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Agrometeorological water balance in the west of São Paulo State

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Abstract

The agriculture economic viability is a result of a correct planning and knowledge of the crop production environment. The level of meteorological information in the region can be improved through the water balance, making the agricultural planning more accurate. The objective of this study was to characterize the West of the São Paulo State through the agrometeorological water balance. Historical daily data from 1992 to 2021, from the meteorological station of the University of West Paulista in Presidente Prudente, São Paulo, were used in the study. The sequential water balance (deficit and excess of water in the soil) was evaluated during the agricultural season (from October to March) and off-season (from April to September). The annual water deficit was -303.2 mm, being -125.2 mm in the agricultural season and -178.0 mm in the off-season. The frequent occurrence of deficit in the region, in the beginning of spring and mainly during the autumn-winter, makes it necessary to adopt special management practices and to use irrigation in order to reach high agricultural productivity in West Paulista.

Keywords: precipitation; available water; water deficit; agricultural season.

Balanço hídrico agrometeorológico do Oeste Paulista

Resumo

A viabilidade econômica da agricultura se dá em função de um correto planejamento e conhecimento do ambiente de produção de cultivo. Através do balanço hídrico é possível aumentar o nível de informações meteorológicas da região, tornando o planejamento agrícola mais preciso. O objetivo deste estudo foi realizar a caracterização do Oeste do Estado de São Paulo através do balanço hídrico agrometeorológico. Utilizou-se no estudo os dados diários históricos de 1992 a 2021 da estação meteorológica da Universidade do Oeste Paulista de Presidente Prudente, São Paulo. Foi avaliado o balanço hídrico sequencial (déficit e excesso de água no solo) nos períodos da safra agrícola (outubro a março) e da entressafra (abril a setembro). O déficit de água anual foi de -303.2 mm, sendo -125.2 mm no período da safra agrícola e -178.0 mm na entressafra. A frequente ocorrência de déficit na região, no início da primavera e principalmente durante o outono-inverno, faz com que seja necessária a adoção de práticas especiais de manejo e a necessidade do uso da irrigação para que se atinjam elevadas produtividades agrícolas no Oeste Paulista.

Palavras-chave: precipitação; água disponível; déficit hídrico; safra.

Introduction

West Paulista is considered one of the poorest regions of the São Paulo State. The region has a predominance of sandy soils and the agricultural activity in the region has gone through several cycles (CORDEIRO *et al*., 2020). Currently, pasture and sugarcane are the most planted crops in the region (IEA, 2021). Grain cultivation in the region is still in the beginning, due to the lack of tradition, as well as unfavorable climate and soil conditions (MORO; BORGUI, 2018).

Cordeiro *et al*. (2020) reported that the occurrence of dry spells longer than 30 days associated with high temperatures in West Paulista is very common, causing loss of crop productivity. In a study performed in the region, Barbosa and Feitosa (2021) observed an average of 5.2 episodes of drought in the period from October to April.

In the 2020/21 season, for example, the region was impacted by low rainfall and drought, where the soil water deficit was -377.6 mm. This deficit caused delays and/or inadequate soil moisture conditions for the sowing of the summer season (from September to November) and the off-season (from March onwards) (BARBOSA; TIRITAN, 2021).

In most climate studies, only monthly precipitation data is used. However, these data may not demonstrate the real situation of the region, hiding, for example, periods of drought, and consequently, water deficit in the soil. The study of the water balance, on the other hand, allows characterizing the mean water availability in the soil. It characterizes the drought periods and their effects on agriculture, indicating times less subject to water restrictions (PASSOS; ZAMBRZYCKI; PEREIRA, 2017; VILLA *et al.*, 2022).

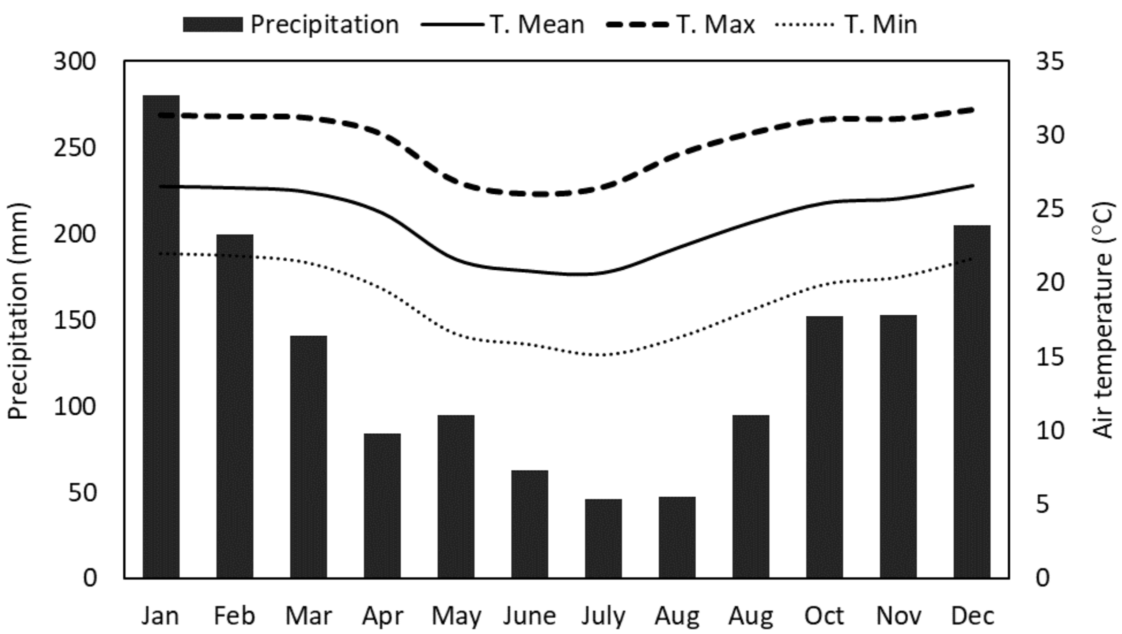
Thus, this study aimed to characterize the agrometeorological water balance (deficit and excess of water in the soil) in the agricultural season and off-season in West Paulista.

Material and Methods

The west region of the São Paulo State mainly comprises the administrative region of Presidente Prudente, which is formed by 53 municipalities, spread over 23,777.10 km^2 (IEA, 2022). The region has a predominance of Argisols, followed by Latosols and a smaller area of Neosols, usually with a medium-sandy texture (OLIVEIRA *et al.*, 1999). The region is classified as having an Aw climate (ROLIM *et al.*, 2007; KÖPPEN; GEIGER, 1928).

The study was performed using the daily database (from 1992 to 2021) of the meteorological station of Unoeste – University of West Paulista, located in Presidente Prudente-SP (22º07'04"S, 51º27'04''W and 413 m altitude). The climatological normals of the period can be observed in Figure 1. The annual precipitation is 1,563.8 mm, with 72.4% (1,132.9 mm) of the observed volume occurring from October to March. The mean, maximum and minimum annual temperature is 24.2; 29.6 and 19.0 °C, respectively.

Figure 1. Climatological norms of Presidente Prudente-SP for the period from 1992 to 2021. Monthly accumulated precipitation (mm) and mean, maximum and minimum monthly air temperature (°C)



In order to associate the study with the growing seasons of the main production systems in the region, two periods were defined: (i) agricultural season period, from October 1st to March 31st of the subsequent season year, in which were characterized the seasons from 1991/92 to 2020/21; (ii) off-season period, from

April 1st to September 30th, in which the years from 1992 to 2021 were included.

The water balance was prepared according to the methodology described by Thornthwaite; Mather (1955). Daily data were organized into ten days, and the Excel™ spreadsheet elaborated by Rolim *et al*. (1998) was used to calculate the sequential water balance. Data from July to March in the agricultural season period (from October to March) and from January to September in the off-season period (from April to September) were used in order to consider the accumulated negative and the water stored in the soil. The available water capacity (AWC) of 70 mm was considered for the calculations.

Results

From October to March - Agricultural Season

In the agricultural season period (from October to March) from 1991/92 to 2020/21, precipitation and accumulated evapotranspiration (ETP) were 1,132.9 and 840.1 mm, respectively. The soil water deficit in the period was -125.2 mm, being more pronounced in the months of October (-28.7 mm) and March (-25.4 mm). The water excess was 413.1 mm in this period (Table 1).

Table 1. Precipitation, evapotranspiration (ETP), deficit and excess (mm) of water in the soil from October to March in the period from 1991/92 to 2020/21 in Presidente Prudente-SP.

Months	Precipitation	ETP	Deficit	Excess
		mm		
October	138.7	127.7	-28.7	35.6
November	166.6	133.7	-24.2	48.7
December	196.0	154.1	-18.7	61.5
January	276.1	153.3	-15.4	130.6
February	217.6	134.1	-12.7	88.3
March	138.0	137.2	-25.4	48.8
From October to March	1.132.9	840.1	-125.2	413.1

The precipitation variation over the seasons can be seen in Figure 2. The accumulated volume in the period ranged from 854.0 mm (1993/94 season) to 1,696.3 mm (2017/18 season). The three seasons with the lowest accumulated precipitation were 1993/94, 2003/04 and 2013/14, respectively. The three seasons with the highest accumulated precipitation were 2017/18, 2015/16 and 2009/10. The evapotranspiration during the evaluated period ranged from 758.4 mm (2010/11) to 895.7 mm (2006/07) and had a mean deviation of 39.1 mm (Figure 3).

Figure 2. Accumulated precipitation (mm) from October to March of agricultural seasons from 1991/92 to 2020/21 in Presidente Prudente-SP. The dotted line represents the mean precipitation for the period and the gray line represents the standard deviation.

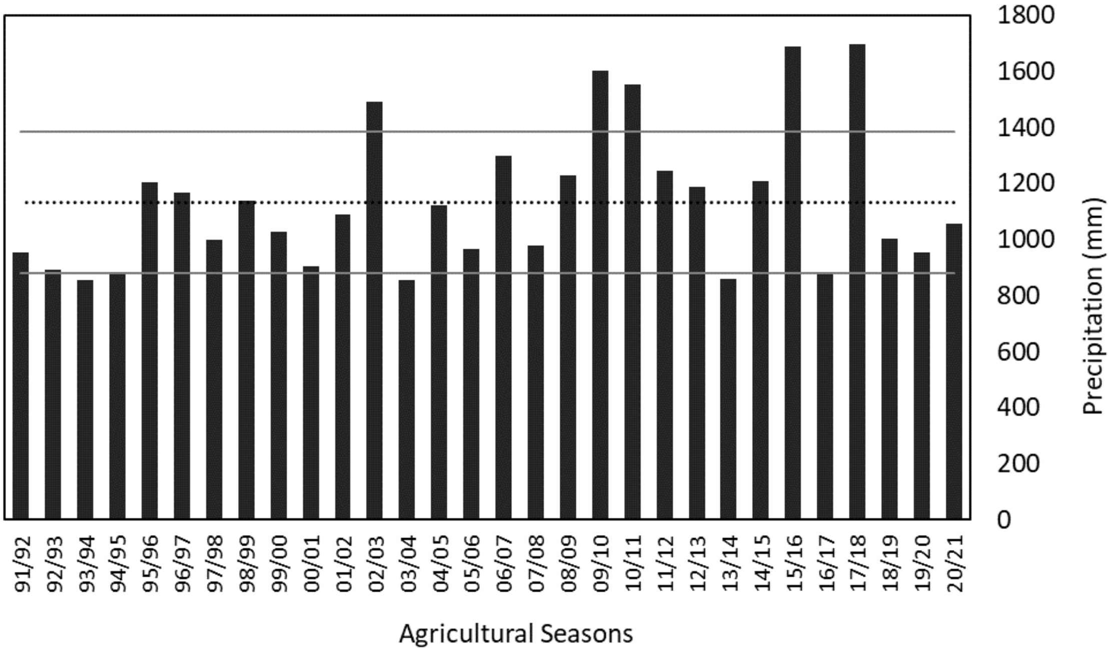
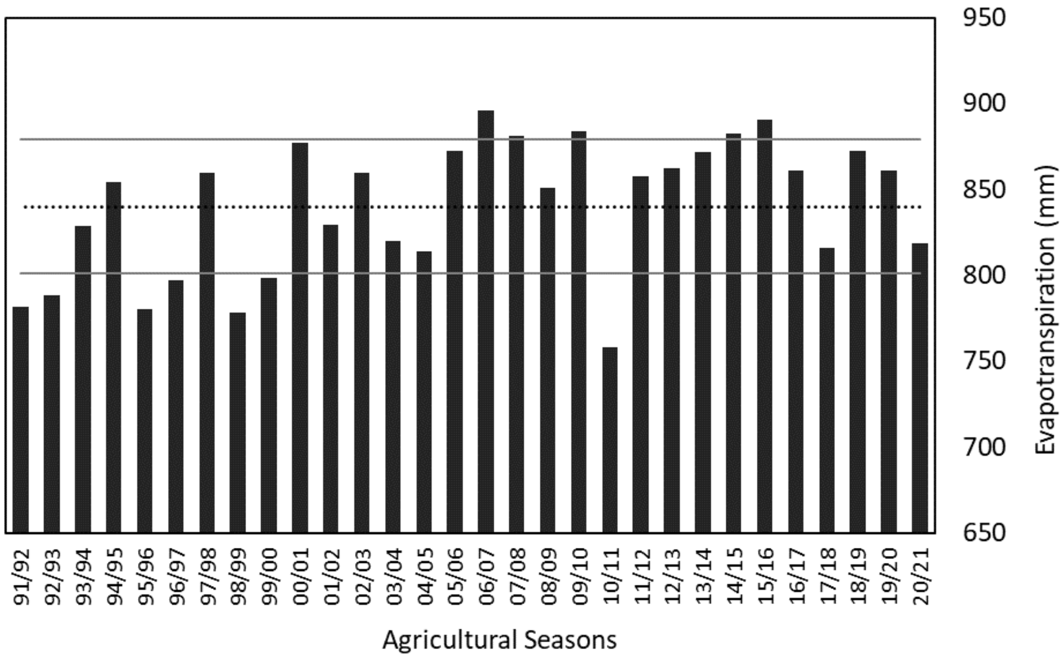


Figure 3. Accumulated evapotranspiration (mm) from October to March of agricultural seasons from 1991/92 to 2020/21 in Presidente Prudente-SP. The dotted line represents the mean evapotranspiration for the period and the gray line represents the standard deviation.



The mean deficit of soil water in the period was -125.2 mm, ranging from -237.6 mm (2019/20) to -21.6 mm (2015/16) with a mean deviation of 56.5 mm (Figure 4). The three largest deficits in the period were -237.6, -227.1 and -191.3 mm in the 2019/20, 2016/17 and 2007/08 seasons, respectively. The three smallest deficits were -21.6 mm (2015/16), -28.9 mm (2010/11) and -46.9 mm (1995/96). The water excess in the soil was 413.1 mm, ranging from 131.0 mm (2013/14) to 932.6 mm (2017/18) with a mean deviation of 219.1 mm (Figure 5).

The smallest deficit of the agricultural seasons occurred from December to February, with a mean deficit of -15.6 mm. In these months there was the greatest water excess in the soil with a mean excess of 93.4 mm, with the highest excess occurring in January (130.6 mm).

Figure 4. Soil water deficit (mm) from October to March in the agricultural seasons from 1991/92 to 2020/21 in Presidente Prudente-SP. The dotted line represents the mean deficit for the period and the gray line represents the standard deviation.

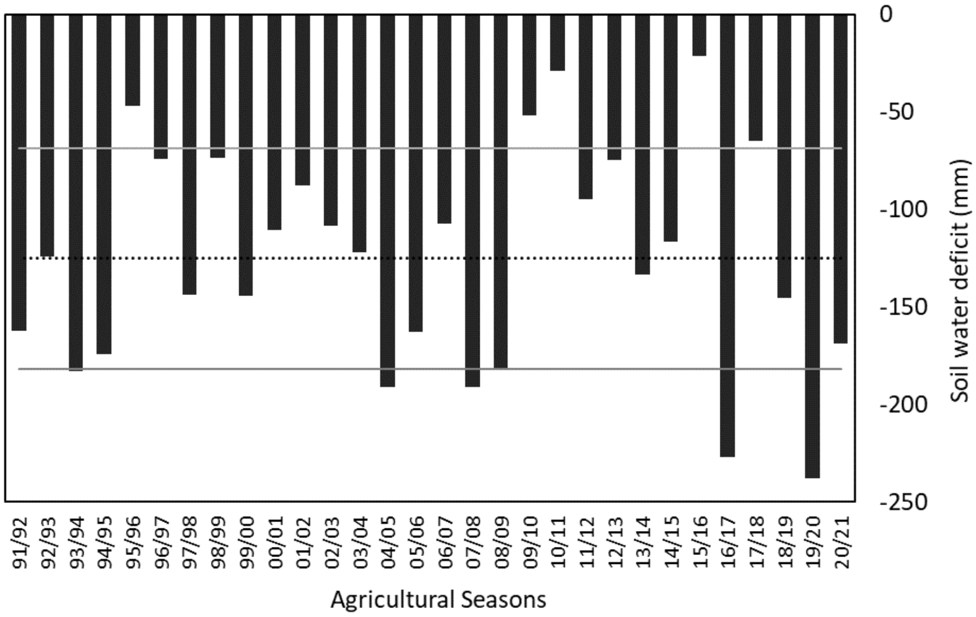
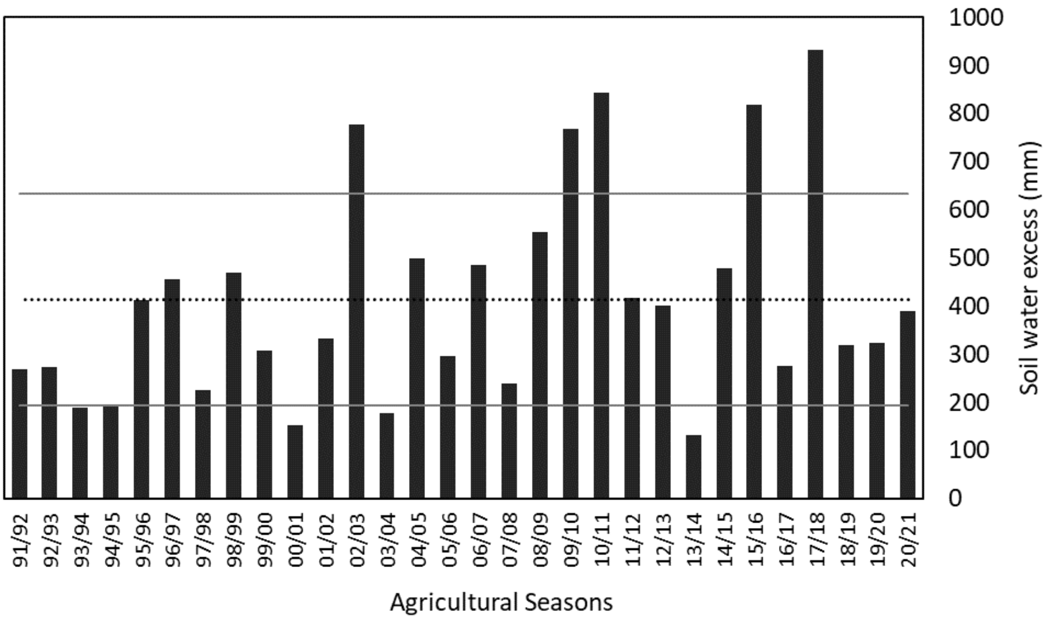


Figure 5. Water excess in the soil (mm) from October to March of the agricultural seasons from 1991/92 to 2020/21 in Presidente Prudente-SP. The dotted line represents the mean excess of the period and the gray line represents the standard deviation.



From April to September – Agricultural off-season

In the agricultural off-season, the accumulated precipitation from April to September from 1992 to 2021 was 430.9 mm, with August being the driest month (46.3 mm) (Table 2). The off-season evapotranspiration was 484.7, being higher in April (107.8 mm). The deficit and excess of water in the soil were -178.0 and 131.1 mm, respectively.

Table 2. Precipitation, evapotranspiration (ETP), deficit and excess (mm) of water in the soil from April to September in the period from 1992 to 2021 in Presidente Prudente-SP.

Months	Precipitation	ETP	Deficit	Excess
		mm		
Apr	83.0	107.8	-38.9	21.8
May	90.3	71.4	-20.6	25.3
June	63.6	58.9	-15.4	27.1
July	46.3	63.5	-24.8	14.1
Aug	52.5	79.5	-35.6	14.8
Sep	95.3	103.6	-42.6	28.0
From Apr to Sep	430.9	484.7	-178.0	131.1

The accumulated precipitation from April to September ranged from 180.5 mm (2006) to 883.4 mm (2012) and had a mean deviation of 178.0 mm (Figure 6). In 50% of the observations, the accumulated precipitation was below normal (430.9 mm).

The highest evapotranspiration occurred in 2007 (575.8 mm) and the lowest occurred in 1992 (388.0 mm). The mean evapotranspiration was 484.6 mm with a deviation of 36.9 mm (Figure 7). In the off-season, the loss of water by evapotranspiration was 53.8 mm higher than the input of water via precipitation.

Figure 6. Accumulated precipitation (mm) from April to September, from 1992 to 2021 in Presidente Prudente-SP. The dotted line represents the mean precipitation for the period and the gray line represents the standard deviation.

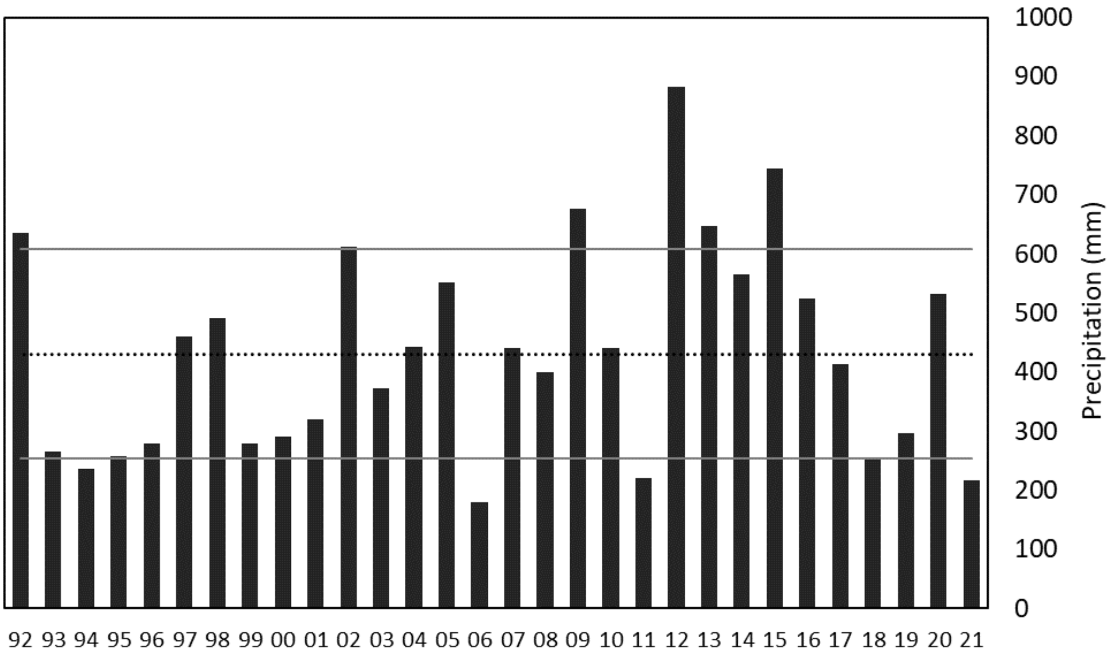
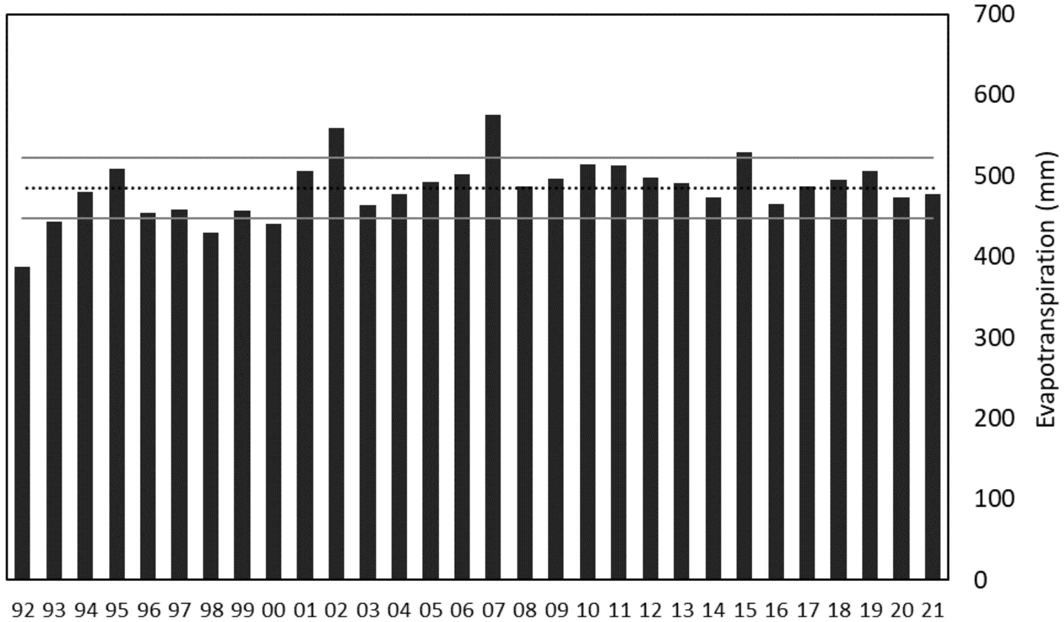


Figure 7. Evapotranspiration (mm) from April to September, from 1992 to 2021, in Presidente Prudente-SP. The dotted line represents the mean evapotranspiration for the period and the gray line represents the standard deviation.



The soil water deficit in the off-season ranged from -55.2 mm (1992) to -311.0 mm (2007) with a mean in the period of -177.9 mm and mean deviation of 68.7 mm (Figure 8). The deficit was higher in the months of September (-42.6 mm) and April (-38.9 mm) due to higher ETP, which in turn was higher as a function of temperature. Therefore, these were the hottest months of the off-season. In 30% of the years observed, the deficit in the off-season was greater than 200 mm. Regarding the water excess in the soil, in 40.0% of the years evaluated, the excess was below 50.0 mm (Figure 9).

Figure 8. Soil water deficit (mm) from April to September, from 1992 to 2021, in Presidente Prudente-SP. The dotted line represents the mean deficit for the period and the gray line represents the standard deviation.

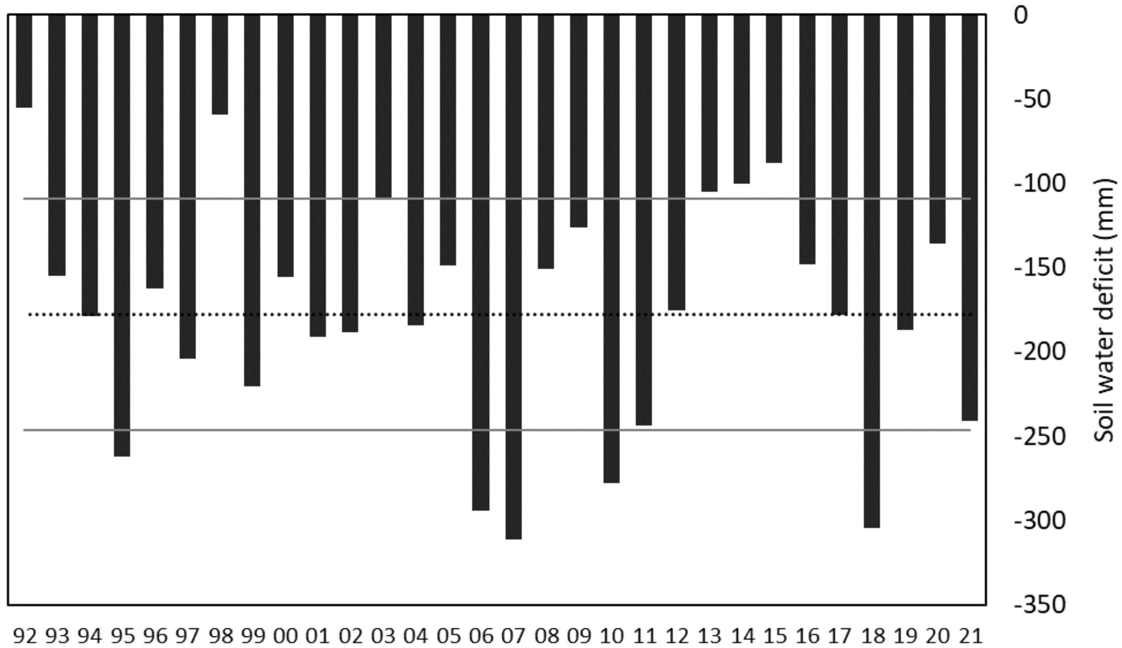
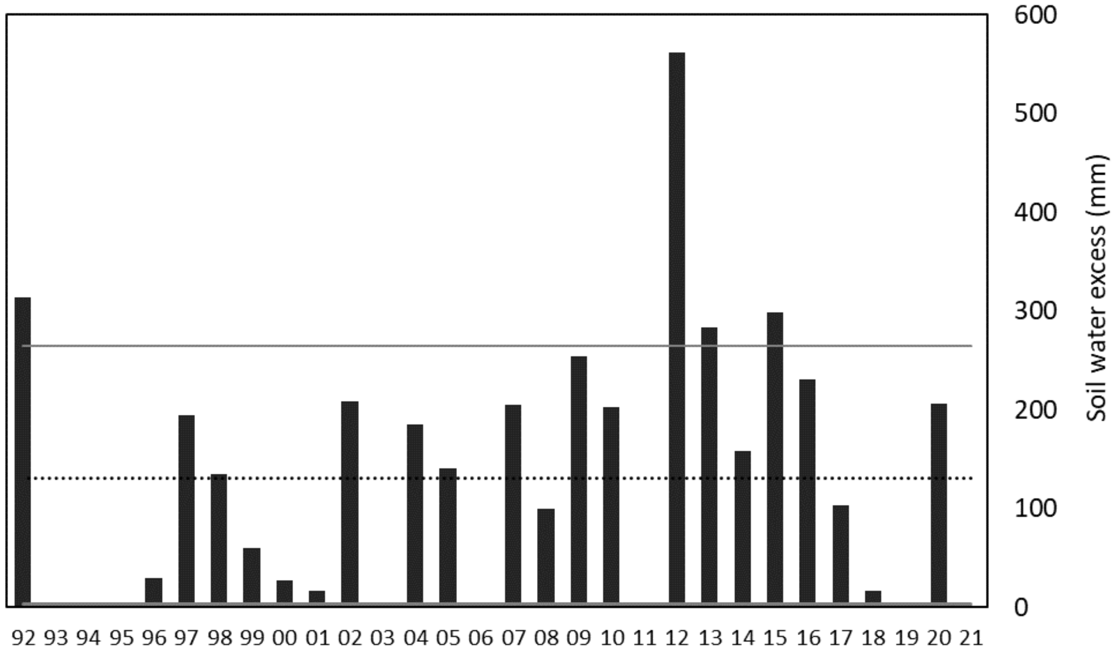


Figure 9. Water excess in the soil (mm) from April to September, from 1992 to 2021, in Presidente Prudente-SP. The dotted line represents the mean soil water excess of the period and the gray line represents the standard deviation.



Discussion

The annual total precipitation of Presidente Prudente-SP is similar to that of the Southeast region of Brazil, as observed by Reboita *et al*. (2010). Considering the annual total, 72.4% occurs between October and March. This high seasonal precipitation variability, characterized by a rainy period in summer and a drier period in winter, is one of the characteristics of the South American monsoon system (GRIMM *et al*., 2005; VERA *et al*., 2006). The highest evapotranspiration in the agricultural season period is in accordance with the climatological norms of the region and occurs due to the higher air temperature and higher solar radiation of the period (INMET, 2009; BARBOSA, 2020).

The annual precipitation (1,560.7 mm) meets the demand of several agricultural crops. However, due to the irregular distribution of precipitation and the occurrence of dry periods, it is common the occurrence of high values of water deficit in the soil in the West Paulista. During the agricultural season, the occurrence of dry spells, even for short periods, promotes the deficit due to the high values of evapotranspiration. In the off-season, the water deficit is characteristic of the region and the loss of water by evapotranspiration exceeds the water input via precipitation.

Thus, the cultivation performed in the rainfed system without the adoption of conservationist practices presents itself as a high risk activity, mainly due to the high variability of rainfall throughout the seasons and off-seasons. The total annual deficit in the region is -303.2 mm, a situation that demonstrates the necessity of irrigation and its viability.

The high values of deficit and excess of water occur mainly due to the sandy texture of the soils in the region. Sandy soils have a predominance of macropores, with excessive drainage, resulting in low water storage capacity. Therefore, these soils are characterized as water fragile (ALBUQUERQUE *et al*., 2015).

Regarding the period from October to March, the water deficit observed demonstrates the frequent occurrence of drought in the region, since in the accumulated period, the input of water into the system via precipitation is greater than the output via evapotranspiration. The deficit observed is due to the frequent occurrence of dry spells in the region associated with high air temperatures, as reported by Moro; Borgui (2018). This observation corroborates with the results obtained by Barbosa and Feitosa (2021), who reported a mean occurrence of 5.2 drought episodes longer than 10 days in Presidente Prudente-SP from October to April.

The agricultural season period is characterized by the cultivation of annual crops of high economic interest, such as soybean, corn, cotton and peanuts. The time when the water deficit occurs (beginning, middle or end of season) can have different effects on the development and management of crops.

In relation to the beginning of the season, from October to November, it was observed that, there was a monthly water deficit below -40.0 mm in 25% of the evaluated months. The low availability of water in the soil at the beginning of the season causes a reduction in the initial development of the plants, a delay in sowing and in some cases, the need for reseeding, also causing delay in the installation of subsequent crops. The water deficit that occurs between December and February coincides with the reproductive phase of crops (grain filling), which ends up compromising the size and weight of grains and, consequently, productivity (CORDEIRO *et al*., 2020).

In the off-season, crop management takes place in a more unfavorable climatic condition, with the occurrence of long periods of drought. This condition can have contributed for the high values of deficit or absence of water excess in the soil observed in some years (Figure 9). Therefore, the risk of growing two crops in sequence (season and off-season) in non-irrigated systems in the region is high, since the delay in sowing the crop of the agricultural season already compromises the development of the off-season crop, due to the installation of the crop outside the recommended period.

The adoption of conservationist and sustainable soil practices must be adopted in the region in order to minimize the effects of water deficit on crops. Nóia Junior and Sentelhas (2019) reported the importance of the sowing season in the soybean-corn system. Therefore, delayed sowing of soybeans provides unfavorable weather conditions for corn development, which results in loss of corn productivity.

The process of soil fertility correction in depth also minimizes the effects of water deficit since it promotes the increase of the root system of plants (CORDEIRO *et al*., 2020), Silva *et al*. (2020) recommended the use of no-tillage system and crop rotation in a study performed in Presidente Prudente-SP, since these managements attenuate the effects of water deficit. Cordeiro *et al*. (2021) reported that the implantation of cover crops in the planting system increases crop productivity in sandy soils due to greater biological activity in the soil.

Thus, in a scenario of climate changes and occurrence of extreme meteorological events (BREUER; FRAISSE, 2020), the elaboration of the regionalized water balance allows a better characterization and increase of climate information. These data can collaborate with the planning of the production and management systems that will be recommended for a certain region according to its edaphoclimatic characteristics.

Conclusions

The annual precipitation (1,560.7 mm) meets the demand of several agricultural crops. However, due to the irregular distribution and the occurrence of periods of drought, it is common the occurrence of high values of water deficit in the soil in West Paulista. The annual water deficit was -303.2 mm, being -125.2 mm in the agricultural season and -178.0 mm in the off-season.

The frequent occurrence of deficit in the region, in the beginning of spring and mainly during the autumn-winter, makes it necessary to adopt special management practices and to use irrigation in order to reach high agricultural productivity in West Paulista.

In a scenario of climate change, monitoring and characterizing future seasons is of great importance, in order to identify changes in the regional climate pattern and in the intensity of annual variations.

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