The spatiality of the soybean crop water deficit in Jales and Andradina microregions, state of São Paulo

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Abstract

Knowledge about soil water availability for future planning is the basis for carrying out its rational use. This work aimed to study the spatiality of water precipitation, crop evapotranspiration, and the need for water supplementation in soybean cultivation in the microregions of Jales-SP and Andradina-SP for the summer harvest. The water balance was determined by the Thorthwaite and Mather (1955) method, with data made available by the Agrometeorological Stations Network operated by the Hydraulics and Irrigation area of UNESP Ilha Solteira. We considered an available water capacity (AWC) of 40 mm. The study took place from the simulation of the water condition of a soybean crop sown on November 4, 2020. In the water deficit condition, the actual evapotranspiration (ETa) was considered null at a 20 % deficit, and the other values followed the same mathematical proportion. The mean rainfall of the period, crop evapotranspiration, and water deficit of each weather station were interpolated through ordinary circular kriging in ArcGIS 10.7 software. The water deficit in the soybean crop in the northwest region of São Paulo is related to the poor distribution of precipitation during the cycle and the significant recurrence of Indian summers all through the area. For the producers' safety, investment in irrigation systems anticipating this poor distribution is justified. The water deficit in the region is variable. In years with good rainfall distribution, it can reach zero values, and in years with poor distribution, it can reach values greater than 180 mm.

Keywords: Water Balance. Irrigation. Kriging. Northwest of the state of São Paulo.

Introduction

Soybean (*Glycine max* L.) is the main crop of Brazilian agribusiness, with a cultivated area of approximately 35.8 million hectares producing 115 million tons per harvest. In the state of São Paulo, grain production reaches 10 million tons (CONAB, 2020).

Water availability is the main challenging factor for soybean yield. However, most soybean crops in the world are carried out under the rainfed system. Due to the expansion of the Brazilian agricultural frontier in recent years, oilseeds are already being cultivated in regions with rainfall limitations through water supplementation carried out via irrigation system (MONTOYA; PINTOS; OTERO, 2017).

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All water that is infiltrated by vegetated soil is subjected to evapotranspiration, which is the sum of the water lost by evaporation and plant transpiration. Water loss to the atmosphere by transpiration seems to be an inevitable consequence of photosynthesis in the terrestrial environment. Carbon gas (CO_2) absorption is coupled to water loss via a common diffusion route: as CO_2 diffuses into the leaves, water vapor diffuses outward (TAIZ *et al.*, 2017).

Accurate crop evapotranspiration (ETc) estimates, which quantify the total water used by a crop, are necessary to optimize irrigation scheduling for vegetable crops and minimize water degradation (VENTURA *et al.*, 2000). Deficient or excessive irrigation can undermine production and interfere negatively with the use of the agricultural technique of supplying water to crops when it is unable to extract the resource of actual available water from the soil (ADR) (SANTOS, HERNANDEZ; ROSSETTI, 2010; CARVALHO *et al.*, 2015).

Reference evapotranspiration (ETo) is known as the rate at which water would be removed from the soil surface and a specific, well-nourished, healthy, and moist plant (JENSEN; BURMAN; ALLEN, 1990). The ETo concept was developed to study the evaporative power of the atmosphere regardless of culture and management. Penman-Monteith FAO is the most accepted and recommended model in the literature (ALLEN *et al.*, 1998; BARROS *et al.*, 2009).

From ETo it is possible to calculate crops water demand by multiplying their values by the cultivation coefficient (Kc) of the crop in question. Kc is the ratio between the potential crop evapotranspiration and the reference evapotranspiration (ETc/ETo) and varies according to the plants' climatic and physiological conditions, thus, varying in time and space (ALLEN; PEREIRA, 2009).

Northwest São Paulo is the region with the highest reference evapotranspiration in the state of São Paulo. The rainfall season there is between November and March, with a water deficit during the remaining seven months (HERNANDEZ *et al.*, 2003; SANTOS, HERNANDEZ; ROSSETTI, 2010). According to Avilez *et al.* (2018), the irregular sequential distribution of rainfall - due to the Indian summers - has been one of the limiting factors to the more significant development and stabilization of the agricultural production in the region.

With the advancement of information technology and the advent of geotechnologies, the more global, regional, and local meteorological information there is, the higher the possibility of agricultural planning success. Geotechnologies made it possible to associate any kind of information, but especially agrometeorological information, with geographic space through satellite images and aerial photographs, the Global Positioning System (GPS) and Geographic Information Systems (GIS) (VOLPATO; ALVES; VIEIRA, 2008).

In this sense, this study aimed to perform the spatiality of precipitation, crop evapotranspiration, and the need for water supplementation in soybean cultivation in the microregions of Jales-SP and Andradina-SP for the summer harvest.

Materials and methods

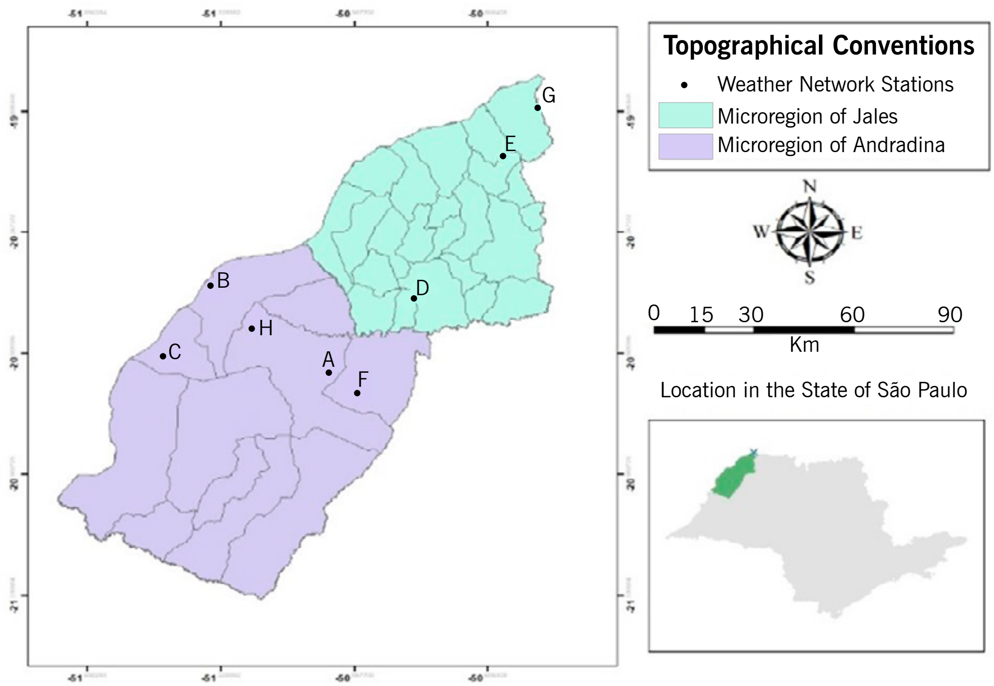
To obtain information about precipitation, water demand, and need for supplementary irrigation for the crops, we used data from eight climatological stations belonging to the Agrometeorological Network of Northwest São Paulo monitored by the Hydraulics and Irrigation area of the São Paulo State University "Júlio de Mesquita Filho" (UNESP) Ilha Solteira Campus. We selected the stations based on the availability of daily climate data and their spatial distribution, and adopted historical series with daily data, with a base period ranging from 2012 to 2019. Table 1 presents the stations used and Figure 1 shows their spatial distribution.

Table 1 – Agrometeorological Network of Northwest São Paulo monitored by the Hydraulics and Irrigation area of UNESP Ilha Solteira Campus. Ilha Solteira, 2019.

Stations	Municipality	Latitude°	Longitude°	Altitude (m)
A. Bonança	Pereira Barreto	-20.6731	-51.0339	357
B. Ilha Solteira	Ilha Solteira	-20.4234	-51.3536	337
C. Itapura	Itapura	-20.6411	-51.4750	335
D. Marinópolis	Marinópolis	-20.4465	-50.8073	370
E. Paranapuã	Paranapuã	-20.0246	-50.5659	436
F. Santa Adélia Pioneiros	Sud Mennucci	-20.7283	-50.9597	350
G. Populina	Populina	-19.8796	-50.4704	394
H. Santa Adélia	Pereira Barreto	-20.5283	-51.2494	426

Source: UNESP (2019).

Figure 1 – Spatial distribution of meteorological stations of Agrometeorological Network of Northwest São Paulo monitored by the Hydraulics and Irrigation area of UNESP Ilha Solteira Campus - Andradina-SP and Jales-SP microregions. Ilha Solteira, 2019.



Source: Elaborated by the authors (2020).

The climate of the region used in the study was classified as Aw type, according to Köppen, with an annual average temperature of 24.5 ºC, average annual precipitation of 1,232 mm, and average relative humidity of 64.8 % (HERNANDEZ *et al.*, 1995).

The study started with the simulation of the hydric condition of a soybean crop sown on November 4, 2020, at the coordinates highlighted in Table 1. The choice of planting date took into account the historical average precipitation, since the soil during the previous months presents a higher water deficit making it impossible to establish the crop in dryland. The cultivar used was AS 3610, which has a cycle of 121 days in the region, according to the manufacturer Agroeste® (2017).

ETo was obtained using the Penman-Monteith equation (Eq. 1) parameterized by FAO (ALLEN *et al.*, 1998), whose input data came from the weather stations described above.

$$ETo = \frac{0,408\Delta(Rn - G) + y\frac{900}{T+273}U_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0,34U_2\right)} \qquad (1)$$

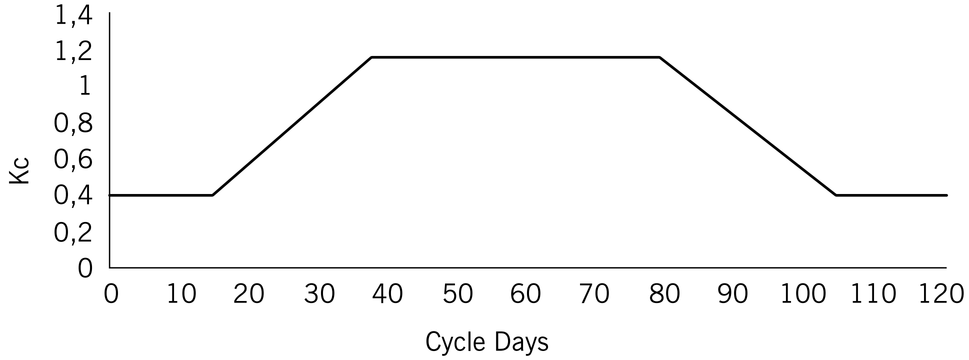
In which:
ETo - Reference evapotranspiration (mm day^{-1});
Rn - Net radiation on the crop surface (MJ m^{-2} day^{-1});
G - Soil heat flux (MJ m-^{2} day^{-1});
T - Average air temperature at 2 m height (°C);
U_2 - Wind speed at 2 m height (m s^{-1});
e_s - Saturation vapor pressure (kPa);
e_a - Actual vapor pressure (kPa);
e_s - e_a - Vapor pressure deficit (kPa);
Δ - Pending vapor pressure curve (kPa °C^{-1});
γ - Psychrometric constant (kPa °C^{-1}).

The daily water balance was performed according to a methodology adapted from Thorthwaite and Mather (1955) considering the total crop cycle, available water capacity (AWC) of 40 mm (1.0 mm cm^{-1} and 0.4 m of effective depth of the root system) - predominant in Argisols in the region, the historical average rain for each day and crop evapotranspiration (ETc) estimated by the product between ETo and Kc, according to Eq 2. The crop coefficients (Kc) of soybean used in the calculation of crop evapotranspiration (ETc) were those indicated by FAO Bulletin 56 for the tropics (FIGURE 2) (ALLEN *et al.*, 1998).

$$ETc = ETo * Kc \qquad (2)$$

In which:
ETc = Crop evapotranspiration;
ETo = Reference evapotranspiration;
Kc = Culture coefficient.

Figure 2 – Crop coefficient (Kc) indicated for the calculation of evapotranspiration of soybean crop in the tropics.



Source: Adapted from Allen *et al.* (1998).

In the AWC, we also considered a 20 % increment coefficient resulting from gravitational water that can be infiltrated and suffer evapotranspiration when precipitation was higher than the soil retention capacity. The actual available water (AAW) adopted was the interval between the field capacity and 50 % of the AWC, i.e. 20 mm.

The actual evapotranspiration (ETa) was considered null at a 20 % water deficit, and when the deficit was less than 20 %, the ETa was calculated through mathematical proportionality. The need for water supplementation was determined as the difference between the actual total evapotranspiration of the potential crop evapotranspiration (Eq. 3).

$$DEF = ETC - ETR \tag{3}$$

In which:
DEF = Water Deficit;
ETc = Crop evapotranspiration;
ETa = Actual crop evapotranspiration.

The mean precipitation rate, crop evapotranspiration, and need for water supplementation of the period obtained through the daily water balance of each weather station were interpolated through ordinary circular kriging in ArcGIS 10.7 software (ESRI, 2019).

Results and discussion

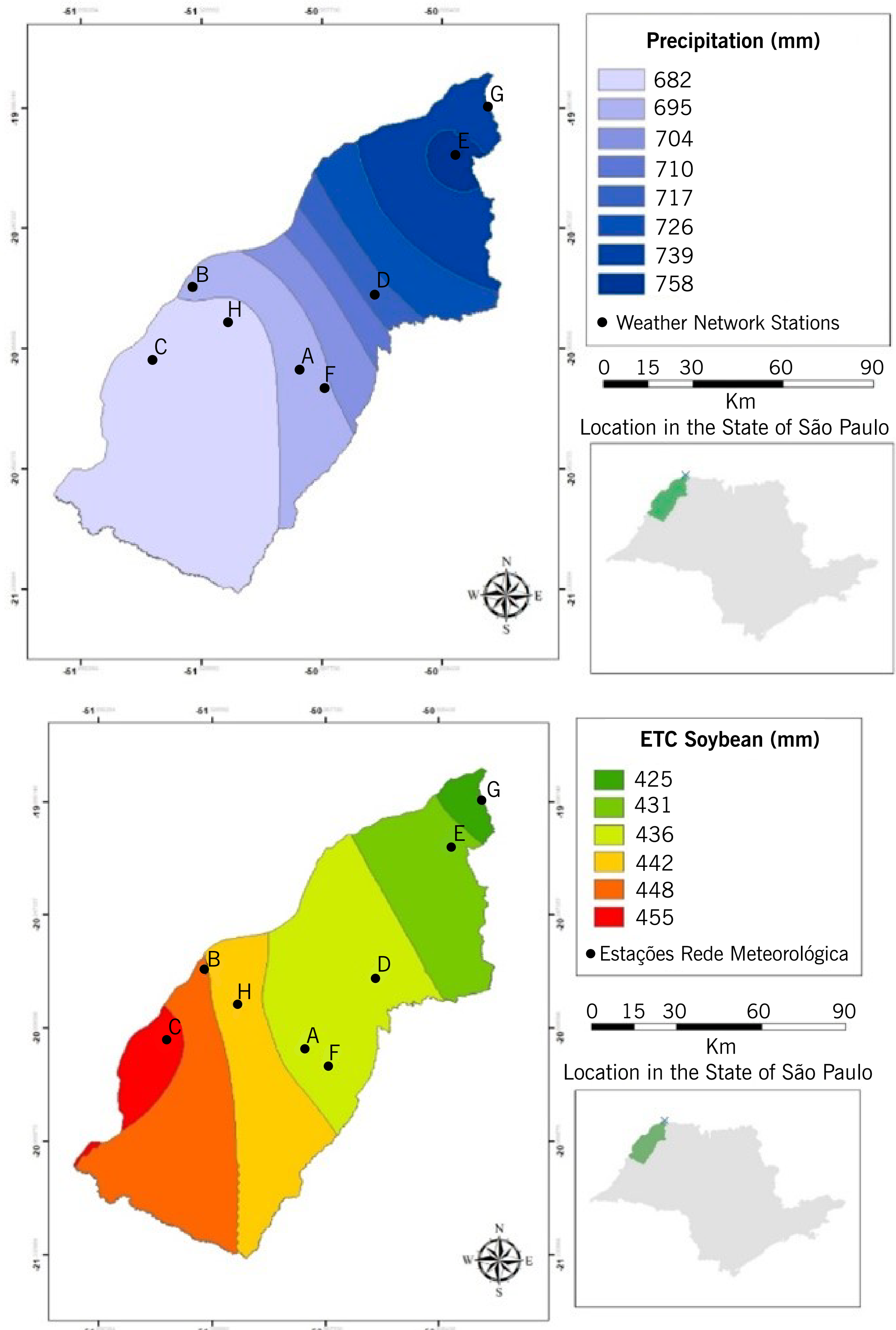
Figure 3 shows the interpolation of average rainfall and crop evapotranspiration throughout the soybean cycle according to all weather stations with average data (2012-2019).

The difference between the rainfall rate of the portion with the highest range and the lowest range of rainfall rate was 76.2 mm. The region comprised of Populina-SP and Paranapuã-SP stations, north of the Jales-SP microregion, presented the highest averages. In contrast, the Itapura-SP region, located in the central portion of the Andradina-SP microregion, presented the lowest averages. A similar result was obtained by Silva *et al.* (2012), who evaluated the precipitation during 2011 in the northwest of São Paulo and found the highest averages in Populina-SP and Paranapuã-SP regions, and the lowest averages in Pereira Barreto-SP and Itapura-SP regions.

The difference between the rainfall rate of the portion with the highest range and the lowest range of rainfall rate was 29.3 mm. The region with the highest crop evapotranspiration comprised the Itapura-SP region. The region with the lowest value was to the north, in the Jales-SP microregion, close to the municipality of Populina-SP. Similar results were found by Americo *et al.* (2014), who evaluated the mean Eto of the microregions during 2012 and 2013, finding the highest values in Itapura-SP and the lowest in the Populina-SP region.

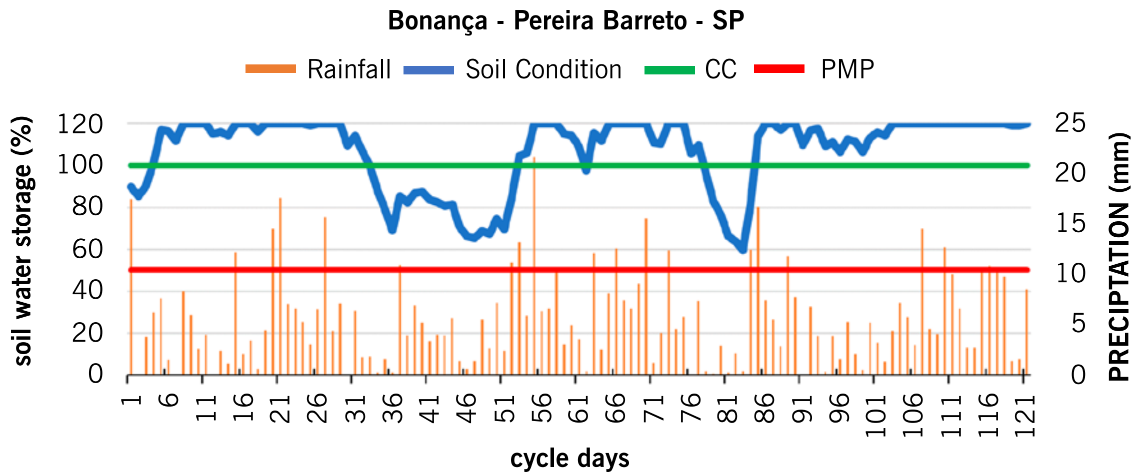
The precipitation all through the region analyzed was higher than the demand for evapotranspiration. In this case, we could routinely infer that there is no water deficit. However, although the total amount of water is higher than the demand, precipitation may not occur at the appropriate time when the crop needs it. As we carry out the daily water balance, we can observe that deficits occur even when precipitation exceeds crop evapotranspiration. Figure 4 shows the prediction of water stored in the soil during soybean cultivation obtained through water balance.

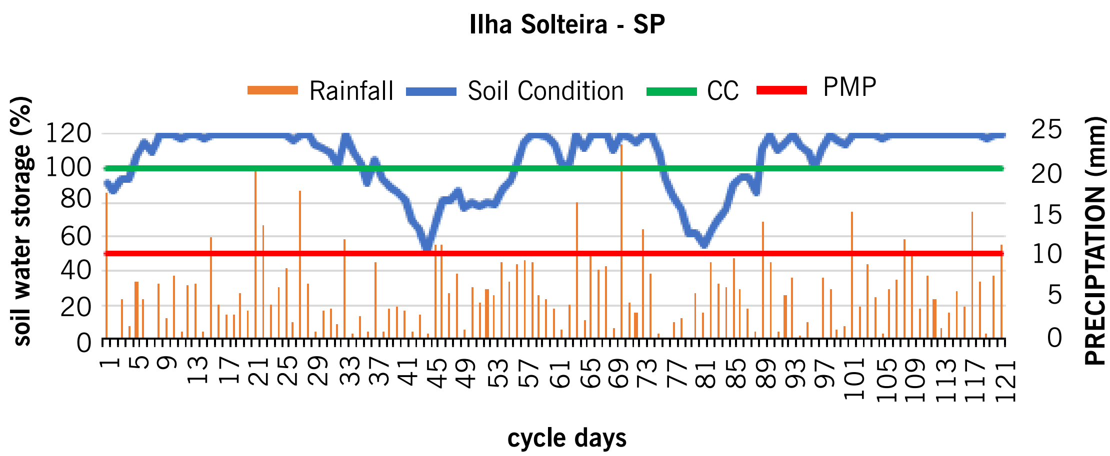
Figure 3 – Precipitation and crop evapotranspiration during soybean cultivation (04-11 to 03-03) for Jales-SP and Andradina-SP microregions (2012-2019).

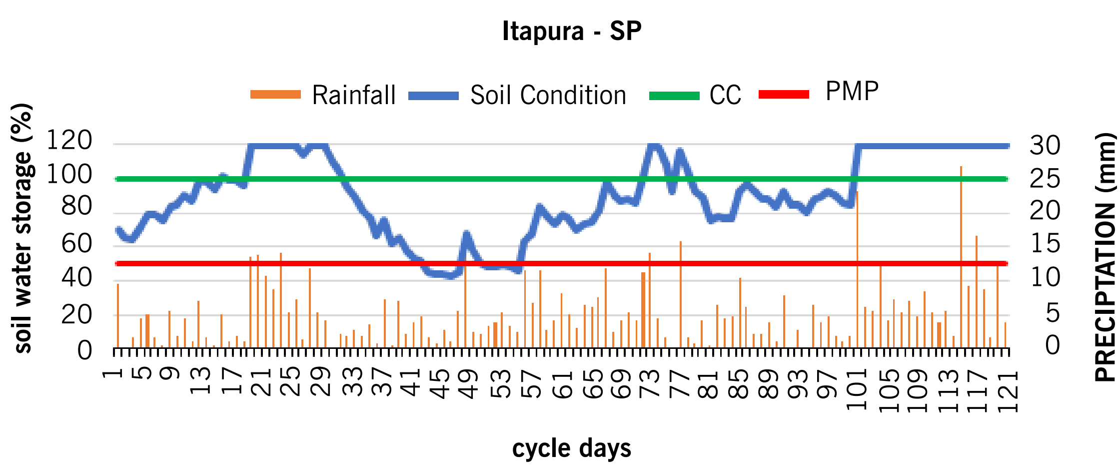


Source: Elaborated by the authors (2020).

Figure 4 – Daily water balance (2012-2019) during soybean cultivation according to meteorological stations of Agrometeorological Network of Northwest São Paulo.







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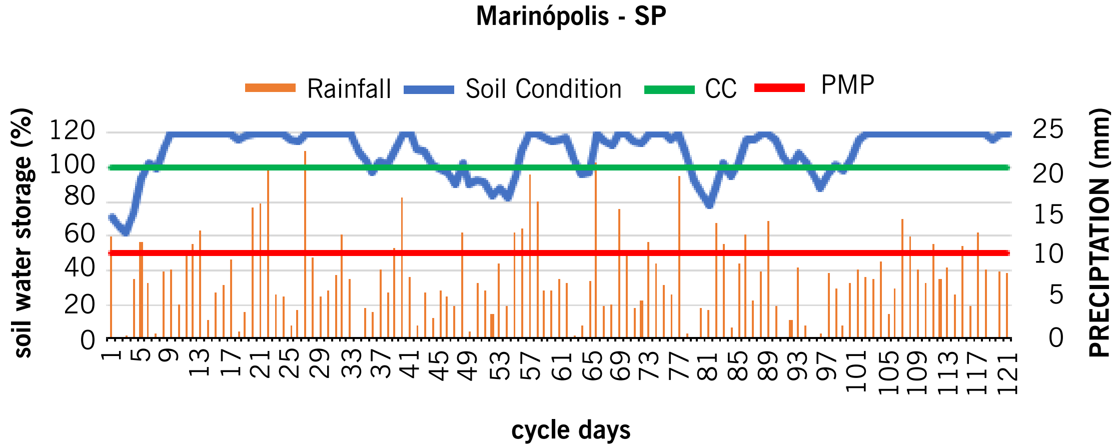

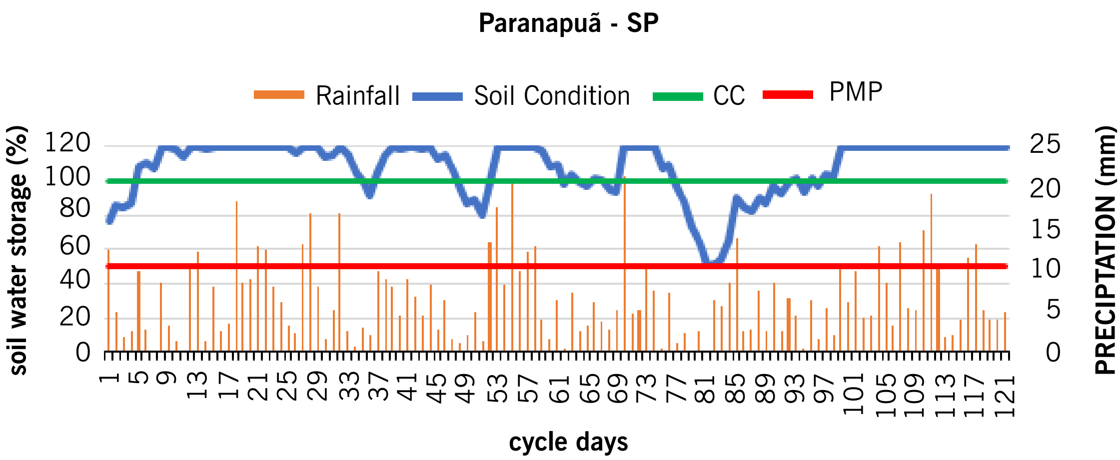

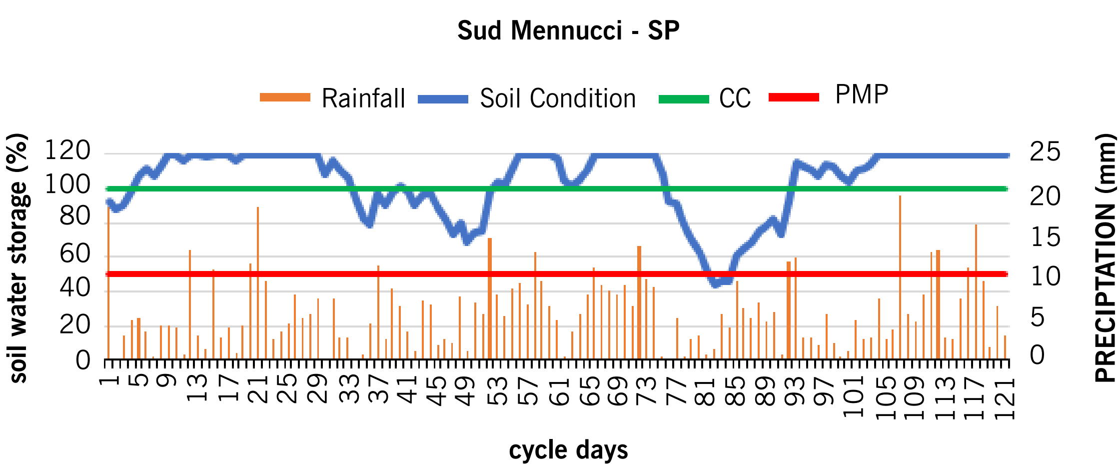

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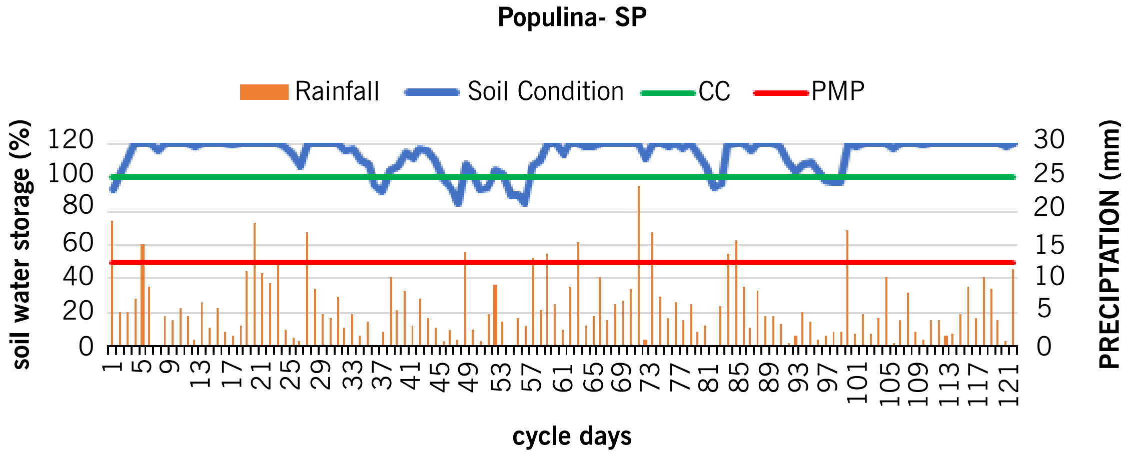
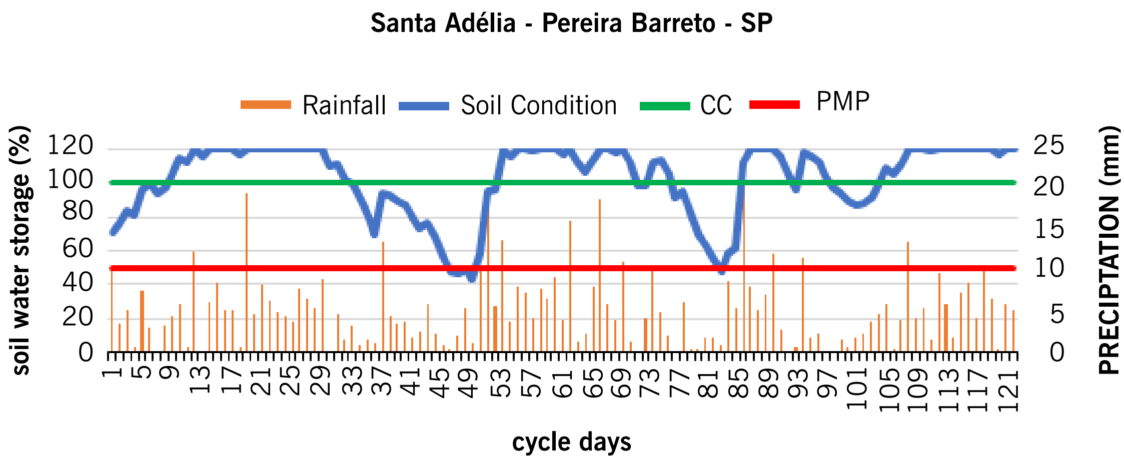




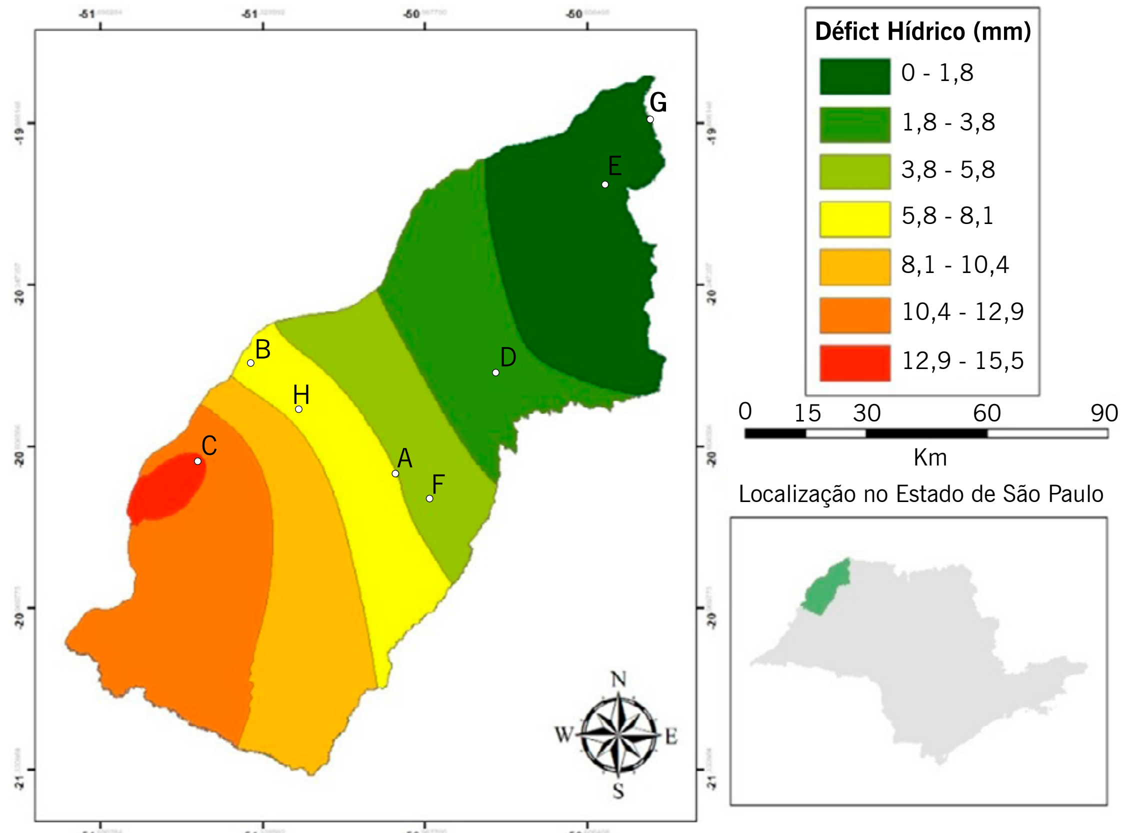
Source: Elaborated by the authors (2020).

In Ilha Solteira-SP and Marinópolis-SP, there is not even a day of water deficit for the soybean crop. This result agrees with Damião *et al.*'s (2010) findings. Performing the water balance between 2000-2010 for Ilha Solteira-SP with AWC of 40 mm, they did not find a water deficit in the region between November and March. However, we noticed that the large decrease in actual available water during the month of January for these municipalities might be due to frequent Indian summers in the region. According to Silva *et al.* (2012), the irregular precipitation sequential distribution - due to the Indian summers - has been a challenging factor for more significant development and stabilization of the agricultural production in the region.

In Paranapuã-SP and Populina-SP, the weather stations, the crop did not suffer any water stress, and the actual available water was close to the field capacity. Considering that the region had the highest rainfall index and the lowest evapotranspiration index, we believe it may not suffer water stress during the summer harvest.

For Itapura-SP, there was a water deficit in two periods. In Santa Adélia-SP (H) and Pereira Barreto-SP and Sud Mennucci, the deficit was isolated in a period ranging from December to January. According to Pereira (2017), water is the most challenging climate element for soybean cultivation today. Variability in water availability during the crop development period is the primary constraint to the expression of soybean yield potential, regardless of the crop cycle, sowing season, and location. The water deficit during the end of December and the beginning of January can generate large losses in soybean productivity because it is usually then that the most critical phenological stages of summer crops occur, technically justifying irrigation in the region in a complementary manner. Figure 5 shows the spatialization of the water deficit.

Figure 5 – Need for water supplementation (2012-2019) during soybean cultivation for Jales-SP and Andradina-SP microregions.

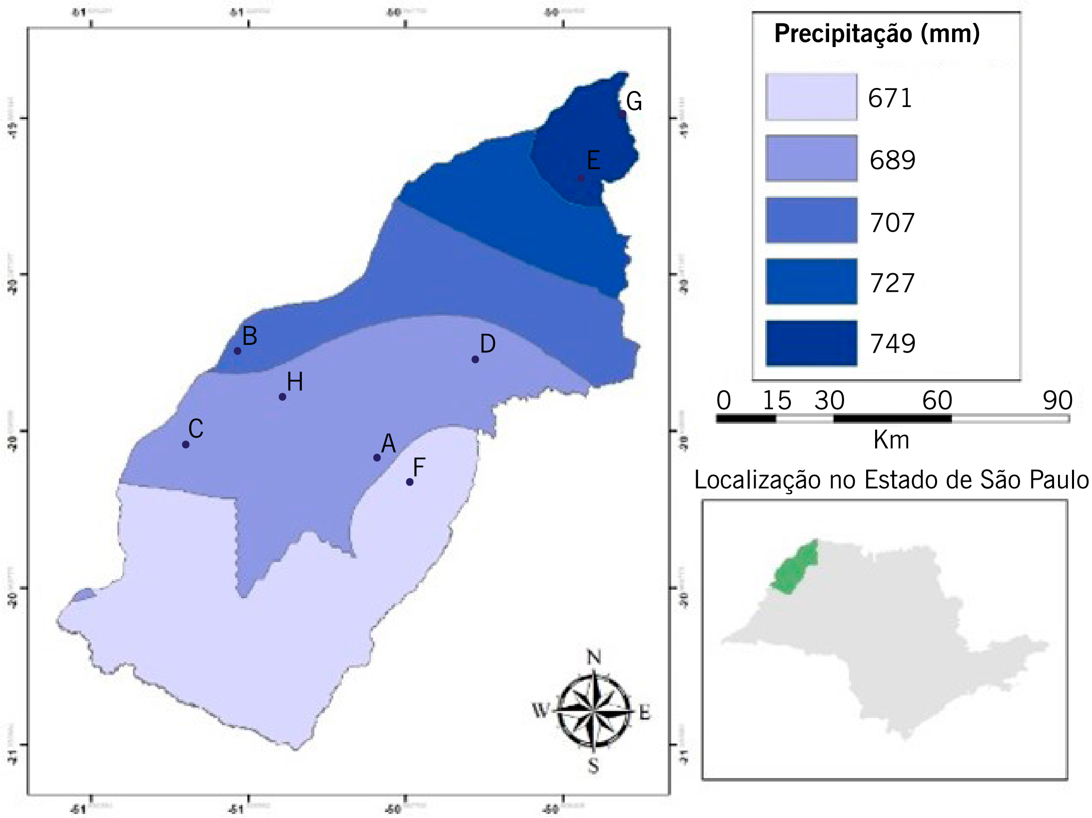


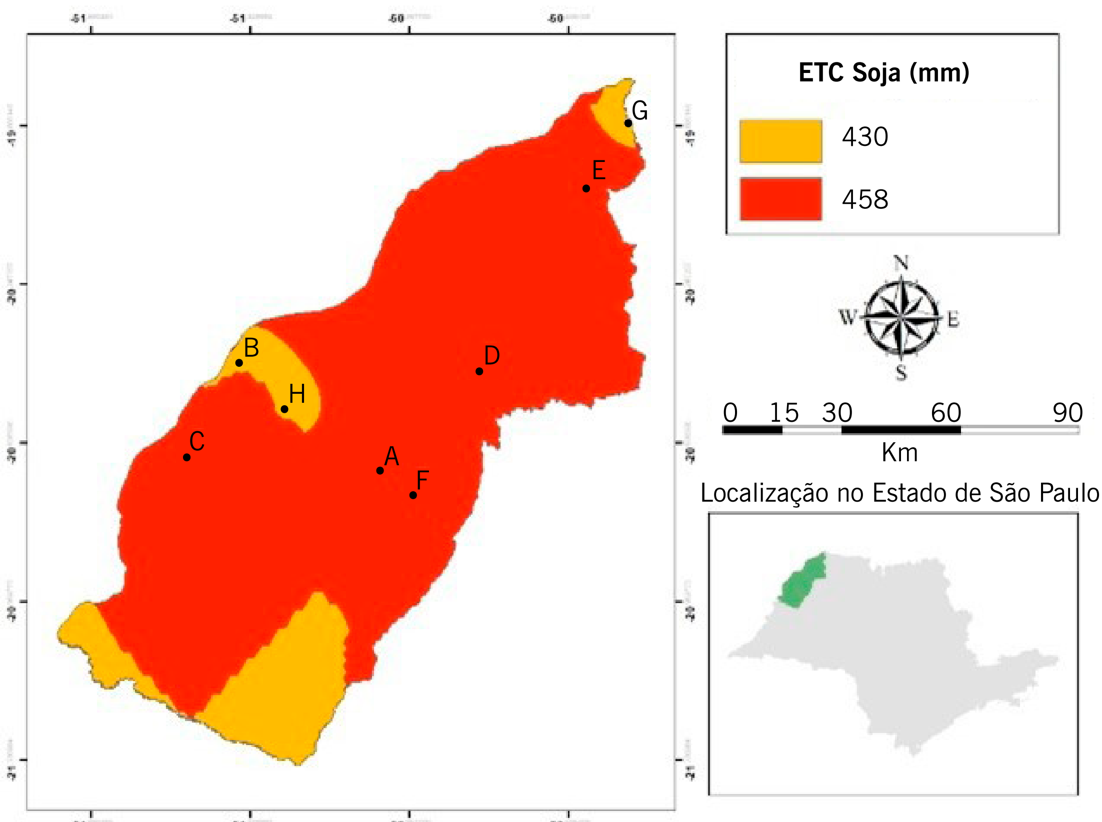
Source: Elaborated by the authors (2020).

Itapura-SP region has the highest water deficit. Jales-SP microregion presented the smallest. This deficit is mainly associated with short Indian summers during summer that can limit the productivity of many rainfed farmers. As we go southeast, there is a significant increase in the water deficit. This water deficit found by the average of the last seven years is insufficient to justify investment in an irrigation system.

However, when we evaluated the agricultural year alone (2018-2019) (FIGURE 6), we found a much more critical condition than that evidenced with the series (2012-2019).

Figure 6 – Rainfall, crop evapotranspiration, and water deficit during soybean cultivation for Jales-SP and Andradina-SP (2018-2019) microregions.





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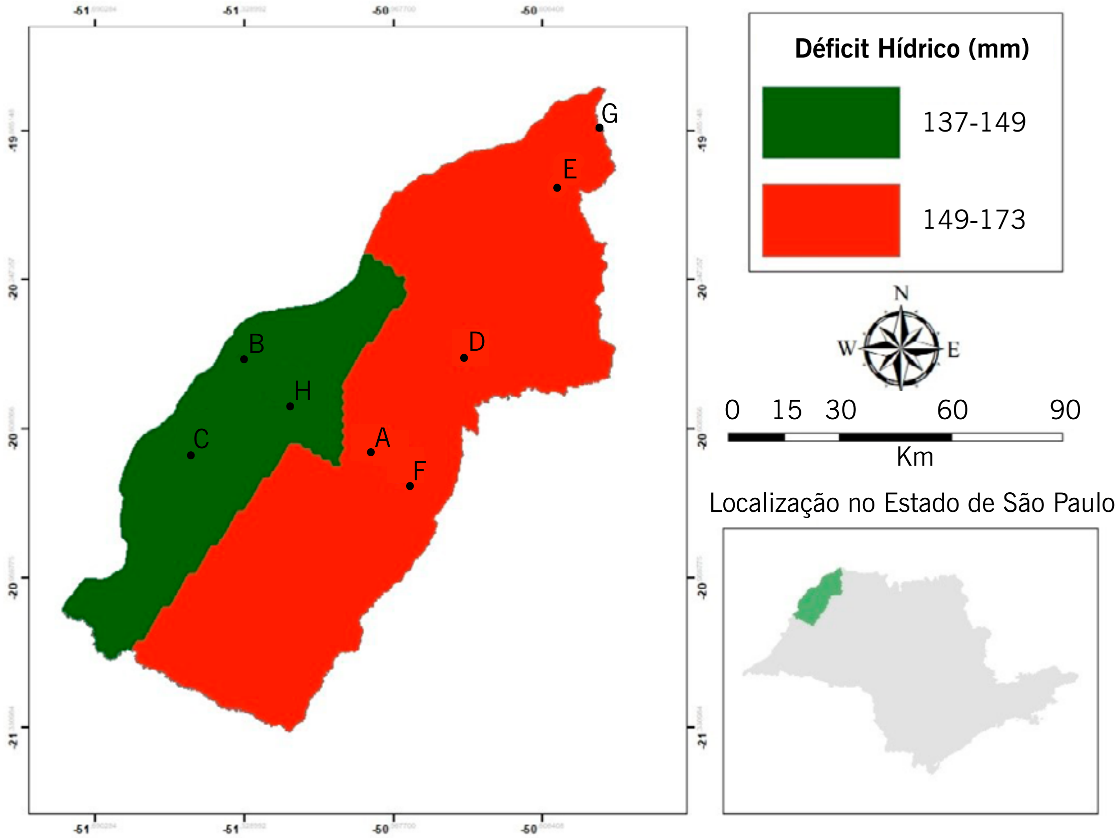

Source: Elaborated by the authors (2020).

There was no significant difference for evapotranspiration and total precipitation during the cycle between the last harvest and the average data of the previous seven years. Again, the deficits occurring in the region occur over the days, and it is necessary to carry out the daily water balance to find the deficit that the crop presents during the cycle. We interpolated the daily deficit data for the 2018-2019 crop water deficit map.

We observed the appearance of very high values in the last harvest when compared to the averages of the last years. The water deficit was so high during the previous harvest that it would be impossible not to have productivity losses all over the region. Ilha Solteira-SP, Itapura-SP, and Santa Adélia-SP showed the lowest deficits (137 to 149), and the rest of the region behaved uniformly within the range between 149 mm and 173 mm. According to Schutze *et al.* (2012), water deficit can be observed in the northwest of São Paulo both in the rainy season and in the dry season due to the high rate of evapotranspiration in the region and very irregular rainfall regime. This irregularity is related to distribution and not the amount of rain. Those irregularities result in increased risk for cultivation, due to the distribution of rainfall during the crop cycle being limiting production, when in unsatisfactory values for them (MARINI *et al.*, 2012).

Due to this yearly variation in precipitation distribution and consequently increased climatic risk for the agricultural activity, the practice of irrigation as water supplementation becomes quite necessary, since one can no longer depend on a very variable rainfall regime to obtain a productive crop. Implementing irrigation reduces risks in the summer harvest and enables the adoption of 2.5 harvests per year, increases productivity per cycle, and increases the quality of the grain produced.

The microregions of Jales and Andradina behave in different ways. However, the results are homogeneous. The use of meteorological data and the Geographic Information System (GIS) enable the producer to decide considering the true climatic conditions that the soybean crop will present during the cycle.

Conclusions

The water deficit in the soybean crop in the northwest region of São Paulo is related to the poor distribution of precipitation during the cycle and the significant recurrence of Indian summers all through the area. For the producers' safety, investment in irrigation systems anticipating this poor distribution is justified.

The water deficit in the region is variable. In years with good rainfall distribution, it can reach zero values, and in years with poor distribution, it can reach values greater than 180 mm.

Acknowledgments

The authors thank CNPq for the master's scholarship granted to the first author and to the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) for the financial support in the implementation of the Rede Agrometeorologica do Noroeste Paulista (Process 2009/52467-4).

Espacialidade do déficit hídrico na cultura da soja nas microrregiões de Jales e Andradina, estado de São Paulo

Resumo

O conhecimento da disponibilidade da água no solo é a base para executar e planejar o uso racional. Assim, objetivou-se com o presente estudo a realização da espacialidade da precipitação, evapotranspiração da cultura e da necessidade de suplementação hídrica no cultivo da soja nas microrregiões de Jales/SP e Andradina/SP para a safra de verão. O balanço hídrico foi determinado a partir do método de Thorthwaite e Mather (1955) com dados disponibilizados pela Rede de Estações Agrometeorológicas operada pela Área de Hidráulica e Irrigação da UNESP Ilha Solteira. Foi considerada uma Capacidade de Água Disponível (CAD) de 40 mm. O estudo deu-se a partir da simulação da condição hídrica de uma lavoura de soja semeada no dia 4 de novembro de 2020. Na condição de déficit hídrico a Evapotranspiração Real (ETR) foi considerada nula na condição de 20 % de déficit e os demais valores seguiram a mesma proporção matemática. A precipitação média do período, a evapotranspiração da cultura e o déficit hídrico de cada estação meteorológica foi interpolado utilizando o software ArcGIS 10.7 por meio de krigagem ordinária de modelo circular. O déficit hídrico na cultura da soja na região Noroeste Paulista está relacionado à má distribuição da precipitação ao longo do ciclo e à grande recorrência de veranicos por toda a região. Para seguridade do produtor, o investimento em sistemas de irrigação prevendo essa má distribuição é justificado. O déficit hídrico na região é variável podendo chegar a valores nulos em anos com boa distribuição da precipitação e a valores superiores a 180 mm em anos com má distribuição.

Palavras-chave: Balanço Hídrico. Irrigação. Krigagem. Noroeste Paulista.

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