing and harvesting period of each species. In relation to meteorological elements, global incident solar radiation and rainfall showed no restriction for crops, having recommended values within the nonparametric kernel distribution method.

4. CONCLUSION

The lowest incidence of radiation occurred in 2017, consequently in the same year, the highest volume of precipitation among the years was recorded.

The month with the highest average incidence of solar radiation was January, the same month that had the highest average monthly temperature.

June was the month with the lowest average incidence of solar radiation, consequently it was the month that had the lowest average monthly temperature.

The meteorological elements evaluated between the years 2008 and 2017 show that they are not limiting for the cultivation of different species for the region covered by the weather station. However, one should pay attention to the cultivar and species to be used, regarding the sowing and planting period.

The observation of ten years of records of solar radiation, rainfall and air temperature data from the Frederico Westphalen weather station by the nonparametric kernel distribution method gives an indication of how the elements are performing in the period. Despite specific restrictions, the weather/climate is suitable for the cultivation of species that have been used in the region, following the zoning for each crop.

REFERENCES

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; DE MORAES GONÇALVES, J. L. Modeling monthly mean air temperature for Brazil. **Theoretical and applied climatology,** v. 113, p. 407-427, 2013**.** DOI: https://doi.org/10.1007/s00704-012-0796-6.

APIPATTANAVIS, S.; BERT, F.; PODESTÁ, G.; RAJAGOPALAN, B. Linking weather generators and crop models for assessment of climate forecast outcomes. **Agricultural and forest meteorology**, v. 150, n. 2, p. 166-174, 2010. DOI: https://doi.org/10.1016/j.agrformet.2009.09.012.

BAETHGEN, W. E.; CARRIQUIRY, M.; ROPELEWSKI, C. **Bulletin of the American Meteorological Society**, v. 90, n. 2, p. 179-184, 2009. DOI: https://doi.org/10.1175/2008BAMS2429.1.

BECKMANN, M. Z.; DUARTE, G. R. B.; PAULA, V. A. D.; MENDEZ, M. E. G.; PEIL, R. M. N. Radiação solar em ambiente protegido cultivado com tomateiro nas estações verão-outono do Rio Grande do Sul. **Ciência Rural**, v. 36, p. 86-92, 2006. DOI: https://doi.org/10.1590/S0103-84782006000100013.

BERGAMASCHI, H. O clima como fator determinante da fenologia das plantas. In: Rego, C., Negrelle, R.R.B.; Morelatto, L.P.C. Fenologia: ferramenta para conservação, melhoramento e manejo de recursos vegetais arbóreos. **Embrapa Florestas**, Colombo, pp 291-310, 2007. Available in: https://www.alice.cnptia.embrapa.br/alice/bitstream/doc/314067/1/EmbrapaFlorestas-2007-Fenologia.pdf. Accessed on: 10 Oct. 2022.

BINKLEY, D.; STAPE, J. L.; RYAN, M. G. Thinking about efficiency of resource use in forests. **Forest Ecology and Management**, v. 193, n. 1-2, p. 5-16, 2004. DOI: https://doi.org/10.1016/j.foreco.2004.01.019.

BURIOL, G. A.; STRECK, N. A.; PETRY, C.; SCHNEIDER, F. M. Transmissividade à radiação solar do polietileno de baixa densidade utilizado em estufas. **Ciência Rural**, v. 25, p. 1-4, 1995. DOI: https://doi.org/10.1590/S0103-84781995000100001.

BURIOL, G. A.; LAGO, I.; HELDWEIN, A. B.; SCHNEIDER, F. M.; ANDRIOLO, J. L. Disponibilidade de radiação solar para hortaliças cultivadas em ambiente protegido no período invernal no Estado do Rio Grande do Sul. **Revista Brasileira de Agrometeorologia**, v. 13, n. 1, p. 21-26, 2005.

CAMERA, C.; BRUGGEMAN, A.; HADJINICOLAOU, P.; PASHIARDIS, S.; LANGE, M. A. Evaluation of interpolation techniques for the creation of gridded daily precipitation (1× 1 km^2); Cyprus, 1980–2010. **Journal of Geophysical Research: Atmospheres**, v. 119, n. 2, p. 693-712, 2014. DOI: https://doi.org/10.1002/2013JD020611.

CRUZ, J. C.; PEREIRA FILHO, I. A.; ALVARENGA, R. C.; GONTIJO NETO, M. M.; VIANA, J. H. M.; DE OLIVEIRA, M.F.; SANTANA, D.P. Manejo da cultura do milho. **Embrapa Milho e Sorgo-Circular Técnica**, n. 87, p. 12, 2006. Available in: https://www.infoteca.cnptia.embrapa.br/handle/doc/490419. Accessed on: 20 Feb. 2023.

CUNHA, N. G.; SILVEIRA, R. J. C.; KOESTER, E.; OLIVEIRA, L. D.; ALBA, J. M. F.; TERRES, V. C.; LOPES, R. T. Estudos de Solos do Município de Frederico Westphalen, RS. **Embrapa. Pelotas, Brasil, Circular Técnica**, n. 116, p. 32, 2011. Available in: https://www.embrapa.br/busca-de-publicacoes/-/publicacao/905019/estudos-de-solos-do-municipio-de-frederico-westphalen-rs. Accessed on: 10 Feb. 2023.

DOWNS, J. A.; HORNER, M. W. Analysing infrequently sampled animal tracking data by incorporating generalized movement trajectories with kernel density estimation. **Computers, Environment and Urban Systems**, v. 36, n. 4, p. 302-310, 2012. DOI: https://doi.org/10.1016/j.compenvurbsys.2011.12.001.

ELLI, E. F.; SENTELHAS, P. C.; BENDER, F. D. Impacts and uncertainties of climate change projections on Eucalyptus plantations productivity across Brazil. **Forest Ecology and Management**, v. 474, p. 118365, 2020. DOI: https://doi.org/10.1016/j.foreco.2020.118365.

FARIAS, J. R. B.; NEPOMUCENO, A. L.; NEUMAIER, N. Ecofisiologia da soja. **Londrina: Embrapa soja, circular técnica**, n. 48. p. 10, 2007. Available in: https://www.infoteca.cnptia.embrapa.br/handle/doc/470308. Accessed on: 10 Feb. 2023.

FEE. **Fundação de economia e estatística**; Corede Médio Alto Uruguai. 2019. Available in: https://arquivofee.rs.gov.br/perfil-socioeconomico/coredes/detalhe/?corede=M%E9dio+Alto+Uruguai. Accessed on: 26 Mar. 2022.

FERREIRA, M. Escolha de espécies de eucalipto. **Circular Técnica IPEF**, v. 47, p. 1-30, 1979. Available in: https://www.ipef.br/publicacoes/ctecnica/nr047.pdf. Accessed on: 10 Dec. 2022.

FLORES, C. A.; FILIPPINI ALBA, J. M.; WREGE, M. S. Zoneamento agroclimático do eucalipto para o Estado do Rio Grande do Sul e edafoclimático na região do Corede Sul- RS. **Pelotas: Embrapa Clima Temperado**. 87p, 2009. Available in: https://www.infoteca.cnptia.embrapa.br/bitstream/doc/859587/1/13653.pdf. Accessed on: 10 Dec. 2022.

FRISINA, V. D. A.; ESCOBEDO, J. F. Radiation and energy balance of lettuce culture inside a polyethylene greenhouse. **Pesquisa Agropecuária Brasileira**, v. 34, p. 1775-1786, 1999. DOI: https://doi.org/10.1590/S0100-204X1999001000003.

GONÇALVES, J. L.; ALVARES, C. A.; ROCHA, J. H.; BRANDANI, C. B.; HAKAMADA, R. Eucalypt plantation management in regions with water stress. Southern Forests: a Journal of Forest Science, v. 79, n. 3, p. 169-183, 2017. DOI: https://doi.org/10.2989/20702620.2016.1255415.

HAMADA, E., GHINI, R.; FERNANDES, J. L.; PEDRO JÚNIOR, M. J.; ROSSI, P. Spatial and temporal variability of leaf wetness duration in the State of São Paulo, Brazil. **Scientia Agricola**, v. 65, p. 26-31, 2008. DOI: https://doi.org/10.1590/S0103-90162008000700006.

HOOGENBOOM, G. Contribution of agrometeorology to the simulation of crop production and its applications. **Agricultural and forest meteorology**, v. 103, n. 1-2, p. 137-157, 2000. DOI: https://doi.org/10.1016/S0168-1923(00)00108-8.

LARCHER, W. **Ecofisiologia vegetal**. ed, São Carlos Rima, 531 p, 2003.

LUCAS, T. P. B.; PLEC, D.; ABREU, M. L.; PARIZZI, M. G. Identificação de interpoladores adequados a dados de chuva a partir de parâmetros estatísticos. **Revista Brasileira de Climatologia**, v. 13, p. 7-21, 2014. DOI: http://dx.doi.org/10.5380/abclima.v13i0.31259.

MARTÍN, M. B. G. La relación clima-turismo: consideraciones básicas en los fundamentos teóricos y prácticos. **Investigaciones Geográficas (España)**, n. 21, p. 21-34, 1999. DOI: http://dx.doi.org/10.14198/INGEO1999.21.04.

MONTEIRO, J. E. B. A. **Agrometeorologia dos Cultivos, o fator meteorológico na produção agrícola**. 1ª ed, INMET, Brasília, 530 p, 2009.

NOAA. ENSO: **Cold and warm episodes by season.** Available in: https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php. Accessed on: 23 Mar. 2022.

PIMENTEL, A. J. B.; ROCHA, J. R. D. A. S. D. C.; SOUZA, M. A. D.; RIBEIRO, G.; SILVA, C. R.; OLIVEIRA, I. C. M. Characterization of heat tolerance in wheat cultivars and effects on production components. **Revista Ceres**, v. 62, p. 191-198, 2015. DOI: https://doi.org/10.1590/0034-737X201562020009.

REIS, L. S.; SOUZA, J. L. D.; DE AZEVEDO, C. A.; LYRA, G. B.; FERREIRA JUNIOR, R. A.; DE LIMA, V. L. Componentes da radiação solar em cultivo de tomate sob condições de ambiente protegido. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 16, n. 7, p. 739-744, 2012. DOI: https://doi.org/10.1590/S1415-43662012000700006.

SILVA, T. R. G.; DA COSTA, M. L. A.; FARIAS, L. R. A.; DOS SANTOS, M. A.; DE LIMA ROCHA, J. J.; SILVA, J. V. Fatores abióticos no crescimento e florescimento das plantas. **Research, Society and Development**, v. 10, n. 4, p. e19710413817, 2021. DOI: https://doi.org/10.33448/rsd-v10i4.13817.

SILVERMAN, B. W. **Density estimation for statistics and data analysis**. Chapman and Hall, New York, 1986.

SANTOS, W. G. D.; MARTINS, J. I. F. O Zoneamento Agrícola de Risco Climático e sua contribuição à agricultura brasileira. **Revista de política agrícola**, v. 25, n. 3, p. 73-94, 2016. Available in: https://seer.sede.embrapa.br/index.php/RPA/article/view/1157. Accessed on: 10 Oct. 2022.

STONE, P. J.; NICOLAS, M. E. Wheat cultivars vary widely in their responses of grain yield and quality to short periods of post-anthesis heat stress. **Functional Plant Biology**, v. 21, n. 6, p. DOI: 887-900, 1994. https://doi.org/10.1071/PP9940887.

TAIZ, L.; ZEIGER, E.; MØLLER, I. M.; MURPHY, A. **Fisiologia e desenvolvimento vegetal**. 6. ed. Artmed Editora, 888 p, 2017.

VIANNA, L. F. D. N.; PERIN, E. B.; RICCE, W. D. S.; MASSIGNAN, A. M.; PANDOLFO, C. Bancos de dados meteorológicos: Análise dos metadados das Estações Meteorológicas no Estado de Santa Catarina, Brasil. **Revista Brasileira de Meteorologia**, v. 32, p. 53-64, 2017. DOI: https://doi.org/10.1590/0102-778632120150119.

WMO. **Guide to Hydrological Practices: Data Acquisition and Processing, Analysis, Forecasting and Other Applications**. World meteorological organization. Geneva, Switzerland. 1994. Available in: https://www.innovativehydrology.com/WMO-No.168-1994.pdf. Accessed on: 10 Oct. 2022.