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SIMULATION OF THE SEQUENTIAL WATER BALANCE AND THE NEED FOR IRRIGATION FOR SOYBEAN CROPS IN TWENTY AGRICULTURAL YEARS

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1 RESUMO

O presente estudo tem como objetivo realizar a simulação do balanço hídrico sequencial e da necessidade de irrigação para a cultura da soja em 20 anos agrícolas (2001 a 2022) na região edafoclimática de Cachoeira do Sul – RS. Realizou-se uma simulação inicial (modelo CROPWAT 8.0) a partir de dados observados durante a realização de experimento de campo com a cultura da soja no ano agrícola 2021/22, aonde foram coletados todos os dados de entrada necessários. Após, foram realizadas outras 20 simulações para todos os anos agrícolas entre 2001-2 e 2021-22 mantendo os parâmetros observados no agrícola 2021-22 e alterando apenas as chuvas durante o ciclo da cultura. Os valores de chuva acumuladas ao longo do ciclo da soja variaram entre 284 e 1084 mm e a demanda por irrigação suplementar entre 75 e 345 mm. Do total, foram nove anos com chuvas acima da média dos dados, demandando em média 129 mm de irrigação e onze anos com chuvas abaixo da média dos dados, com uma demanda média de 205 mm de irrigação suplementar. A necessidade da irrigação é dependente da distribuição regular das chuvas ao longo do ciclo devido ao melhor aproveitamento da chuva efetiva.

Palavras-chave: *Glycine max*. Cropwat. Requerimento hídrico.

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2 ABSTRACT

The present study aimed to simulate the sequential water balance and the need for irrigation for soybean crops over 20 agricultural years (2001 to 2022) in the edaphoclimatic region of Cachoeira do Sul-RS. An initial simulation was carried out (CROPWAT 8.0 model) based on data observed during the field experiment with the soybean crop in the 2021/22 agricultural year, where all the necessary input data were collected. Afterwards, another 20 simulations were carried out for all agricultural years between 2001-2 and 2021-22, maintaining the parameters observed in the 2021-22 agricultural year and changing only the rainfall during the crop cycle. The accumulated rainfall throughout the soybean cycle ranged between 284 and 1084 mm, and the demand for supplementary irrigation ranged between 75 and 345 mm. In total, there were nine years with rainfall above the data average, with an average of 129 mm of irrigation, and eleven years with rainfall below the data average, with an average demand of 205 mm of supplementary irrigation. The need for irrigation is dependent on the regular distribution of rainfall throughout the cycle due to the increased use of effective rainfall.

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Keywords: *Glycine max*. Cropwat. Water requirement.

3 INTRODUÇÃO

To meet the food production necessary to meet global demand in a sustainable way, since agriculture is responsible for the majority of water consumed, knowledge about plant water consumption and adequate planning of water use in systems are necessary. agricultural. In this context, water balance simulation models are tools that can contribute to evaluating water availability, water demand and the efficiency of management systems, assisting in the planning of reservoirs and irrigation systems. Water balance modeling contributes to maximizing water use efficiency, preventing the scarcity of water resources and minimizing environmental impacts. According to Araújo, Paiva and Silva (2016), these models are fundamental for ensuring water security, sustainable agricultural production and environmental preservation.

The water balance is an accounting method for estimating water availability in the soil and is based on the application of the mass conservation principle (PEREIRA). ; VILLA NOVA; SEDIYAMA, 1997). It allows observing the dynamics of water in the soil based on water storage, deficiency and excess (CAMARGO; CAMARGO, 2000). According to Pereira, Angelocci and Sentelhas (2002), the main components of the water balance used to define water demand and availability are precipitation (P), real evapotranspiration (ETR), potential evapotranspiration (ETP), soil water storage (ARM), water deficiency (DEF) and water surplus (EXC).

The FAO 56 bulletin by Allen *et al.* (1998) represented a major advance with regard to concepts and methods for estimating evapotranspiration (ET). In that document, the Penman–Monteith FAO (FAO-PM) method was parameterized to estimate reference evapotranspiration (ETo). The bulletin also addressed the update of the culture coefficient (Kc), which serves as a correction factor to take into account the physical and physiological differences between the culture under study and the reference culture. According to Pereira *et al.* (2015), the publication of the FAO 56 bulletin represented a major advance in the application of Kc curves to a wide variety of climates and locations. Thus, the standard methodology for estimating crop evapotranspiration (ETc: ETo × Kc) was established.

The CROPWAT (FAO) model uses information and calculation methodologies based on the FAO 56 bulletin and the FAO 33 bulletin in a graphical interface, with some ease of handling, contributing to irrigation management. Knežević *et al.* (2013), simulating the water balance for wheat in Bijelo Polje- Montenegro, concluded that the water balance was successfully simulated by the model. Oliveira *et al.* (2020) stated in their study that the use of the CROPWAT model with weather forecast data to estimate ETo can be used as a tool for estimating the water requirement of soybeans in the edaphoclimatic region of Cachoeira do Sul-RS.

With the increase in global demand for food, soybeans have become one of the most cultivated grains in the world. The global soybean harvest in 2021/22 reached approximately 356 billion tons in a cultivated area of 130,935 million hectares (EMBRAPA, 2023). However, the productivity of this crop has been limited by water deficit (ZANON *et al.*, 2018; OLIVEIRA *et al.*, 2020), which is caused by the irregular distribution of rainfall and high evaporative demand from the atmosphere (ZIPPER; QIU; KUCHARIK, 2016), which has recurrently spread in the southern region of the country and worsened during La Niña years (BERLATO; FONTANA, 2003).

The water requirement of soybeans varies from 450 to 800 mm throughout the phenological cycle, depending on the local climatic conditions (DOOREMBOS; KASSAM, 1994 ; ZANON *et al.*, 2018). During the soybean crop cycle, it is important to ensure that there is no water deficit during the critical phases: the crop establishment phase and the reproductive phase (DOOREMBOS; KASSAM, 1994; THOMAS; COSTA, 2010 ; ZANON *et al.*, 2018).

Thus, supplementary irrigation is a fundamental practice for ensuring good productive performance of soybean plants in the state (SENTELHAS *et al.*, 2015). Oliveira, Knies and Gomes (2020) observed an increase of 13 bags ha $^{-1}$ more soybeans with the use of supplementary irrigation in Cachoeira do Sul in the 2019-20 agricultural year. Therefore, the present study aimed to simulate the sequential water balance and the need for irrigation for soybean cultivation over twenty agricultural years (2001 to 2022) in the edaphoclimatic region of Cachoeira do Sul – RS.

4 MATERIALS AND METHODS

The initial modeling was carried out based on data observed during a field experiment with soybean crops in the 2021/22 agricultural year. The site for collecting soil and crop data was at the Experimental Station of the State University of Rio Grande do Sul (UERGS), located in the district of Três Vendas in the municipality of Cachoeira do Sul (29°53' S and 53° 00' W, altitude 125 m), in the central depression of the state. According to Köppen, the climate is defined as humid subtropical (Cfa) and is predominant in the southern region. The soil in the experimental area was classified as typical dystrophic Red Argisol (EMBRAPA, 2013). The cultivar analyzed was BMX Garra IPRO (relative maturity group 6.3).

The irrigation system was a conventional sprinkler (Agropolo NY 25 sprinklers) installed with a spacing of 12x12 m and a fixed irrigation blade of 15 mm; this sprinkler was applied whenever the depletion of the available water capacity in the soil (CAD) was 40%. Table 1 presents the soil volumetric moisture values at field capacity (CC) and the permanent wilting point (PMP) that result in the available soil water capacity (CAD) for each layer evaluated from 0-60 cm of the soil profile.

Monitoring water availability in the soil, called the current CAD, was carried out by determining the volumetric water content using an FDR set (Frequency Domain Reflectometry, Campbell Scientific), whose sensors were installed in layers from 0 to 30 cm and from 30 to 60 cm in the irrigated area and in the rainfed area. Determinations are made on specific dates, as the system does not have automatic acquisition for collecting and sending data.

Rainfall data were obtained from a rain gauge installed in the experimental area. The reference evapotranspiration (ETo) was estimated by the FAO-PM method from the automatic meteorological station installed at the UFSM Cachoeira do Sul, approximately 15 km from the experimental site. To calculate crop evapotranspiration (ETc), simple Kc was used, with the following values: 0.15 (initial), 1.15 (medium) and 0.3 (final). To adjust the Kc curve, the methodology proposed by Allen *et al*. was used. (1998) with the canopy cover fraction (Fc).

Table 1. Characterization of water availability in the soil profile.

Soil data			
Profile layer (cm)	**θCC**	**θPMP**	**CAD (mm)**
00-20	0.284	0.13	30.8
20-40	0.314	0.15	32.8
40-60	0.357	0.17	37.4

where θCC is the volumetric humidity at field capacity (cm ^{3} cm3); θPMP is the volumetric humidity at the permanent wilting point (cm ^{3} cm3); and CAD = (θCC - θPMP) × layer depth (mm).
Source: Authors.

Table 2 presents the dates of occurrence and the percentages of canopy closure used to adjust the Kc curve. During the soybean development cycle, phenological assessments were carried out, and the maximum exploration depth of the root system was determined to be 60 cm deep by means of a trench when the crop was at the R2 stage (full flowering).

Table 2. Dates of occurrence of the main stages of the development cycle necessary to schedule the need for irrigation.

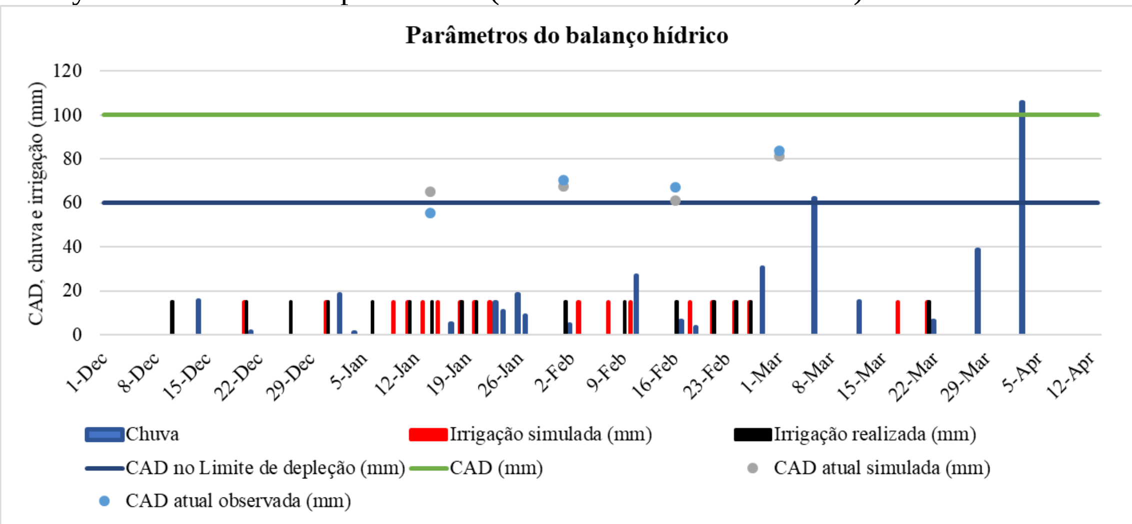
Stage	Date
Seeding	11/30/2021
10% of the closure of the cultivation row	12/15/2021
100% closure of the cultivation row	01/12/2022
Beginning of senescence	03/15/2022
Harvest	04/14/2022

Source: Authors.

The reported parameters served as input data for the CROPWAT model, with the following input parameters being used in the model: climate - ETo (estimated by the FAO – PM method); rainfall obtained at the experimental site; culture - minimum and maximum depth of the root system, set at 10 and 60 cm, respectively; maximum crop height of 100 cm; critical depletion (set at 40 mm and fixed blade at 15 mm); duration of crop development subperiods as per Table 2; soil - total water available between field capacity (CC) and permanent wilting point (PMP) (Table 1) – 168 mm/m; maximum root system depth of 60 cm (determined in R2); and initial depletion 0 mm – determined on the day of sowing.

The software was run under the same conditions as those used for the fieldwork, and the observed simulated parameters were very close to those estimated for the CAD and number and dates of irrigation (Figure 1). After this initial simulation (Figure 1), another 20 simulations were carried out for all agricultural years between 2001-2 and 2021-22, maintaining the modeling parameters during the 2021-22 agricultural year and only changing rainfall during the crop cycle. Rainfall data were obtained from a historical series from a rural producer in the town of Bosque Cachoeira do Sul, located approximately 10 km from the experiment site (2001-2016), from data collected at the experiment site itself and from data from the metrological station. from UFSM-CS (2017 to 2022).

Figure 1. Soybean water balance parameters (simulated vs. observed data).

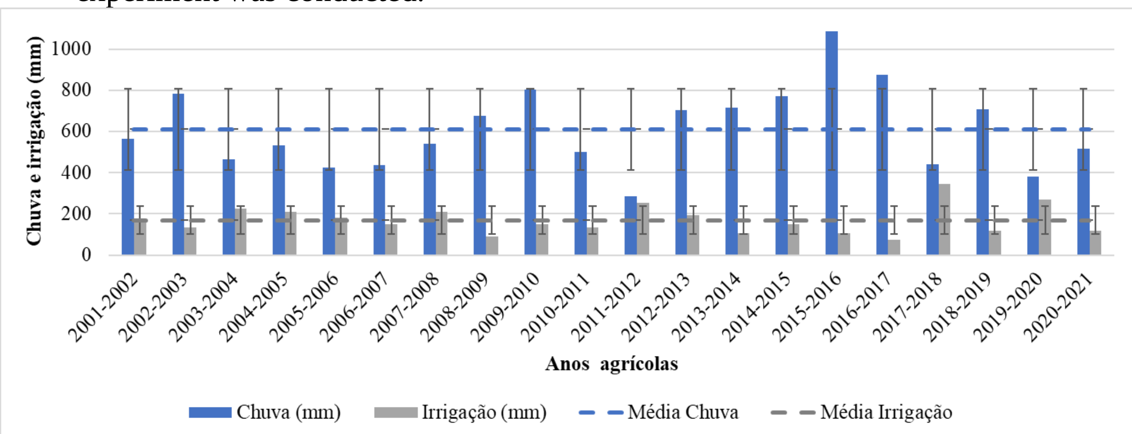


Source: Authors.

5 RESULTS AND DISCUSSION

Figure 2 shows the observed rainfall and simulated irrigation data for the agricultural years from 2001-2002 to 2020-2021. The accumulated rainfall during the soybean development cycle varied between 284 and 1084 mm, with an average value of 610 mm. The average rainfall values observed are higher than the climatological normal for Cachoeira do Sul of 473.6 mm for 1/12 to 14/04 (INMET, 2023). There were nine years with rainfall above the data average, five consecutive years between 2012-13 and 2016-17, eleven years with rainfall below the average, and five consecutive years between 2003-04 and 2007-08.

Figure 2. Global temperature and solar radiation results for the period during which the experiment was conducted.



Source: Authors.

The variation in the irrigation depth required to supplement rainfall was between 75 and 345 mm, depending on the quantity and distribution of rainfall. According to Farias, Neumaier and Nepomuceno (2017), who analyzed metrological data from 1976 to 2008 for RS, although the total amount of rainfall during the entire soybean development cycle reached values close to 700 mm, the yields achieved were not high due to the poor distribution of precipitation, especially during the most critical phase (reproductive period), limiting the achievement of high grain yields.

Agricultural years with more accumulated rainfall did not necessarily require less irrigation (Table 3) because rainfall events are often concentrated, thus exceeding the CAD, and more water is lost through surface runoff or drainage, becoming a rain that is not useful for the crop's water balance. For example, comparisons between two dry years (2005-06 and 2006-07) and two wet years (2013-14 and 2014-15) revealed similar accumulated rainfall and different values of surface runoff and supplementary irrigation depth (Table 3). According to Carlesso (2010), adequate irrigation management determines when and how much to irrigate based on crop water needs, soil characteristics and meteorological conditions of the cultivation environment, aiming to optimize the quality and quantity of production. obtained.

Table 3. Results of water balance parameters for soybean crops in the agricultural years 2001-02 to 2020-21.

Agricultural year	Rain (mm)	Surface runoff (mm)	Irrigation (mm)	ETc (mm)	Average deficit (mm)
2001-2002	564.0	92.0	165.0	512.6	29.8
2002-2003	784.0	299.7	135.0	516.7	26.5
2003-2004	464.0	164.4	225.0	496,5	37,4
2004-2005	533,0	136,7	210,0	501,6	34,7
2005-2006	425,0	66,4	180,0	511,0	35,0
2006-2007	436,0	22,7	150,0	513,8	30,0
2007-2008	542,0	92,0	210,0	508,2	33,7
2008-2009	674,0	194,5	90,0	535,9	29,8
2009-2010	801,0	219,5	150,0	520,9	35,5
2010-2011	499,0	71,4	135,0	514,8	32,2
2011-2012	284,0	30,8	255,0	481,3	39,6
2012-2013	705,0	287,8	195,0	516,5	28,6
2013-2014	717,0	133,3	105,0	527,8	27,9
2014-2015	772,0	308,8	150,0	526,4	30,0
2015-2016	1084,0	453,5	105,0	529,6	25,7
2016-2017	876,0	338,9	75,0	540,6	26,4
2017-2018	440,2	203,7	345,0	562,8	20,7
2018-2019	706,6	255,5	120,0	562,6	17,4
2019-2020	380.4	170.7	270.0	483.4	39.6
2020-2021	516.4	103.5	120.0	517.4	29.9

Source: Authors.

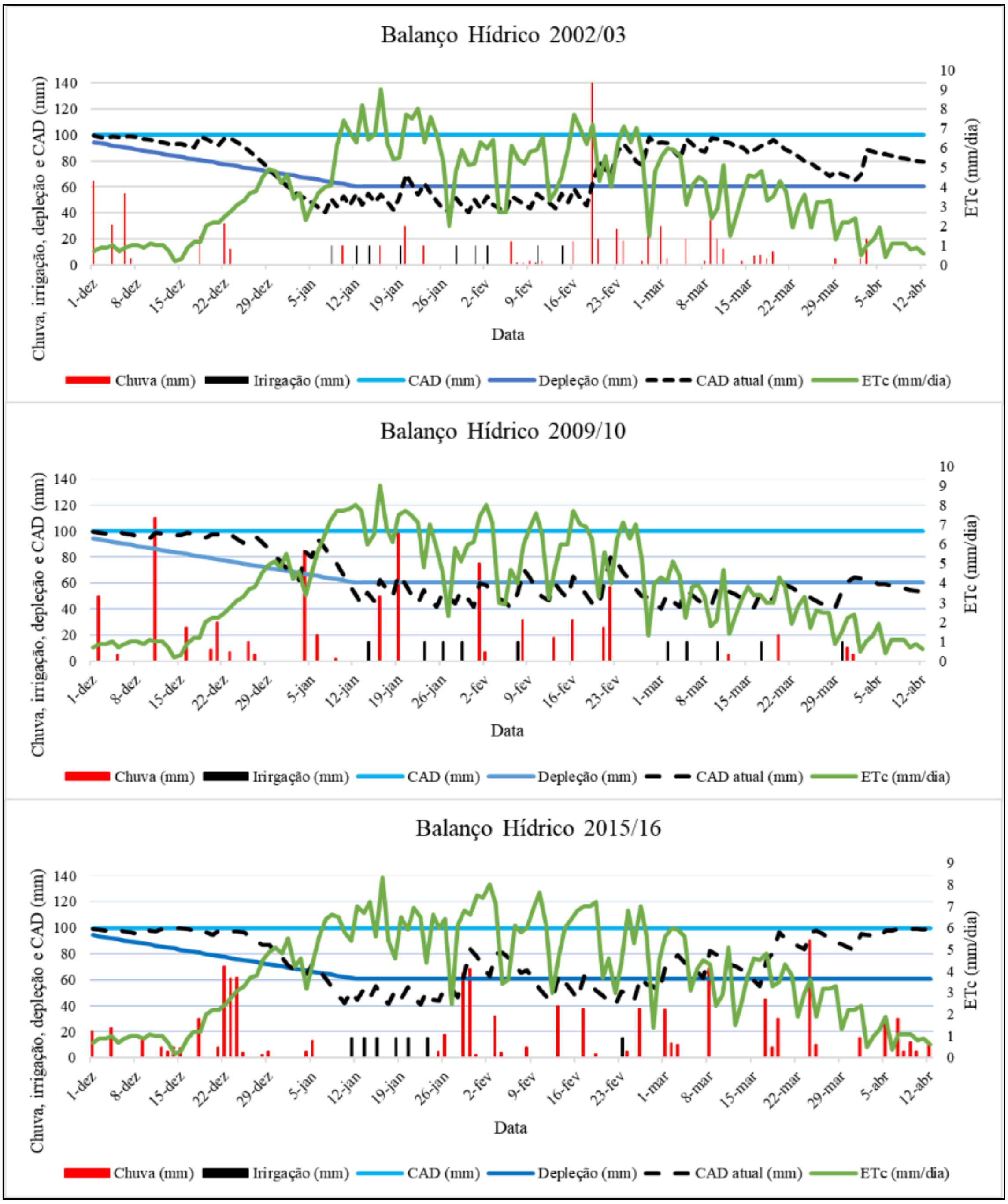
The variation in the ETc values accumulated during the cycle for the different agricultural years (Table 3) is attributed to the fact that the model uses the stress coefficient (Ks) to reduce Kc as the CAD decreases. According to Allen *et al.* (1998), under conditions of water stress, Ks < 1 indicates a reduction in water availability in the soil; otherwise, when there is no effect of water stress on crop transpiration, Ks = 1. Thus, this parameter has a direct effect on crop Kc and impacts ETc, causing ETc to be greater in humid years.

The average deficit in water storage in the soil (mm) throughout the cycle for different agricultural years (Table 3) is also variable, being greater in drier years and smaller in wetter years. Although a fixed value of water depletion in the soil was established for modeling, this may be linked to the distribution of rainfall throughout the cycle. Therefore, under more spaced-out rain conditions, the deficit is close to the set depletion limit. However, when rain events are closer, the water supply returns to ideal conditions, and the deficit is reduced.

Figures 3 and 4 present the sequential water balance for three wet years (rainfall above the data average) and three dry years (rainfall below the data average), respectively. The accumulated rainfall amounts were 784, 801 and 1084 mm for the agricultural years 2002-2003, 2009-2010 and 2015-2016, respectively, with a good distribution of rainfall throughout the cycle (Figure 3). Even so, there are concentrated rain events that generate surface runoff (Table 3) and periods with several consecutive days without rain.

In the case of the 2002-2003 agricultural year (Figure 3), there were 18 consecutive days without rain in the rapid plant growth phase and 13 days in the reproductive phase (when ETc reached its maximum), requiring 9 additional irrigations to maintain water storage in the soil at desirable levels. In the 2009-2010 agricultural year, there was also a long interval between rains during the reproductive period (two times), once 13 days without rain (in January) and another time for 18 days (in March), a critical period for water deficit, with an impact straight to productivity components. In the 2015-2016 agricultural period, the wettest in the data series, there was a need for 7 supplementary irrigations concentrated in the period that comprised two phases of the cycle, rapid crop growth and medium development, when there were 20 consecutive days without rain (Figure 3).

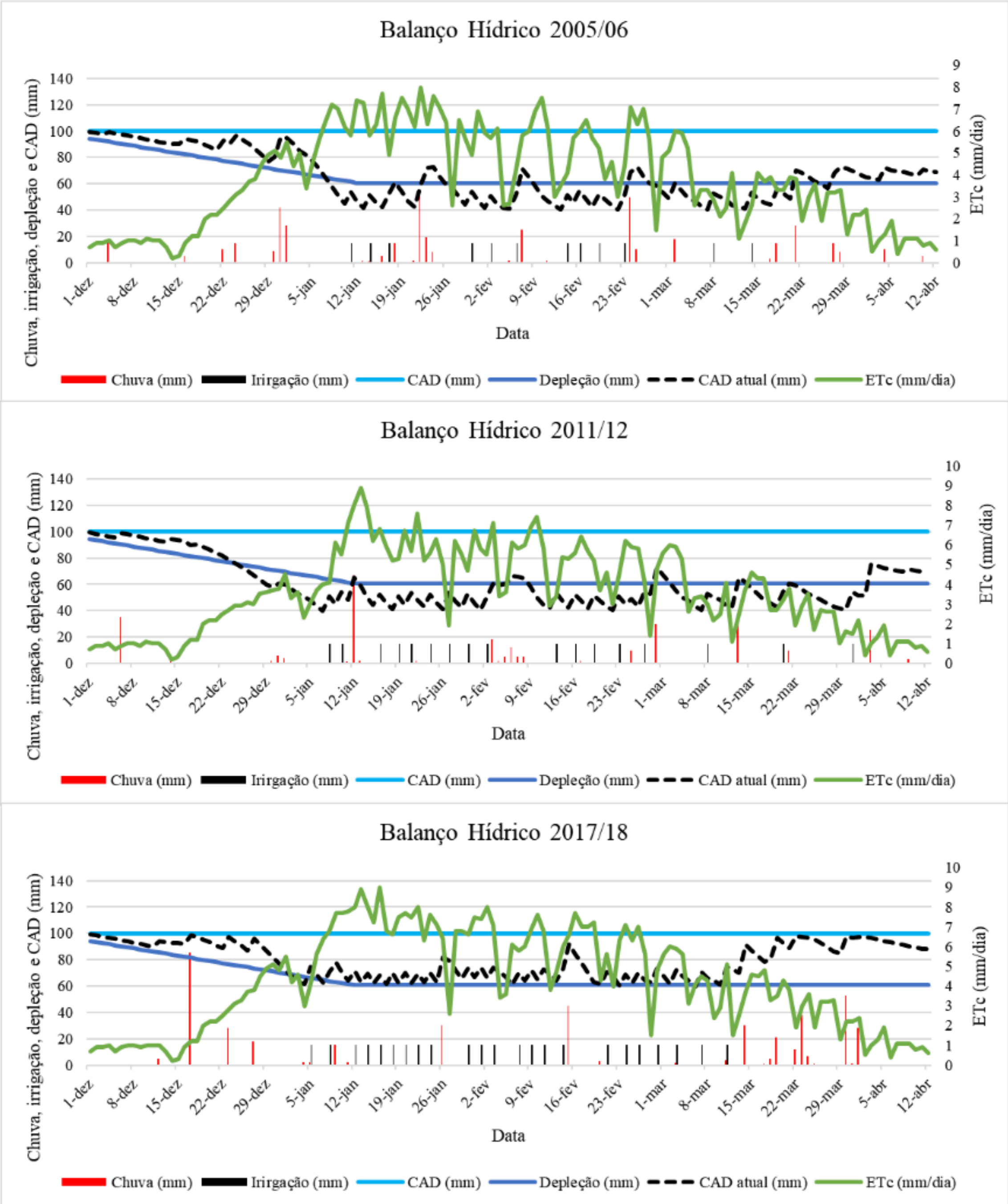
Figure 3. Sequential water balance of soybean crops for the agricultural years 2002/03, 2009/10 and 2015/16.



Source: Authors.

For years with rainfall below the average of 425, 284 and 440 mm in 2005-2006, 2011-2012 and 2017-2018, respectively (Figure 4), in addition to the low amount of rainfall and lower demand of the crop, there was also a concentration of rain events that generated surface runoff (Table 3) and long periods without rain, requiring supplementary irrigation throughout the entire development cycle to maintain humidity at desired levels.

Figure 4. Sequential water balance of soybean crops for the agricultural years 2005/06, 2011/12 and 2017/18.



Source: Authors.

Among the dry years examined, 2005-2006 had the best rainfall distribution, with the lowest demand for supplementary irrigation (12 irrigations). In 2017-2018, the accumulated rainfall was very similar to that in 2005-2006, but most of the rainfall was lost to surface runoff (203 mm) due to the close distribution of the events when the soil was already at the maximum CAD. Thus, there was the greatest need for supplementary irrigation of the entire data series, totaling 23 irrigations. The year 2011-2012 was the year that presented the lowest values of accumulated rainfall (284 mm); however, this year had a good distribution and effectiveness but was insufficient to meet the crop's water demand throughout the entire development cycle, as 17 irrigation events are fundamental for maintaining water supply conditions for soybean crops.

In this study, the number of irrigations/cycle ranged from 5 to 23 (Table 4), with a total depth ranging from 75 to 345 mm (Table 3). Vivan (2010), who studied the response to supplementary irrigation in different scenarios for soybean cultivation in the microregion of Passo Fundo, RS, identified the need to apply irrigation depths ranging from 54.1 to 429.9 mm, depending on the cycle length and sowing time.

The highest concentrations of irrigation occurred in the months of January and February, with the maximum demand observed being 10 and 9 irrigations in January and February, respectively, in the years 2017-18 (with grains below the data average). These findings indicate the importance of planning reservoirs to store the water necessary for supplementary irrigation during these most critical months. Thus, the results of this study serve as an indication of the need for supplementary irrigation for soybean cultivation in the study region, which could contribute to the planning of reservoirs and irrigation systems. Ewaid, Abed and Al-Ansari (2019), studying the programming and need for irrigation in southern Iraq, concluded that the CROPWAT model contributes to understanding the water needs of crops (wheat, barley, sorghum and tomatoes) and to planning water resources more efficiently.

Table 4. Results of the number of irrigations per month and total for the crop cycle in the agricultural years 2001-02 to 2020-21.

Agricultural	**Number of irrigation/month of the soybean cycle**				
year	**January**	**February**	**March**	**April**	**Sum**
2001-2002	6	5	0	0	11
2002-2003	6	3	0	0	9
2003-2004	6	4	4	1	15
2004-2005	5	6	3	0	14
2005-2006	4	6	2	0	12
2006-2007	6	4	0	0	10
2007-2008	7	6	1	0	14
2008-2009	2	3	1	0	6
2009-2010	4	1	5	0	10
2010-2011	6	1	2	0	9
2011-2012	8	6	2	1	17
2012-2013	6	6	1	0	13
2013-2014	4	3	0	0	7
2014-2015	0	5	5	0	10
2015-2016	6	1	0	0	7
2016-2017	0	4	0	1	5
2017-2018	10	9	4	0	23
2018-2019	2	4	1	1	8
2019-2020	5	8	5	0	18
2020-2021	4	2	1	0	7

Source: Authors.

4 CONCLUSIONS

For Cachoeira do Sul-RS, for a period of twenty agricultural years, variations were observed in the accumulated rainfall throughout the soybean crop development cycle between 284 and 1084 mm and in the demand for supplementary irrigation between 75 and 345 mm. In total, there were nine years in which rainfall was above the average recorded in the data, which resulted in an average need for 129 mm of irrigation, and in eleven years, rainfall was below average, requiring a greater amount of supplementary irrigation, on average, of 205 mm. The need for irrigation is influenced by the regular distribution, intensity and quantity of rainfall throughout the crop's development cycle, as this directly affects the efficiency of the use of rainfall in the crop's water balance.

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