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BALANÇO HÍDRICO CLIMATOLÓGICO NORMAL E SEQUENCIAL DO MUNICÍPIO DE PEREIRA BARRETO - SP COMO AUXILIO PARA O PLANEJAMENTO DA AGRICULTURA IRRIGADA

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1 RESUMO

Este trabalho teve como objetivo gerar um balanço hídrico climatológico (BHC) normal e sequencial para o município de Pereira Barreto, SP para identificar os períodos do ano com excedente e déficit de água no solo. Foram realizados dois BHCs para o município, determinados a partir do método de Thorthwaite e Mather (1955), com base nos dados das estações agrometereologicas automáticas Bonança e Santa Adélia, pertencentes à Rede Agrometeorológica do Noroeste Paulista, operada pela Unesp de Ilha Solteira. A precipitação média anual é de 1.214 mm e a evapotranspiração de 1.340 mm para a Estação Bonança, enquanto para a Santa Adélia, a precipitação média anual é de 1.204 mm e evapotranspiração de 1.574 mm. Com a Capacidade de Água Disponível (CAD) de 40 mm, os BHCs constataram sete meses de déficit hídrico no solo, entre março e outubro na Estação Bonança, localizada às margens do rio Tietê e de abril a novembro na Estação Santa Adélia, localizada na porção noroeste do município. O excesso de água no solo na Estação Bonança aconteceu entre os meses de novembro e fevereiro e na Santa Adélia entre janeiro e março. O BHC mostrou ser grande o risco de frustação de safra com culturas anuais no município sem a utilização de irrigação.

Palavras-chave: evapotranspiração, déficit hídrico, irrigação, agrometeorologia, Noroeste Paulista.

ABREU, P. A. S.; HERNANDEZ, F. B. T.
NORMAL AND SEQUENTIAL CLIMATOLOGICAL WATER BALANCE IN THE MUNICIPALITY OF PEREIRA BARRETO - SP AS AID FOR THE PLANNING OF IRRIGATED AGRICULTURE

2 ABSTRACT

This work aimed to generate a normal and sequential climatological water balance (BHC) for the municipality of Pereira Barreto, SP to identify the periods of the year with surplus and deficit of water in the soil. Two BHCs were carried out for the municipality determined by the method of Thorthwaite and Mather (1955), based on data from the automatic agro-

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meteorological stations Bonança and Santa Adélia, belonging to the Northwest Agro-meteorological Network of the Northwest, operated by Unesp of Ilha Solteira. The average annual precipitation is 1214 mm and the evapotranspiration is 1340 mm for the Bonança Station, while for the Santa Adélia Station, the average annual precipitation is 1204 mm and evapotranspiration is 1574 mm. With the available Water Storage (CAD) of 40 mm, the BHCs found seven months of water deficit in the soil, between March and October in the Bonança Station, located on the banks of the Tietê River and from April to November in the Santa Adélia Station, located in the northwest portion of the municipality. Excess water in the soil in the Bonança Station occurred between the months of November and February and in the Santa Adélia Station, between January and March. BHC showed a high risk of crop failure with annual crops in the municipality without the use of irrigation.

Keywords: evapotranspiration, water deficit, irrigation, agrometeorology, Northwest Paulista.

3 INTRODUCTION

Brazil is one of the world's leading producers of agricultural commodities, particularly soybeans, sugarcane, and corn. In the 2020/21 harvest, these three crops alone produced 524 million tons, with soybeans and corn producing 87 and 137 million tons, respectively (Companhia Nacional de Abaster, 2021a), and sugarcane producing 300 million tons (Companhia Nacional de Abaster, 2021b). Grains account for a significant portion of the export/import trade surplus, and sugarcane is almost entirely used in the country's sugar–alcohol complex.

Although Brazil has significant agricultural potential, potential climate change raises concerns, particularly regarding increased droughts, which could lead to serious food insecurity worldwide (VARSHNEY et al., 2011). The most viable solution for crops during periods of water deficit is irrigation, a practice used by producers to ensure crop maintenance in areas with low or uneven rainfall distributions, in addition to enabling increased productivity (LOPES et al., 2011). However, water resources must be used efficiently, which requires proper agricultural planning.

The use of irrigation is increasing in the country, with a focus on the use of central pivots. Northwest São Paulo is an example of this evolution, as between 2000 and 2018, the area irrigated by this equipment increased from 6,662 ha to 17,135 ha, with 241 new central pivots being acquired to meet the demands of these properties (OLIVEIRA, 2020). The municipality of Pereira Barreto, which comprises Northwest São Paulo, is responsible for irrigating 2,347 ha via twenty central pivots (OLIVEIRA, 2020).

A benefit for irrigated agriculture producers in this region is the availability of climate data provided by agroclimatic monitoring coordinated by the Hydraulics and Irrigation Area of São Paulo State University “Júlio de Mesquita Filho” (Unesp) in Ilha Solteira (UNESP, 2020). The dissemination of these data is of utmost importance for decision-making regarding the correct time to irrigate, the depth to use, the sizing of irrigation systems, and the determination of the best planting and harvesting times for different crops.

Compiling water balances across different locations via climate data from a monitoring network enables water resource planning and management, agroclimatic zoning, and climate classification (YAMADA, 2011). This tool is crucial for producers and professionals in the field when making decisions about whether to purchase irrigation systems. The water balance can help identify potential long periods of accumulated soil water deficits, highlighting the need for irrigation for crop development and water resource management.

In view of the above, the present work aims to generate the normal and sequential climatological water balance for the municipality of Pereira Barreto, SP, with the aim of identifying the periods of the year with surplus and deficit of water in the soil to serve as an aid for planning crop irrigation in the municipality.

4 MATERIALS AND METHODS

This work was based on the municipality of Pereira Barreto, SP, located in northwestern São Paulo state. Data series recorded between 2011 and 2019 were collected at the automatic agrometeorological stations Bonança (latitude of 20° 40' 23.1” S, longitude of 51° 2' 2.1" W and altitude of 357 m) and Santa Adélia (latitude of 20° 31' 42” S, longitude of 51° 14' 58" W and altitude of 426 m), which are located in the southern and northwestern portions of the municipality, respectively.

The municipality of Pereira Barreto is 630 kilometers from the state capital and has an area of 974.247 km2, [and] the climate of the region, according to the Köppen classification, is of the rainy tropical type, with a dry winter (Aw) (ALVARES et al., 2014).

The climatological water balance (BHC) was obtained via the method of Thornthwaite & Mather (1955). Considering that most cultivated crops in the municipality are cultivated annually, a soil available water capacity (SWC) of 40 mm was established. This value was defined considering an effective root depth of 40 cm (annual crops) and that most of the soils in the region are composed of Argisols with an average SWC of 1 mm cm^{-1} of soil, according to Reichardt (1987).

From the 2011--2019 series, the normal BHC was determined, and the sequential BHC was performed with climatological data from January 2016--December 2019, which were based on average monthly precipitation (P) and reference evapotranspiration (ETo) data, which were estimated via the Penman–Monteith equation (ALLEN et al., 1998). The values used were those recorded at the stations that make up the agrometeorological network of northwestern São Paulo, which was coordinated by Unesp in Ilha Solteira. The characterization of the sensors and *modus operandi* of the stations are available on the Unesp CLIMA Channel website (UNESP, 2020).

Potential evapotranspiration (ETP) was estimated from the sum of the monthly historical averages of ETo, soil water storage (SWS), water surplus (SWS), water deficiency (SWD), water withdrawal (SWD), and water replacement (SWP). The water balance values and graphs were generated via the BHnorm and BHseq spreadsheets (ROLIM; SENTELHAS; BARBIERI, 1998). With the normal and sequential climatological water balance, it is possible to decide when to irrigate and achieve the best crop yields.

5 RESULTS AND DISCUSSION

The normal climatological water balance generated according to the Thornthwaite & Mather method (1955) is shown in Tables 1 and 2. The sum of the monthly precipitation recorded by the Bonança station was 1,214 mm, with the months of January, February, March, November and December being responsible for the accumulation of 824.7 mm, representing 67.9% of the total precipitation. Similar results were found for Santa Adélia Station, where the sum of precipitation was close to that of Bonança Station (1,204.9 mm). The months from November to March also received the most precipitation, accounting for 59.4% of the region's total, since these months are in accordance with the period in which the climate is characterized as hot and humid.

Table 1. Normal climatological water balance of the municipality of Pereira Barreto (Bonança Station).

Month	P (mm)	ETP (mm)	ARM (mm)	ETR (mm)	DEF (mm)	EXC (mm)	VEN (°)
January	200.71	134.46	40.0	134.5	0.0	66.3	171.4
February	146.58	121.80	40.0	121.8	0.0	24.8	180.6
March	129.48	123.23	40.0	123.2	0.0	6.2	190.6
April	72.86	98.63	21.0	91.9	6.8	0.0	163.3
May	71.26	78.66	17.5	74.8	3.9	0.0	144.0
June	40.95	67.13	9.1	49.3	17.8	0.0	145.8
July	20.60	79.44	2.1	27.6	51.8	0.0	133.8
August	28.75	103.08	0.3	30.5	72.6	0.0	137.5
September	72.92	124.67	0.1	73.2	51.5	0.0	158.3
October	81.93	138.47	0.0	82.0	56.5	0.0	167.8
November	181.19	134.67	40.0	134.7	0.0	6.5	181.7
December	166.72	136.40	40.0	136.4	0.0	30.3	189.5
Total	1,214	1,340.6	250.1	1,079.8	260.8	134.1	-

P: Precipitation (mm), ETP: reference evapotranspiration (mm), ARM: storage (mm), ETR: actual evapotranspiration (mm), DEF: deficiency (mm), EXC: excess (mm), VEN: wind direction (°).

Table 2. Normal climatological water balance of the municipality of Pereira Barreto (Santa Adélia Station).

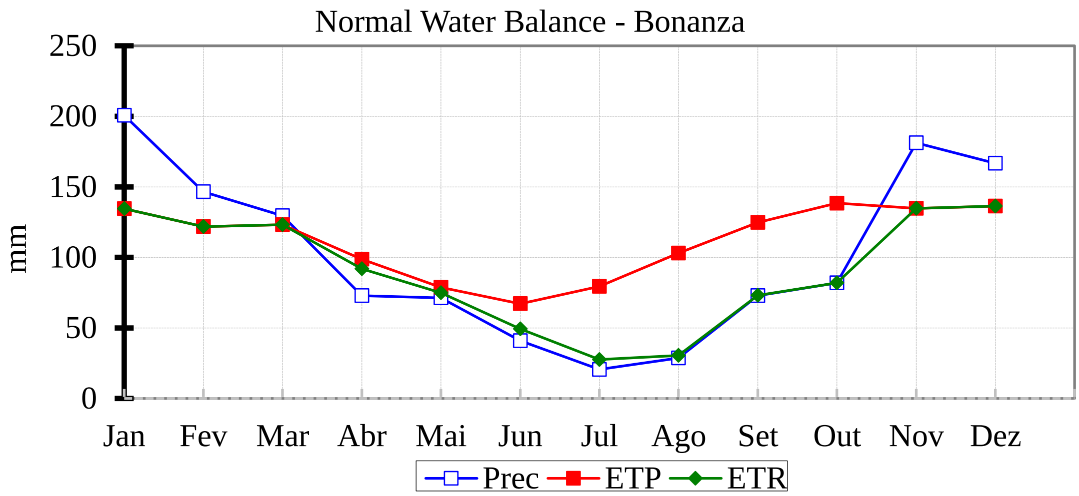
Month	P (mm)	ETP (mm)	ARM (mm)	ETR (mm)	DEF (mm)	EXC (mm)	VEN (°)
January	188.06	141.83	40.0	141.8	0.0	30.3	115.0
February	135.45	124.60	40.0	124.6	0.0	10.9	118.3
March	145.66	132.91	40.0	132.9	0.0	12.8	143.3
April	86.39	114.38	19.9	106.5	7.9	0.0	128.9
May	72.83	96.88	10.9	81.8	15.1	0.0	124.8
June	42.38	92.63	3.1	50.2	42.5	0.0	130.8
July	20.33	115.39	0.3	23.1	92.2	0.0	120.5
August	26.52	145.36	0.0	26.8	118.6	0.0	123.6
September	72.62	157.33	0.0	72.6	84.7	0.0	125.0
October	96.64	159.13	0.0	96.6	62.5	0.0	133.0
November	149.53	141.33	8.2	141.3	0.0	0.0	124.8
December	168.49	152.59	24.1	152.6	0.0	0.0	134.2
Total	1,204.9	1,574.3	186.5	1,151.0	423.4	53.9	-

P: Precipitation (mm), ETP: reference evapotranspiration (mm), ARM: storage (mm), ETR: actual evapotranspiration (mm), DEF: deficiency (mm), EXC: excess (mm), VEN: wind direction (°).

According to Tables 1 and 2, the sums of potential evapotranspiration were 1,340.6 and 1,574.3 mm for the Bonança and Santa Adélia Stations, respectively, with the months of January, February, March, November, and December having the highest ETP values. The lowest evapotranspiration values were recorded during the months of May, June, July, and August in both seasons; these values are expected because these months present the lowest temperatures during the year. The sums of P and ETP found in this research were close to those reported by Silva Júnior et al. (2018), who carried out a climatological water balance of Northwest São Paulo, using eight agrometeorological stations, including the stations in the municipalities of Pereira Barreto, Bonança, and Santa Adélia, with a data series from 2012--2015. The values of P and ETo found were 1,214 and 1,369 mm and 1,241 and 1,531 mm, respectively.

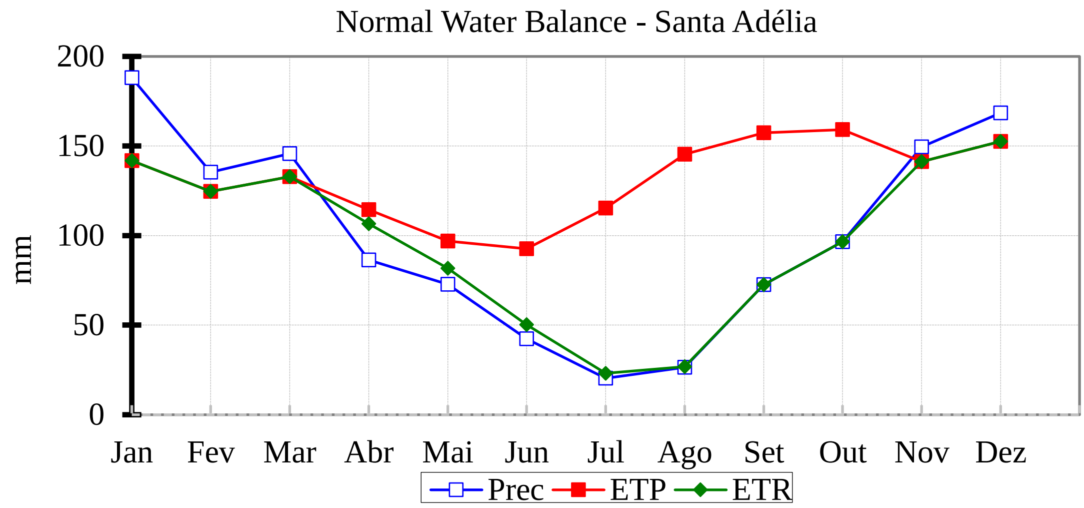
Figure 1 shows that despite having an ETP of 1,341 mm, the ETR was 1,080 mm, indicating that the precipitation during the year was not sufficient to meet the soil water demand, resulting in a soil water deficiency, with an annual sum of 261 mm. The same happened in Figure 2, with an ETR also lower than the estimated ETP; however, there was a higher accumulated DEF than that of the Bonança Station, with 423 mm, even though both recorded very similar precipitation and were in the area of the same municipality.

Figure 1. Monthly behavior of precipitation, potential evapotranspiration and actual evapotranspiration at Bonança station.



Prec: Precipitation, ETP: Potential evapotranspiration, ETR: Actual evapotranspiration

Figure 2. Behavior of precipitation, potential evapotranspiration and actual evapotranspiration at Santa Adélia Station.



Prec: Precipitation, ETP: Potential evapotranspiration, ETR: Actual evapotranspiration

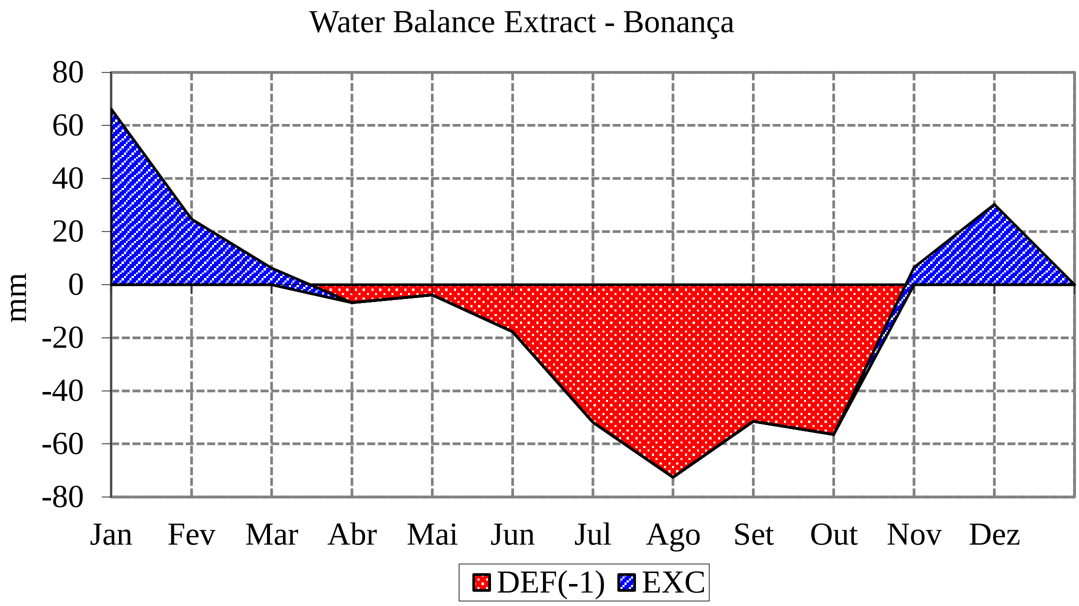
The greatest water deficit recorded at Santa Adélia can be explained by the location of the stations and the effect of the wind direction. The prevailing wind throughout the year at Bonança Station comes from Southeast China, bringing with it a large amount of water from the Tietê River. It is located in the center of 2,111 hectares irrigated by a central pivot, generating an oasis effect and, thus, a lower reference evapotranspiration in this region (Figure 3). At Santa Adélia Station, the prevailing wind is also from Southeast China but has the effect of continentality. There are no water bodies or irrigated areas to influence the agroclimatic variables of temperature and relative humidity, which will be the basis for estimating reference evapotranspiration. Furthermore, the station is surrounded by extensive areas of nonirrigated sugarcane, thus presenting a greater evapotranspiration demand and a greater soil water deficit. It can be inferred that the Bonança Station region has more favorable climatic conditions for irrigated agriculture if we consider the economic issues linked to investment and cost of irrigation systems and, from an agronomic point of view, the continentality of the Northwest Region of the municipality and the greater water deficit make investment in irrigation systems an imposition for the sustainability of the business of producing food on the basis of annual cycles, as is the case with soybean, corn, peanut or bean crops, for example.

Figure 3. Diagram of the wind direction at the Bonança and Santa Adélia Stations. The arrows indicate the predominant wind direction at the stations.

The sums of soil water storage were 250.1 and 186.5 mm for the Bonança and Santa Adélia Stations, respectively. At the Bonança Station, in five months, the ARM was equal to the CAD adopted in this work (Table 1), whereas at Santa Adélia, this occurred in only three months (Table 2), and for the remaining months, the water storage in the soil was less than 40 mm, with the months of lower precipitation presenting the most critical ARM values. According to Tables 1 and 2, after one and three months, the storage time reached zero at the Bonança and Santa Adélia Stations, respectively. The same behavior was observed in the water balance carried out by Santos, Hernandez and Rossetti (2010) for the city of Marinópolis, a municipality neighboring the site of the present study.

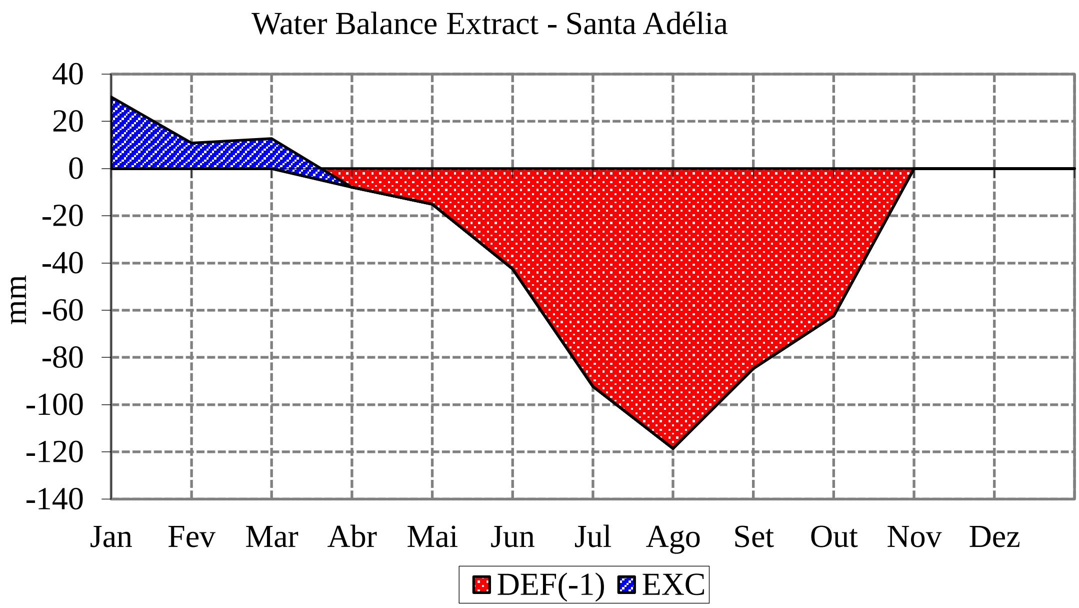
Figure 4 shows that there was an accumulation of soil water deficiency over seven months, with a total of 260.9 mm between April and October at Bonança Station and a deficit of 423.5 mm between April and November at Santa Adélia Station (Figure 5). With respect to the water balance carried out by Santos, Hernandez and Rossetti (2010) for the municipality of Marinópolis, which is located 50 km away from Pereira Barreto, the authors observed a water deficiency for a period longer than that of this research, equal to 490 mm; however, the annual precipitation, 1,111 mm, was also lower than that recorded by the Bonança and Santa Adélia Stations. Silva Júnior (2017), through water balance, reported a soil water deficit for different locations in northwestern São Paulo via a CAD of 60 cm and reported an accumulated deficiency of 349 mm for Santa Adélia Station, which was lower than that reported in this work, whereas the deficit for Bonança Station, 266 mm, was greater than that reported in this research. Silva Júnior et al . (2018) performed a water balance using the averages of the entire Agrometeorological Network of Northwest São Paulo and reported values of 236 mm, with the soil water deficiency of the Bonança and Santa Adélia Stations being higher than the average found for Northwest São Paulo.

Figure 4. Representation of the normal climatological water balance of the municipality of Pereira Barreto, SP, by Bonança Station.



DEF: Soil water deficiency, EXC: Soil water excess.

Figure 5. Representation of the normal climatological water balance of the municipality of Pereira Barreto, SP, by Santa Adélia Station.



DEF: Soil water deficiency, EXC: Soil water excess.

With the decrease in rainfall starting in March, a period of soil water deficit begins, increasing until July, August, and October, when the highest DEF levels are observed. Although rainfall occurs during these months, it is insufficient to replenish all the soil water deficit. Only with the precipitation that occurs in November does excess soil water at Bonança Station return, with storage once again reaching the CAD. The water deficit in the Santa Adélia Station area, especially between July and September, is so critical that not even the heavy rainfall from November onward is sufficient to generate excess soil water.

However, this study revealed values close to those of Silva Júnior et al. (2018) regarding annual P and ETP values, it is possible to observe that the water balance obtained by the authors for the Bonança and Santa Adélia Stations, with a CAD of 60 mm (more suitable for perennial crops such as pasture, sugarcane, and citrus, for example), presented water deficit values on a different time scale and high monthly DEF values, such as the DEF observed in August, equal to -100 mm at Bonança Station and -141 mm at Santa Adélia Station. This difference occurred because of the addition of four years of data, from 2016--2019. It is necessary to incorporate new historical data series to update the local water balance to obtain a better understanding of the situation. This can be confirmed by the sequential water balances (BHseq) of both stations (Tables 3 and 4).

Table 3. Sequential climatological water balance of the municipality of Pereira Barreto.

Calm (mm)					Saint Adelia (mm)				
Month	**P**	**ETP**	**DEF**	**EXC**	**Month**	**P**	**ETP**	**DEF**	**EXC**
Jan/16	194.1	127.1	0.0	67.0	Jan/16	187.5	127.1	0.0	60.4
Feb/16	153.9	114.8	0.0	39.1	Feb/16	186.7	117.6	0.0	69.1
Mar/16	118.1	120.9	0.1	0.0	Mar/16	190.8	133.3	0.0	57.5
Apr/16	95.7	114.0	4.6	0.0	Apr/16	87.6	135.0	19.6	0.0
May/16	150.9	74.4	0.0	60.1	May/16	135.6	86.8	0.0	21.0
Jun/16	71.1	63.0	0.0	8.1	Jun/16	58.4	81.0	5.3	0.0
Jul/16	2.5	83.7	46.5	0.0	Jul/16	4.1	111.6	86.3	0.0
Aug/16	89.4	96.1	5.9	0.0	Aug/16	98.5	130.2	30.9	0.0
Sep/16	52.1	114.0	58.4	0.0	Sep/16	54.6	132.0	76.8	0.0
Oct/16	118.1	136.4	18.0	0.0	Oct/16	117.3	145.7	28.3	0.0
Nov/16	73.7	135.0	60.8	0.0	Nov/16	68.1	138.0	69.9	0.0
Dec/16	134.4	130.2	0.0	0.0	Dec/16	109.5	148.8	39.3	0.0
Jan/17	250.9	114.7	0.0	100.5	Jan/17	205.2	120.9	0.0	44.3
Feb/17	51.8	131.6	45.2	0.0	Feb/17	33.8	128.8	58.7	0.0
Mar/17	115.1	124.0	7.8	0.0	Mar/17	102.1	130.2	26.2	0.0
Apr/17	108.7	93.0	0.0	0.0	Apr/17	108.5	102.0	0.0	0.0
May/17	117.1	77.5	0.0	19.7	May/17	137.9	86.8	0.0	19.4
Jun/17	9.7	66.0	26.1	0.0	Jun/17	8.6	84.0	41.5	0.0
Jul/17	0	83.7	75.1	0.0	Jul/17	0	108.5	102.8	0.0
Aug/17	39.9	93.0	52.2	0.0	Aug/17	43.9	124.0	79.8	0.0
Sep/17	21.3	132.0	110.4	0.0	Sep/17	20.1	168.0	147.8	0.0
Oct/17	157.7	127.1	0.0	0.0	Oct/17	132.3	151.9	19.6	0.0
Nov/17	201.4	126.0	0.0	66.0	Nov/17	196.8	129.0	0.0	27.8
Dec/17	302	120.9	0.0	181.1	Dec/17	295.4	142.6	0.0	152.8
Jan/18	307.8	117.8	0.0	190.0	Jan/18	319	130.2	0.0	188.8
Feb/18	105.7	112.0	0.5	0.0	Feb/18	119.4	114.8	0.0	4.6
Mar/18	73.4	124.0	26.1	0.0	Mar/18	68.3	136.4	35.4	0.0
Apr/18	58.4	93.0	29.0	0.0	Apr/18	49.5	105.0	50.0	0.0
May/18	6.1	83.7	74.1	0.0	May/18	1.5	93.0	89.9	0.0

P: precipitation (mm), ETP: reference evapotranspiration (mm), ETR: actual evapotranspiration (mm), DEF: deficiency (mm), EXC: excess (mm).

Table 4. Sequential climatological water balance of the municipality of Pereira Barreto.

Calm (mm)					Saint Adelia (mm)				
Month	**P**	**ETP**	**DEF**	**EXC**	**Month**	**P**	**ETP**	**DEF**	**EXC**
Jun/18	3	69.0	65.5	0.0	Jun/18	0	96.0	95.8	0.0
Jul/18	0	80.6	80.5	0.0	Jul/18	1	114.7	113.7	0.0
Aug/18	33	89.9	56.9	0.0	Aug/18	34	117.8	83.8	0.0
Sep/18	126	108.0	0.0	0.0	Sep/18	100.3	135.0	34.7	0.0
Oct/18	116.1	114.7	0.0	0.0	Oct/18	162.8	136.4	0.0	0.0
Nov/18	298.9	111.0	0.0	167.3	Nov/18	272.5	123.0	0.0	135.9
Dec/18	58.9	136.4	43.3	0.0	Dec/18	62	173.6	74.1	0.0
Jan/19	200.4	142.6	0.0	23.6	Jan/19	63.3	170.5	104.9	0.0
Feb/19	112.3	109.2	0.0	3.1	Feb/19	249.7	120.4	0.0	89.5
Mar/19	159.8	117.8	0.0	42.0	Mar/19	37.6	120.9	48.3	0.0
Apr/19	62	93.0	9.4	0.0	Apr/19	61.5	105.0	40.2	0.0
May/19	36.1	74.4	26.9	0.0	May/19	68.1	86.8	18.1	0.0
Jun/19	22.9	72.0	44.1	0.0	Jun/19	19.8	99.0	78.3	0.0
Jul/19	31.2	83.7	51.0	0.0	Jul/19	16.5	105.4	88.8	0.0
Aug/19	56.1	99.2	42.7	0.0	Aug/19	34.8	127.1	92.3	0.0
Sep/19	21.1	126.0	104.7	0.0	Sep/19	24.9	159.0	134.1	0.0
Oct/19	46	151.9	105.9	0.0	Oct/19	44.7	179.8	135.1	0.0
Nov/19	75.4	135.0	59.6	0.0	Nov/19	74.7	159.0	84.3	0.0
Dec/19	220	117.8	0.0	62.2	Dec/19	291.6	142.6	0.0	109.0
Total	4860.2	5161.8	5161.8	1029.8	Total	4760.8	6015.2	2234.5	980.1

P: precipitation (mm), ETP: reference evapotranspiration (mm), ETR: actual evapotranspiration (mm), DEF: deficiency (mm), EXC: excess (mm).

The sequential climatological water balances from the Bonança and Santa Adélia Stations generated according to the Thornthwaite & Mather method (1955) are shown in Table 3, with annual average total precipitation (P) and potential evapotranspiration (ETP) values of 1,215 and 1,291 mm, respectively, for the Bonança Station and 1,190 and 1,504 mm, respectively, for the Santa Adélia Station.

At both stations, 2019 was the year with the lowest rainfall of the four years studied. The values were 1,043 and 987 mm at the Bonança and Santa Adélia Stations, respectively. At Bonança Station, rainfall of 1,254 mm (2016) was recorded. 1,376 (2017) and 1,187 mm (2018), whereas at Santa Adélia Station, rainfall amounts of 1,299 (2016) were observed, with values of 1,285 (2017) and 1,190 mm (2018), with 2019 also standing out from the others in terms of evapotranspiration demands, with the Bonança and Santa Adélia Stations recording 1,323 and 1,576 mm, respectively.

The BHseq performed for the Bonança station (Figure 6) revealed that there was variation in summer rainfall, resulting in different soil water excesses between the months of January and March during the four years evaluated. This process altered the historical water balance performed by Silva Júnior et al. (2018), changing the periods and concentrations of excess soil water.

Figure 6. Representation of the sequential climatological water balance with a series of data from 2016--2019 for the municipality of Pereira Barreto, SP, recorded by Estação Bonança.

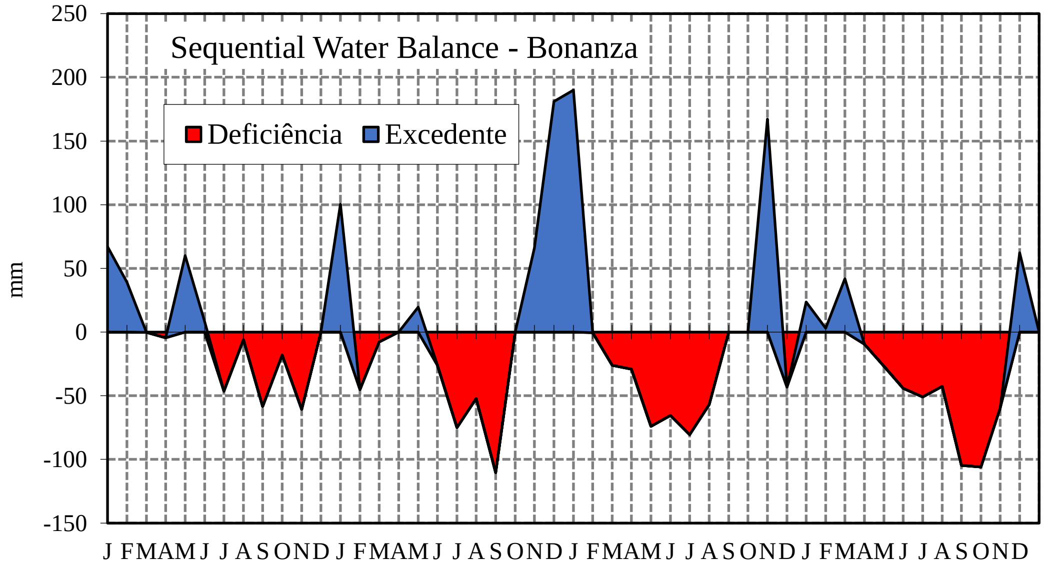
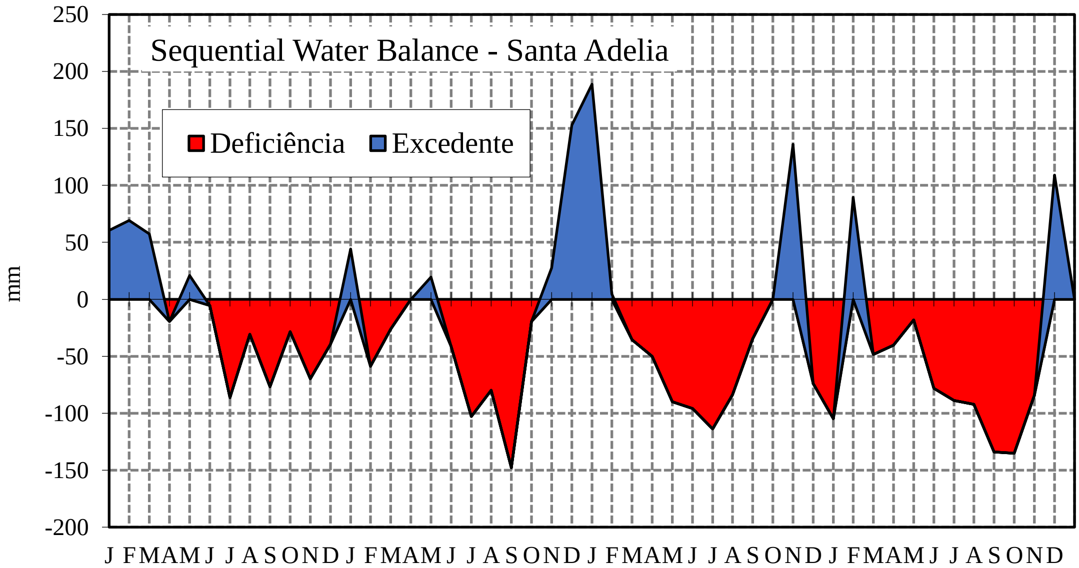


Figure 7. Representation of the sequential climatological water balance with a series of data from 2016 to 2019 for the municipality of Pereira Barreto, SP, recorded by the Santa Adélia Station .



For Santa Adélia Station (Figure 7), the main change found by the historical water balance performed by Silva Júnior et al. (2018) occurred in September. The authors reported a soil water deficit of -32 mm, whereas a water balance with data from 2011--2019 generated a soil water deficit of -118.6 mm. This difference can be explained by the BHseq performed for the station with the 2016 to 2019 dataset; a high water deficit occurred for this month, mainly in 2017 and 2019, with the water deficiency reaching almost 147 and 135 mm, respectively. The four-year difference in data caused changes in the excess and deficit values of the soil water; thus, it is necessary to update the municipality's water balance to better serve the producer regarding irrigation needs.

The sequential water balance at Bonança station (Figure 6) revealed that 2019 was the year with the longest period of soil water deficiency, lasting from April to November. In October, a DEF accumulation of -105.4 mm was observed, the highest for that year. This was due to lower precipitation between September and November and high potential evapotranspiration. During this period, a precipitation amount of 143.6 mm was observed, whereas in 2018, this figure was 541 mm. The 397.4 mm decrease contributed to the prolongation of soil water deficiency.

In the BHseq performed at Santa Adélia Station (Figure 7), 2019 had the longest period of soil water deficit, which lasted from March to November and lasted nine months. The same reasons observed for the Bonança Station are valid for the Santa Adélia Station. The low precipitation of 144 mm observed between September and November 2019 compared with that in 2016 (240 mm), 2017 (349 mm), and 2018 (535 mm) exacerbated this soil water deficiency. In these months, an ETP of 498 mm was also observed, which was the highest in this period among all years, a factor that favored this longer period of water deficit.

Soil water deficits can cause serious problems in various crops, disrupting various plant processes and ultimately impacting yield. The deficit begins when the plant's transpiration process outpaces its water absorption (LOPES; LIMA, 2015). Water deficits begin when a plant can no longer adjust its water absorption and transpiration processes, resulting in restricted transpiration due to a lack of available soil water (FARIAS; NEPOMUCENO; NEUMAIER, 2007).

According to the Brazilian Institute of Geography and Statistics (IBGE) (2018), the municipality of Pereira Barreto has a total of 66.2 thousand hectares planted. The main crops cultivated are sugarcane, soybeans, and corn. Between 2008 and 2018, there was an ~~increase~~ in the area planted with sugarcane and soybeans and a decrease in the area allocated to corn cultivation. In 2008, the areas planted with sugarcane and soybeans represented 14,637 and 325 hectares, respectively, whereas in 2018, the same crops occupied areas of 27,000 and 1,065 hectares, respectively (BRAZILIAN INSTITUTE OF GEOGRAPHY AND STATISTICS, 2018). On the other hand, corn cultivation caused an abrupt decrease in the planted area during this 10-year period (2008--2018) in the municipality. The areas occupied by corn cultivation were 2,912 and 1,345 hectares for the years 2008 and 2018, respectively. In 2018, sugarcane produced 1.62 billion tons, soybeans produced 4,07 thousand tons, and corn produced 9,08 thousand tons.

The use of irrigation systems in the municipality of Pereira Barreto is crucial, given that the municipality suffers from seven months of accumulated DEF, with rainfall alone not being sufficient to supply more than 66,000 hectares of cultivated land. Irrigation is also crucial between November and February, a period when excess soil water is present. However, scattered and concentrated rainfall can occur, necessitating irrigation water to supply crops.

The challenge for farmers in Pereira Barreto is deciding when and how much to irrigate and which station to use for their area. By defining which station is most appropriate for their crops, they can create agricultural plans on the basis of a monthly water balance. This helps producers determine the water depth and purchase an irrigation system, potentially generating savings when choosing a system. However, they must decide whether to address the greatest need or the greatest deficiency. In the case of Estação Bonança, considering a crop coefficient of 1.0, which represents the average value of an annual crop cycle, the highest evapotranspiration demand occurs in November, at 4.5 mm.day $^{-1}$, but the greatest accumulated water deficiency occurs in August, at 3.33 mm.day $^{-1}$. The same can be observed for Santa Adélia Station, where August presented an ETc of 4.69 mm.day $^{-1}$, which was the month with the largest accumulated deficit. However, September had the highest evapotranspiration demand, with a value of 5.24 mm.day $^{-1}$. At both stations, if producers adopt irrigation systems that meet the depth requirements of the soil water deficit period, prioritizing savings in the acquisition of the systems, they will not be able to supply crops during periods of greatest evapotranspiration.

The sequential water balance showed that in some years, during rainy periods such as February, soil water deficits can occur, and during periods with less rainfall, such as May, soil water excess can occur. Thus, BHseq proved to be more detailed and suitable for use in agricultural planning in the region.

Agrometeorological monitoring in the municipality of Pereira Barreto, SP, with more than one station, has proven to be highly important in providing irrigated agriculture with real conditions for the efficient management of water resources.

6 CONCLUSION

The months of August to October and July to September proved to be more critical for irrigated agriculture in relation to soil water storage in the areas of the Bonança and Santa Adélia Stations, respectively, with cultivation not being recommended without the presence of irrigation systems, and the northwest part of the municipality of Pereira Barreto requires more robust irrigation systems owing to the greater evapotranspirometric demand.

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