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

CLIMATOLOGICAL WATER BALANCE OF THE MUNICIPALITY OF IBIRUBÁ-RS FOR THE 2020/21 AND 2021/22 SOYBEAN HARVESTS

FABIO DANIEL ROHR TIEMANN [1]; JARDEL HENRIQUE KIRCHNER [2]; MARIA CLARA PIERI DE QUADROS SANDRI[3] AND MARCOS PAULO LUDWIG [4]

[1] *Academic of Agronomy, Federal Institute of Education, Science and Technology, Rua Nelsi Ribas Fritsch, n º 1111, Bairro Esperança, CEP 98200-000, Ibirubá, RS, Brazil. E-mail: tiemannfabio@gmail.com.*
[2] *Agricultural Engineer, PhD, Professor at the Federal Institute of Rio Grande do Sul, Ibirubá Campus, Rua. Nelsi Ribas Fritsch, 111 -Esperança, Ibirubá, RS, 98200-000, jardel.kirchner@ibiruba.ifrs.edu.br*
[3] *Student of Agronomy, Federal Institute of Education, Science and Technology, Rua Nelsi Ribas Fritsch, n º 1111, Bairro Esperança, CEP 98200-000, Ibirubá, RS, Brazil. E-mail: clarasandri@gmail.com.*
[4] *Agricultural Engineer, PhD, Professor at the Federal Institute of Rio Grande do Sul, Ibirubá Campus, Rua. Nelsi Ribas Fritsch, 111 -Esperança, Ibirubá, RS, 98200-000, marcos.ludwig@ibiruba.ifrs.edu.br*

1 SUMMARY

In recent soybean harvests in some regions of Brazil, severe droughts have become frequent, where the irregular and scarce distribution of rainfall compromises soybean production and causes losses to rural producers. Studying the climatic characteristics of cultivation sites is necessary in an attempt to mitigate the impact of drought and propose solutions for agricultural activities. The present research aimed to identify and quantify water surpluses and deficits in the 2020/21 and 2021/22 harvests in the municipality of Ibirubá-RS. Using data from the climatological station of the National Institute of Meteorology, the Thornthwaite and Mather (1955) system and the Penman–Monteith method, the available water capacity in the soil, the monthly accumulated precipitation, and the daily reference evapotranspiration were determined, and the climatological water balance (BHC) was determined. The 2020/21 harvest presented a water deficit in five of the seven months studied, reaching 262 mm. During the following harvest, there were four months of water deficit, with a total accumulated water of 330 mm, and two months of surplus, with 149 mm. The knowledge of BHCs from two different harvests can serve as a reference for producers and technicians in the region when planning the installation, management and harvest of the next harvests.

Keywords: soil water balance, rainfall surplus, rainfall deficit, Penman–Monteith method.

TIEMANN, FDR; KIRCHNER, JH; SANDRI, MCP; LUDWIG, M.P.
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2 ABSTRACT

In the last few soybean crops in some regions of Brazil, severe droughts have become more common, and the scarce and irregular distribution of precipitation compromises soy production and results in financial losses for farmers. Studying the climatic characteristics of the cultivation site is necessary to mitigate the impact of drought and help propose solutions for agricultural

Recebido em 15/02/2023 e aprovado para publicação em 09/10/2023
DOI: http://dx.doi.org/10.15809/irriga.2023v28n4p756-774

activities. The aim of this research was to identify and quantify water surpluses and deficits in the 2020/21 and 2021/22 harvests in the municipality of Ibirubá -RS. Using data from a climatological station of the National Meteorological Institute (INMET), the Thornthwaite and Mather (1955) system and the Penman–Monteith method, it was possible to determine the available water capacity of the soil, the monthly accumulated rainfall, the daily reference evapotranspiration and the climatic water balance (CWB). The 2020/21 crop presented a water deficit in five of the seven months studied, reaching 262 mm. In the following harvest, there were four months of water deficit, with a cumulative total of 330 mm, and two months of water surplus, with 149 mm. The knowledge of the CWB from two different crops can be used as a reference for regional farmers and technicians when planning the installation, management and harvesting of future crops.

Keywords: soil water balance, rainfall excess, rainfall deficit , Penmann–Monteith method.

3 INTRODUCTION

Agriculture is characterized by economic activity that is highly dependent on agrometeorological and edaphoclimatic conditions, which involve the adequate management of soil, water, and climate and the management of water resources (Romani *et al*., 2016).

According to Zambiazzi *et al.* (2017), soybean is one of the most produced legumes in Brazil and in the world and is considered one of the agricultural crops that has grown the most in the last three decades, with a relevant cultivation area corresponding to more than 50% of the entire area cultivated with grains in Brazil (Soja, 2022). It has economic potential for commercialization in the national and international markets, being the commodity that stands out the most in the Brazilian territory and one of the main crops in agribusiness (Vinhal-Freitas, 2011).

According to Fietz and Urchei (2002), soybean production is highly negatively affected when droughts occur during its cycle. In the last soybean harvests in the state of Rio Grande do Sul, the scarcity or poor distribution of rainfall has become frequent during the crop development cycle, which is a limiting factor for obtaining high productivity.

Drought is defined as a deficiency of precipitation over a prolonged period that results in water scarcity for some activities, groups or environmental sectors (Oliveira *et al*., 2020). The sharp drop in surface and subsurface water reserves in a given region is described as drought, which also has negative consequences for agricultural activity (Souza Junior; Sausen; Lacruz, 2010).

These increasing droughts in Brazil, which are influenced by the La Niña phenomenon, are intensifying the use of irrigation in crops, both perennially and annually. Irrigation involves techniques, forms or means to apply water to plants artificially, satisfying the water needs of the crop. It is associated with a high level of technology; however, it is practiced in many inappropriate ways, wasting water and energy (Marouelli *et al.*, 2011; Testezlaf, 2017).

To achieve success in agricultural planning and obtain high productivity, climate monitoring is highly important for determining the best time and most promising areas for sowing. In this sense, the study and monitoring of periods of greater or lesser occurrence of precipitation, optimal temperatures for crops, radiation availability and water balance are essential for achieving productive returns (Villa *et al*., 2022).

In agriculture, the provision of agrometeorological data is highly important for understanding the distribution of water resources in time and space, increasing the viability of activities (Matos *et al*., 2018). Furthermore, the climatological water balance makes it possible to classify the climate of a region, assisting in agroclimatic and environmental zoning, knowing the periods of greatest availability and need for water in the soil, and facilitating water resource planning (Santos; Hernandez; Rossetti, 2010; Souza *et al*., 2013).

Although carrying out studies on the subject is an uncommon practice, knowledge of the climatic characteristics of the municipality of Ibirubá is necessary, especially with respect to generating information on the dynamics of water in the soil, especially during the soybean cultivation period in the municipality.

In view of the above, the present work aimed to obtain, organize and analyze climate data and generate a climatological water balance (BHC) for the municipality of Ibirubá - RS during the 2020/21 and 2021/22 soybean harvests.

4 MATERIALS AND METHODS

4.1 Study area

The work was carried out in the municipality of Ibirubá, which is located in the northwest region of the state of Rio Grande do Sul. The data were collected from the Ibirubá Automatic Meteorological Station (Latitude 28°39'12.4” S, Longitude 53°06'42.6” W, altitude 455 meters) belonging to the National Institute of Meteorology (INMET), which is located in the agricultural sector of the Federal Institute of Education, Science and Technology of Rio Grande do Sul – Ibirubá Campus.

The weather station began operating on December 13, 2012. It measures and records the values of the following meteorological variables at each hour: air temperature, relative humidity, dew point, atmospheric pressure, wind speed, radiation and rainfall. The data recorded at the station can be found on the INMET website.

According to a survey by the Brazilian Institute of Geography and Statistics (2022), the municipality of Ibirubá has an area of 607.185 km2 ^{and} is 292 km from the capital Porto Alegre. According to the Brazilian Soil Classification System, the predominant soil in the municipality is classified as Red Latosol (Museu de Solos do Rio Grande do Sul, 2022).

The climate of the municipality of Ibirubá, according to the Koppen climate classification, is type Cfa (temperate, humid, with hot summers). The average maximum temperatures in the municipality vary approximately 25 °C, and the average minimum temperatures reach 13.1 °C. The average annual rainfall in the municipality is 1810.1 mm, with the highest accumulations occurring in October and the lowest accumulations occurring in May (Instituto Rio Grandense do Arroz, 2022).

4.2 Carrying out the water balance

The climatological water balance was determined via climate data series from October 2020 to April 2021 and from October 2021 to April 2022. The month of October is characterized by the beginning of crop sowing in the municipality. According to the Ministry of Agriculture and Livestock, the Agricultural Zoning of Climatic Risk identifies suitable areas and sowing periods with the lowest climate risk for soybean cultivation (Brazil, 2022). A water balance model for the crop is performed, taking into account rainfall (historical series of at least 15 years), potential evapotranspiration, the phenological phase of the crop (cycles ranging from 100 to 180 days), the crop coefficient, and maximum water availability in the soil.

São considerados solos do tipo 1,2 e 3 com capacidade de armazenamento de água de 35, 55 e 75 mm, respectivamente. São considerados três faixas de risco, 20%, 30% e 40%, e para indicação por macrorregião sojícola, as cultivares são agrupadas de acordo com seu grupo de maturação relativa (GMR), onde para macrorregião 1 do Rio Grande do Sul deve ser seguido a especificação de cultivares Grupo I (GMR < 6.2), Grupo II ($6.2 \leq$ GMR ≤ 7.2) e Grupo III (GMR > 7.2).

The sowing period table indicates the sowing season by decade (10-day periods). January 1st to 10th represents the first decade, and the thirty-sixth (last decade) occurs from December 21st to 31st. In the municipality of Ibirubá, during sowing, there is a predominance of cultivars with GMRs lower than 6.2. Taking into account type III soil, the sowing period with a 20% risk range occurs from October 11th to January 10th, and the 30% risk range is from January 11th to January 31st, according to the ZARC for the 2021/22 harvest.

The crop cycle depends on the maturity group of each cultivar, which normally varies from 120--160 days. Soybean harvesting usually occurs in the municipality in April, which is why the period described for the preparation of BHCs was chosen, as it is the soybean cultivation period in the municipality.

The climate data were obtained from the website of the National Institute of Meteorology (INMET), accessing the tool “Station data table” in the “Meteorological Data” tab, selecting the type of station (automatic or conventional), the state in which the station is installed, the station and the period of data collection. The automatic station measures and records the data every hour, with higher precision than conventional stations, which collect data only three times a day. To determine precipitation (P), the daily sum of the accumulated amounts was subsequently calculated for monthly summation.

The reference evapotranspiration (ETo) was determined by the Penman–Monteith method parameterized by the FAO, which is currently considered the standard method for estimating ETo (Bernardo; Soares; Mantovani, 2013). A spreadsheet in Microsoft Excel software developed by Embrapa was used, which aims to calculate the reference evapotranspiration automatically using the same variables as the FAO Penman–Monteith method.

To determine the daily ETo, it was necessary to fill in the spreadsheet prepared and made available by Embrapa with information on date, latitude, Julian day, altitude and municipality. The cells of the meteorological variables maximum temperature (°C), minimum temperature (°C), maximum relative humidity (%), minimum relative humidity (%), atmospheric pressure (hPa), wind speed (ms $^{-1}$) and global radiation (KJ.m $^{-2}$) were subsequently filled in with the values for each time. The sum of the ETo for each day was then performed to obtain the monthly reference evapotranspiration.

Climatic data on maximum temperature (°C), minimum temperature (°C), maximum relative humidity (%), minimum relative humidity (%), atmospheric pressure (hPa), wind speed (ms $^{-1}$) and global radiation (KJ.m $^{-2}$) were used to determine the daily ETo.

Thornthwaite and Mather method (1955)

The climatological water balance proposed by Thornthwaite and Mather (1955) provides an excellent basis for quantifying water storage, surplus and deficit (Reis, 2016). The definition of available water capacity (AWC) is one of the first steps and consists of the soil moisture range between the field capacity (FC) and the permanent wilting point (PMP), depending on the soil type and crop (Borges;

Hernandez; Fauvel, 2021). The AWC was determined via equation 1:

$$CAD = CAD_{média} \times Z_r (1)$$

where:

CAD - available water capacity (mm);

$_{Average}$ CAD – average available water capacity (mm/cm);

Z_r – specific depth of the root system (cm).

Doorenbos and Kassam (1994) determined that for clayey soils, an average CAD value of 2.0 mm/cm should be considered. For Alfonsi, Pedro Júnior and Camargo (1995), the effective depth of the root system of soybean crops is 50 cm (Sentelhas; Angelocci, 2012). Therefore, a CAD of 100 mm was adopted.

After P, ETo and CAD were determined, the difference between the precipitation and reference evapotranspiration (P-ETo) was quantified. Months in which P-ETo is positive indicate that precipitation was greater than evapotranspiration; however, when P-ETo is negative, evapotranspiration was greater than precipitation. The calculation is necessary to determine the accumulated negatives. P -ETo was determined via equation 2:

$$P - ETo_n = P_n - ETo_n (2)$$

where:

P – Eto $_n$ – difference in precipitation and reference evapotranspiration (mm);

P – precipitation (mm);

ETo – reference evapotranspiration (mm);

n – reference month of the calculation.

Then, the accumulated negative (NAc) was determined, which consists of the sum of the sequence of negative P-ETo values. The NAc represents the month in which the water balance was initialized and is very important for quantifying soil water storage. The following situations were observed for its determination:

The NAc calculation is initiated in the first month of negative P-ETo after a positive P-ETo sequence, and the same negative P-ETo value of the month in question is repeated for the NAc.

The P-ETo value remains negative in the following month, and the P-ETo value for the month in question was added to the NAc value for the previous month.

If the month's storage is greater than or equal to the CAD, the NAc value will be 0.

The month in which P-ETo returned to positive after a negative sequence was first calculated for storage via Equation 3, and then for the NAc, it was quantified via Equation 4.

$$ARM = (P - ETo)_n + ARM_{n-1} (3)$$

where:

ARM – soil water storage (mm);

P – Eto – difference in precipitation and reference evapotranspiration (mm);

n – reference month of the calculation.

$$NAc = CAD \times ln\, ln\, (ARM/CAD)\ (4)$$

where:

NAc – accumulated negative (mm);

CAD – available water capacity (mm);

ARM – soil water storage (mm).

With the quantified accumulated negative, the soil water storage (SWS) was determined, which is the amount of water that was present in the soil considering its inputs and outputs, where:

- For months in which P-ETo was < 0, Equation 5 was used to quantify storage.

$$ARM_n = CAD \times e^{-[Nac/CAD]} \quad (5)$$

where:

ARM – soil water storage (mm);

CAD – available water capacity (mm);

NAc – accumulated negative (mm);

n – reference month.

With the quantified ARM, it was possible to determine the variation in soil water storage (ALT), i.e., how much soil water storage varied from month to month, which is important in determining real evapotranspiration and water surplus. Equation (6) was used to calculate the change in soil water storage.

$$ALT_n = ARM_n - ARM_{n-1} \quad (6)$$

where:

ALT – variation in soil water storage (mm);

ARM – soil water storage (mm);

n – reference month of the calculation.

The actual evapotranspiration (ETR) was subsequently calculated, which would be the evapotranspiration that actually occurs on the basis of the availability of water in the soil. The ETR is used to determine the water deficit, and in months of water deficiency, it is always lower than the reference evapotranspiration. The following situations were considered in the calculation of the ETR:

- Os meses em que a P-ETo foi ≥ 0, para a ETR foi adotado o mesmo valor da ETo;
- For months in which P-ETo was < 0, Equation (7) was used to determine the ETR:

$$ETR_n = P_n + [ALT_n] \quad (7)$$

where:

ETR – actual evapotranspiration (mm);

P – precipitation (mm);

ALT – variation in soil water storage (mm);

n – reference month of the calculation.

The soil water deficiency (SWD) was subsequently determined, that is, the amount of water that was missing from the soil, since the water output from the soil was greater than the amount that was retained, via Equation 8:

$$DEF_n = ETo_n - ETR_n \quad (8)$$

where:

DEF – water deficiency (mm);

ETo – reference evapotranspiration (mm);

ETR – actual evapotranspiration (mm);

n – reference month of the calculation.

After determining the DEF, the excess water in the soil (EXC) was quantified, that is, the amount of water left over, which was not used by the vegetation and was lost through percolation or surface runoff because the soil reached its maximum water retention capacity, in which:

- In months where ARM < CAD, the value adopted for the water surplus was 0;
- For months that presented ARM ≥ CAD, Equation 9 was used to quantify the surplus:

$$EXC_n = (P - ETo)_n - ALT_n \quad (9)$$

where:

EXC – water surplus (mm);

P – Eto – difference between the precipitation and reference evapotranspiration (mm);

ALT – variation in soil water storage (mm);

n – reference month of the calculation.

The precipitation and evapotranspiration data were entered into

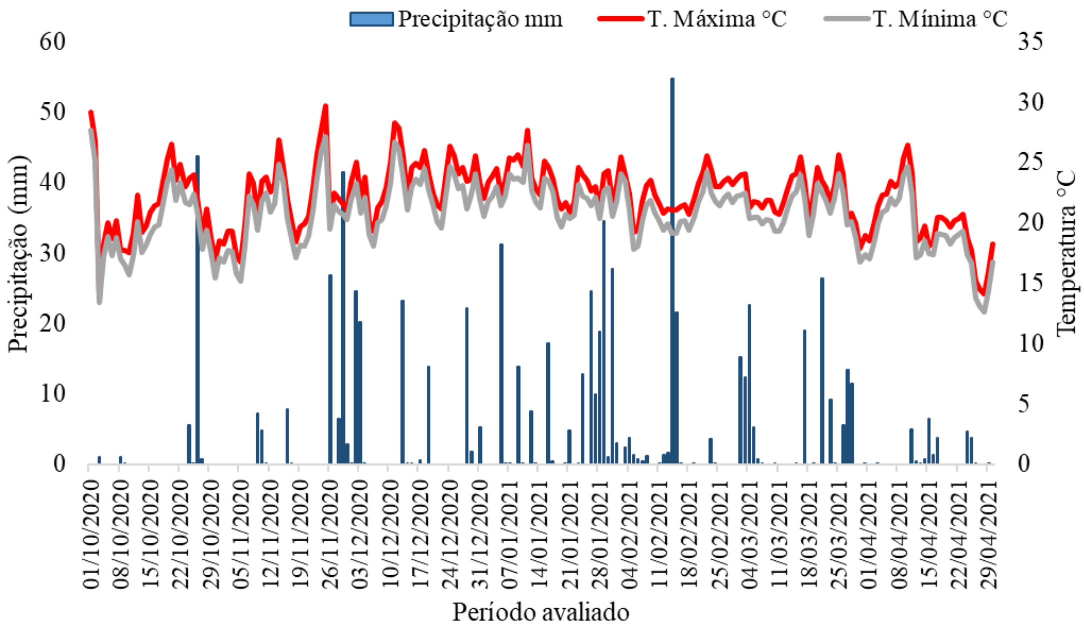
Microsoft Excel software to calculate the monthly sum. On the basis of the data on available water capacity, precipitation, reference evapotranspiration, accumulated negative, soil water storage, variation in soil water storage and actual evapotranspiration, the deficit and surplus of soil water during the period studied were quantified. The balance was then measured, observing the accuracy of the calculations via the following relationships:

$\Sigma P = \Sigma ETo + \Sigma (P - ETo)$;
$\Sigma P = \Sigma ETR + \Sigma EXC$;
$\Sigma ETo = \Sigma ETR + \Sigma DEF$;
$\Sigma ALT = 0$.

5 RESULTS AND DISCUSSION

Figure 1 shows the variations in precipitation and temperature from October 1, 2020, to April 30, 2021.

Figure 1. Variation in precipitation and temperature in the municipality of Ibirubá from October 1, 2020, to April 30, 2021.



As shown in the previous figure, from October to December, the minimum temperatures varied from 13 °C to 27 °C, and the maximum temperatures ranged from 13 °C to 29 °C. In the months from January to March, the temperatures ranged from 18 °C to 28 °C. °C. In April, temperatures began to decrease, mainly from the second half of the month. According to Farias, Neumaier and Nepomuceno (2021), temperatures below 20 °C at the time of sowing delay the germination–emergence process. Temperatures in the range of 30 °C are ideal for crop development.

The beginning of October is characterized by a low volume and irregular distribution of rainfall, with no soil moisture that would allow for sowing the crop or good germination and seedling emergence in the sown areas.

Only at the end of the month was there significant rainfall that made it possible to sow soybeans. In November, the beginning of the month was again characterized by low rainfall volumes, and only in the second half of the month did the rainfall have high volumes, providing greater security for producers in the municipality to sow the crop.

The months of January, February and March are the periods in which most soybean areas in the municipality normally move from the vegetative phase to the reproductive phase. During the reproductive phase, the crop's water demand increases, since after the start of flowering, a greater volume of water is needed to form the legumes and, later, the grains. Notably, this change in phase depends on the photoperiod and the relative maturity group, which varies among the cultivars adopted by the producers. The months of January and March were the two months during soybean cultivation in the municipality that had the most frequent rainfall and the highest accumulations.

According to Oliveira *et al.* (2021), the amount and distribution of rainfall between January and March may be the main limiting factors for soybean productivity in Rio Grande do Sul. Soybean harvesting usually occurs in the second half of March and in April. In the second half of March, in the municipality of Ibirubá, the soybean areas sown earlier (October and early November) are harvested, and in April, the areas sown in the second half of November and early November are harvested. In April, rainfall was irregularly distributed and had a low volume of water. With respect to soybean crops, it is important that there is not much rainfall at the time of harvest to avoid affecting the quality of the grains.

The climatological water balance following the Thornthwaite and Mather (1955) methodology for the municipality of Ibirubá during the 2020/21 soybean harvest is shown in Table 1.

Table 1. Climatological water balance for the municipality of Ibirubá during the 2020/21 soybean harvest.

Month	P	ETo	(P-ETo)	NAc	ARM	ALT	ETR	DEF	EXC
	(mm)								
Out	53	153	-100	-180	17	-28	81	72	0
Nov	98	159	-61	-241	9	-8	106	53	0
Ten	112	176	-64	-305	5	-4	116	60	0
Jan	206	146	+60	-43	65	60	146	0	0
Feb	97	133	-36	-79	45	-20	117	16	0
Sea	142	123	+19	-45	64	19	123	0	0
Apr	27	107	-80	-80	45	-19	46	61	0
Σ	735	997	-262	-	-	0	735	262	0

Note: P = Precipitation; ETo = Reference evapotranspiration; (P- ETo) = Difference between precipitation and reference evapotranspiration; NAc = Accumulated negative; ARM = Soil water storage; ALT = Change in soil water storage; ETR = Real evapotranspiration; DEF = Water deficiency; EXC = Water surplus.

The 2020/21 harvest was characterized by total precipitation during the evaluated period of 735 mm, where the highest monthly precipitation, 206 and 142 mm, occurred in the months of January and March, respectively. On the other hand, in

April, only 27 mm of precipitation occurred. According to Carvalho *et al.* (2013), a soybean crop has a water requirement that varies between 450 and 850 mm to achieve high productivity. During harvest, the accumulated precipitation in the months of soybean cultivation in the municipality was within the crop's needs.

Despite a significant volume of precipitation during the period evaluated, an uneven distribution of this precipitation was observed. The frequency and distribution of precipitation must be regular during the development of soybeans. Souza (2019) reported that the irregular distribution of rainfall during the soybean crop cycle affects the availability of water to plants.

During the period evaluated, the municipality had an accumulated reference evapotranspiration of 997 mm, with the highest value of 176 mm occurring in December. The month of April presented the lowest reference evapotranspiration value, 107 mm.

The months of January and March were characterized by more precipitation than evapotranspiration, unlike the months of October, November, December, February and April, where more evapotranspiration than precipitation occurred.

In the months of October, November and December, the soybean crop is in the vegetative stage, and the seedlings develop their root system. After the initial development, they begin to emit trifoliate leaves and new branches until their reproductive phase. In these months, the water storage in the soil is very low, especially in the months of November and December, when only 9 and 5 mm of water are stored in the soil, respectively.

From January to April, the period between the vegetative phase and the reproductive phase of soybean crops, when the plants stop producing new branches and trifoliates to develop vegetables and grains, soil water storage is greater than that in the previous three months.

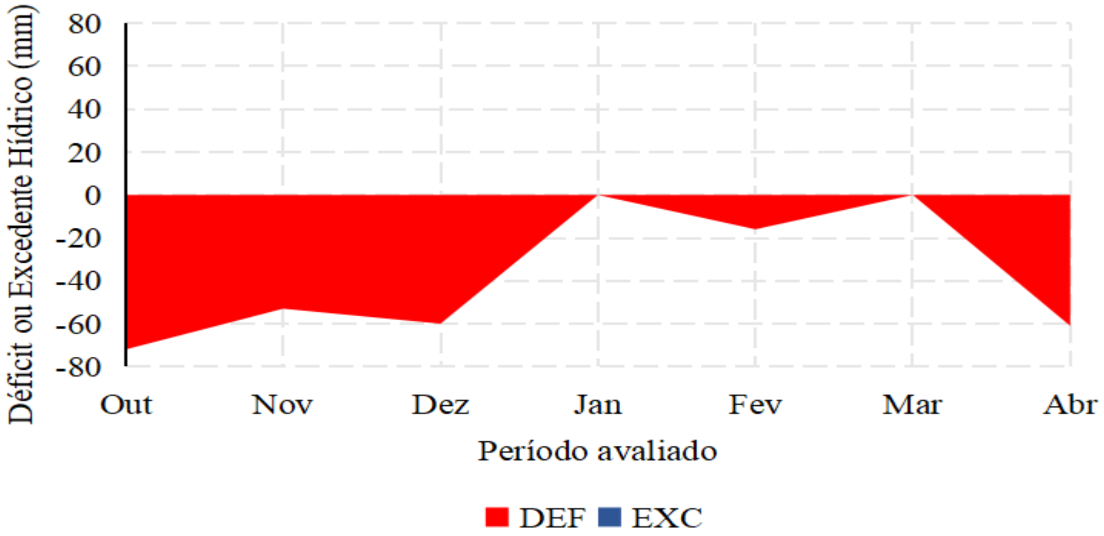
According to Costa *et al.* (2015), water storage in the soil depends on its texture, distribution, pore size, and structure. Most of the area cultivated with soybeans in Rio Grande do Sul is under no-till farming, and despite the benefits, the occurrence of compaction of the surface layer of the soil has been observed due to machinery traffic or cattle trampling (Souza, 2019).

Soil uses that cause soil compaction reduce water storage in the soil, as the organization of solid soil particles during the compaction process causes the soil's porous space to be reduced, reducing water infiltration into the soil and the distribution of the crop's root system (Costa *et al.*, 2015).

The accumulated total ETR reached 735 mm. In the months of January and March, when precipitation was greater than evapotranspiration, that is, when there was no water deficit, the actual evapotranspiration was the same as that of the reference, and the ETR was lower than the ETo in the months when the reference evapotranspiration exceeded the monthly precipitation.

Figure 2 shows the water deficits and surpluses of the climatological water balance during the 2020/21 harvest.

Figure 2. Representation of the climatological water balance for the municipality of Ibirubá during the 2020/2021 soybean harvest.



In the figure above, it is possible to observe that there was no water surplus in any month, even with a high accumulation of precipitation during the period covered by soybean cultivation in the municipality, since in none of the months did the water storage in the soil reach the CAD. For water deficiency, the BHC characterized 262 mm of water deficit.

An analysis of the soybean sowing period in the municipality, which normally occurs from October to December, revealed that there was a large water deficit, mainly in the month of October, which had the largest water deficit in the soil during the 2020/21 harvest.

The months of January and March did not present a soil water deficiency, as the volume of precipitated water was greater than the volume of evapotranspired water. Importantly, soybean plants in the reproductive stages (flowering and grain filling) do not suffer from water stress. The effects of water stress on the reproductive phase of soybean, according to Gava *et al.* (2016), include the abortion of flowers, ovules and legumes, subsequently affecting the size of the grains.

With respect to the water balance, only the month of February presented a water deficit in the soil during the flowering and grain-filling periods since the volume and frequency of precipitation were lower than those in the months of January and March. The month of April was characterized by the second largest monthly water deficit during the 2020/21 harvest, due to the irregular distribution and low monthly accumulation of precipitation.

Figure 3 represents the variation in precipitation and temperature in the municipality of Ibirubá from October 1, 2021, to April 30, 2022.

Figure 3. Variation in precipitation and temperature in the municipality of Ibirubá from October 1, 2021, to April 30, 2022.

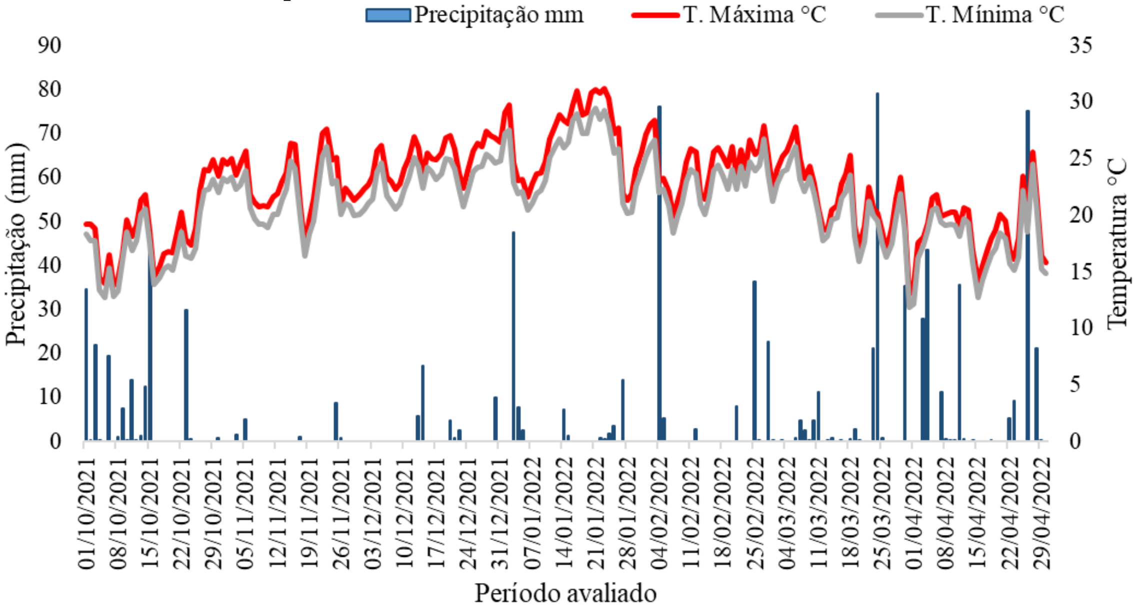


Figure shows that during the rainiest periods, both the maximum and minimum temperatures were lower than those during the period of water scarcity. During the period of greatest rainfall scarcity, the maximum temperatures exceeded 30 °C, and the minimum temperatures were between 20 °C and 25 °C. According to Nepomuceno, Farias and Neumaier (2007), high temperatures combined with water scarcity intensify a reduction in soybean crop productivity, especially during the flowering and grain-filling periods. Low temperatures during the crop maturation phase, associated with rainy periods or high humidity, cause delayed maturation and consequently delay harvest.

The rainfall in October had a slightly more uniform frequency and distribution, as did the high accumulated rainfall. The months of November and December, which also include the soybean sowing period in the municipality, presented a different scenario than October did, with a very irregular distribution and very low accumulated rainfall, hindering the sowing process and the germination and emergence of seedlings. The initial development of the crops in the areas that were sown between late October and early November was severely affected by the water shortage.

Furthermore, the lack of rainfall in November caused producers to feel very insecure about sowing the crop in soil with low humidity, so they chose to delay sowing until December. However, December was also characterized by an irregular distribution and low accumulated rainfall. Thus, many producers in the municipality sowed soybeans outside the period indicated by the Agricultural Climate Risk Zoning (ZARC) for the crop in question. In accordance with Silva and Aguila (2020), the sowing season determines the exposure of soybeans to variations in climatic factors. Therefore, sowing outside the indicated period can affect size, cycle, and grain yield.

Owing to the occurrence of severe droughts in some regions of Rio Grande do Sul in recent soybean harvests, the Ministry of Agriculture, Livestock and Food Supply defined six classes of available water capacity for the ZARC of the 2023/24 soybean harvest for RS, namely, classes AD1, AD2, AD3, AD4, AD5 and AD6, with storage capacities of 24 mm, 32 mm, 42 mm, 55 mm, 72 mm and 95 mm, respectively (Brasil, 2023). The depth of the soybean root system at 60 cm was also considered. This better characterizes the moments of lowest climatic risk for sowing the crop in each municipality of the state.

The months of January, February and March also presented very irregular distributions of rainfall; however, with the exception of the month of January, the accumulated rainfall was high.

In April, rainfall was more evenly distributed than in previous months, and there was also high accumulation. According to Giasson (2015), excessive rainfall during soybean harvest delays the removal of the product from the field, accelerates the deterioration and viability of the seeds, and negatively affects the quality of the grains.

The climatological water balance of the municipality of Ibirubá during the 2021/22 soybean harvest is presented in Table 2.

Table 2. Climatological water balance for the municipality of Ibirubá for the 2021/22 soybean harvest.

Month	P	ETo	(P-ETo)	NAc	ARM	ALT	ETR	DEF	EXC
	(mm)								
Out	187	135	+52	0	100	0	135	0	52
Nov	17	167	-150	-150	22	-78	95	72	0
Ten	41	203	-162	-312	4	-18	59	144	0
Jan	86	202	-116	-428	1	-3	89	113	0
Feb	151	152	-1	-429	1	0	151	1	0
Sea	165	114	+51	-65	52	51	114	0	0
Apr	231	86	+145	0	100	48	86	0	97
Σ	878	1059	-181	-	-	0	729	330	149

Observation: P = Precipitation; ETo = Reference evapotranspiration; (P- ETo) = Difference between precipitation and reference evapotranspiration; NAc = Accumulated negative; ARM = Soil water storage; ALT = Change in soil water storage; ETR = Real evapotranspiration; DEF = Water deficiency; EXC = Water surplus.

For the 2021/22 harvest, the accumulated precipitation in the evaluated period was 878 mm, meeting the amount required by the soybean crop and 143 mm higher than the total accumulated precipitation in relation to the previous harvest; however, the distribution of precipitation was very irregular.

The month with the highest monthly rainfall was October, the month in which soybean sowing begins in the municipality of Ibirubá, and April, which corresponds to the month in which soybean harvesting occurs. The period with the lowest rainfall occurred in the months of November and December, with only 17 mm and 41 mm of rainfall, respectively.

The accumulated reference evapotranspiration during this period was 1059 mm, with higher values in December and January (203 and 202 mm, respectively). Compared with the previous harvest, the 2021/22 harvest had a greater evapotranspiration of 62 mm. The month of

April had the lowest volume of reference evapotranspiration.

In the months from November to February, the reference evapotranspiration was greater than the precipitation, in contrast to the months of October, March and April, where the precipitation was greater than the evapotranspiration.

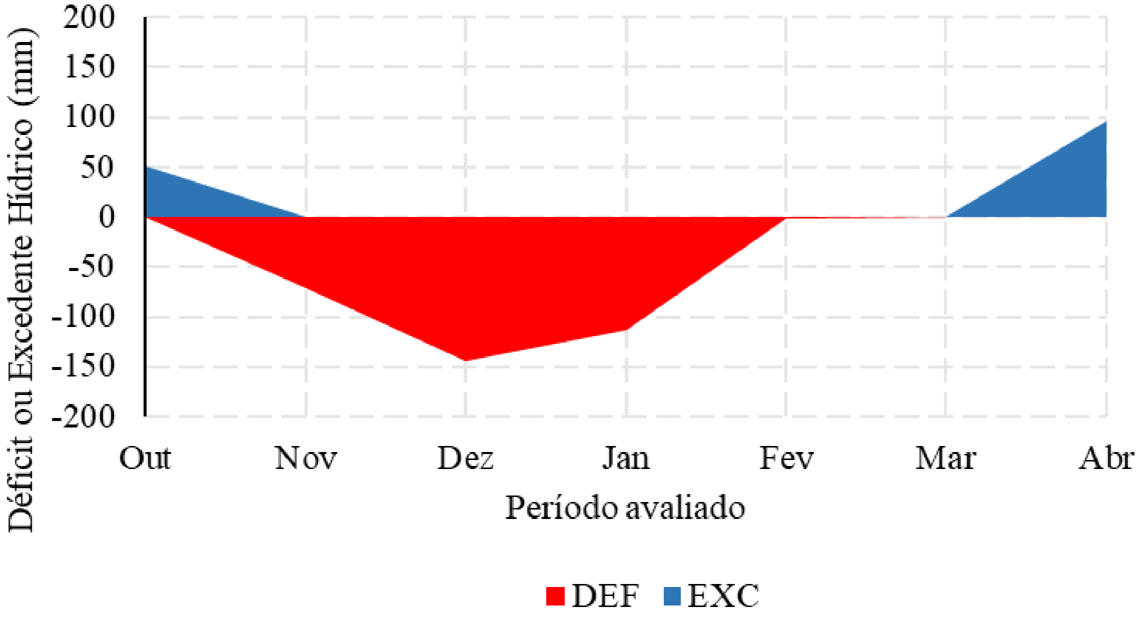
In terms of the water balance, the soil water storage was very different during the 2021/22 harvest. In the months of October and April, storage exceeded the soil CAD for the municipality of Ibirubá. On the other hand, from November to March, the soil water storage was very low, especially during the months of December, January and February, when the soil water storage was very close to zero.

With very low soil water storage, the vegetative and reproductive phases of the soybean crop are strongly affected by the low availability of water to the plants.

The actual evapotranspiration during the evaluated period had a cumulative total of 729 mm. The months of October, March and April were characterized by more precipitation than evapotranspiration; thus, the actual evapotranspiration had the same values as the reference evapotranspiration in these three months. For the months of November, December, January and February, the actual evapotranspiration was lower than the reference evapotranspiration since the precipitation was lower than the reference evapotranspiration.

Figure 4 represents the soil water deficits and surpluses of the climatological water balance of the municipality of Ibirubá during the 2021/22 soybean harvest.

Figure 4. Representation of the climatological water balance for the municipality of Ibirubá during the 2021/22 soybean harvest.



The accumulated water surplus during the cultivation of soybean crops in the municipality of Ibirubá was 149 mm. The figure above shows that the water surplus occurred in the months of October and April, as the water storage in the soil in these two months exceeded the available water capacity of the soil.

The soil water deficit occurred from November to February, with a total deficit of 330 mm. Compared with the previous harvest, the 2021/22 harvest presented a greater water deficit of 68 mm. The month of December was characterized by the highest monthly water deficit. Even though the monthly precipitation was lower in November than the monthly precipitation in December, the water deficit was lower in November because the month of October had excess water in the soil, which still contained some moisture.

An analysis of the flowering and grain-filling periods, which normally occur from January to March, revealed that January presented a marked water deficit. The month of February presented only a 1 mm water deficit. The month of March did not present a water deficiency in the soil, since the precipitation of the month was greater than its evapotranspiration, and it also did not present a water surplus in the soil because the month of February has very low soil water storage, which did not contribute to the storage in March exceeding the CAD.

Similar results were reported by Schaparini *et al.* (2019), in which a climatological water balance was carried out for the municipality of Carazinho, RS, between the months of October and March of 2015/16, 2016/17 and 2017/18 soybean harvests. The water balance was determined via the method of Thornthwaite and Mather (1955), and the ETP was estimated via the Penman–Monteith method. The CAD used was 150 mm, 50 mm greater than the available water capacity adopted in this work.

The BHC carried out by Schaparini *et al.* (2019) characterized the water deficit in the 2015/16 harvest in the month of January. During the 2016/17 harvest, water deficit occurred at the end of December and between the end of January and the beginning of February. The 2017/18 harvest presented a very short period of water deficit, only in the second half of January.

The water deficit during the three harvests coincided with some periods of water deficiency that were characterized in the 2020/21 and 2021/22 harvests, mainly in the period when the soybean crop was in the phase of greatest water need.

Soybean production was greater in the 2020/21 harvest than in the 2021/22 harvest in the state of Rio Grande do Sul, and in the municipality of Ibirubá, at the time of establishment of the crop, there were no serious problems due to very low soil moisture, delaying the sowing process, as occurred in the 2021/22 harvest.

In terms of the climatological water balance of soybean crops in the municipality of Ibirubá during the period with the greatest water need for soybean crops (flowering-grain filling), which normally occurs in the months of January, February and March, the 2020/21 harvest had a lower water deficit during this period than did the 2021/22 harvest. The distribution of rainfall during the cultivation of the crop in the municipality was slightly more regular in the 2020/21 harvest than in the subsequent harvest, which explains the superiority of soybean production in the 2020/21 harvest in relation to the 2021/22 harvest in the municipality and region.

6 CONCLUSION

With the completion of this work, it was possible to characterize the climatological water balance as an excellent tool for understanding the periods of greatest climate risk with regard to water deficit or surplus, which is an important tool for agricultural planning.

The results obtained in this study allowed us to understand the distribution of precipitation, the amount of evapotranspired water, and the storage of water in the soil during two different soybean harvests in the municipality of Ibirubá, as well as to identify the months that had a water deficit or surplus. This can serve as a reference for producers in the region to plan their agricultural activities related to soybean cultivation.

The climatological water balance demonstrated that rainfall is not sufficient to meet the water needs of the soybean crop if it does not occur frequently and is evenly distributed during its development, especially during periods of greatest water need.

Furthermore, the importance of increasing the accumulation of water in the soil is highlighted to alleviate the effects of droughts, intensifying the use of soil conservation management practices that aim to increase water infiltration into the soil.

7 ACKNOWLEDGMENTS

This work was carried out with the support of the Federal Institute of Education, Science and Technology of Rio Grande do Sul (IFRS).

To the Hydraulics and Irrigation Laboratory of IFRS – Ibirubá Campus.

To the Federal Institute of Education, Science and Technology of Rio Grande do Sul – Ibirubá campus for academic training and provision of the internal funding grant for research and innovation projects 2022/2023.

To the National Institute of Meteorology for providing climate data to carry out this work.

Embrapa for providing the spreadsheet used to determine evapotranspiration.

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