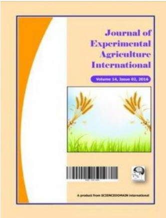

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Effect of Water Stress on the Development of Soybean Crop

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Authors' contributions

This work was carried out in collaboration among all authors. The authors PSXP, ALS, RFD, AGC, AB and MAS performed the experiment and wrote the first draft of the manuscript. The authors JHCJ, TAXP and DSP discussed the results, corrected and improved the writing of the manuscript in Portuguese and English versions. All authors read and approved the final manuscript.

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ABSTRACT

The present work had the objective of evaluating the effects of the spatial variability of the main meteorological elements on soybean yield, variety M7739 IPRO from Monsoy, with an early cycle of 105 days, with sowing at the beginning of October and harvesting at the beginning of the month in February, in two agricultural years (2013/14 and 2014/15) at Santa Luzia farm, located in the municipality of Campo Verde - MT (15º42'28 ''S, 55º19'59'' W, 736 m). The meteorological data of the region were obtained through the 9th district of meteorology (9th DISME) of the National Institute of Meteorology - INMET. The coefficient of culture (kc) was defined following the development stages of the culture. The estimates of evapotranspiration (potential and crop) were determined by

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the water balance method and the sensitivity coefficients (ky) of the soybean crop were estimated by the expression Ky=(1-Yr/Ym)/(1-ETr/ETm), in which ky = yield response factor; Yr = actual yield of the crop; Ym = maximum yield of the crop; ETr = actual evapotranspiration e ETm = maximum evapotranspiration. The values of Ky were all lower than 1, both for the crop cycle in the 2013/14 crop year and for the crop cycle 2014/15, indicating that the soybean crop is adaptable to water deficit.

Keywords: Coefficients of sensitivity; evapotranspiration; Glycine max; water balance.

1. INTRODUCTION

Soybean (*Glycine max* L.) is among the world's most consumed agricultural and oilseed plants. It is considered a plant species of great importance to Brazilian agribusiness, contributing, with a significant portion of the country's exports.

Among the major world producers (the United States, Brazil, Argentina), Brazil has the greatest capacity to multiply current production, both by increasing productivity and by the potential for expansion of the cultivated area [1].

For [2], the growth in soybean production is due, among many factors, to two reasons: high oil and protein content (20% and 40%, respectively). According to [1], the growth of soybean cultivation in Brazil has always been associated with scientific advances and the availability of technologies to the productive sector. By 2020, Brazilian soybean production is expected to exceed 100 million tons, and may be the world leader in grain production [3].

Even in this promising scenario to the expansion of the crop, considering that Brazil meets conditions favorable to the growth of the Brazilian soybean production, [4], emphasize that the unpredictability of weather variations and adversities are the main risks and failure factors in soybean cultivation. Still on this aspect, [5], reaffirm that the meteorological variations constitute the factor of greater difficulty of control, characterizing limitations to obtain the maximum productivities.

In this context, the agro-meteorological models play an important role, since, based on meteorological data, they can monitor the effects of time during the crop cycle and relate them to growth, development and productivity [5]. In order to identify the agro-meteorological models that best describe the behavior of the field crop in a given region, it is possible to insert such models in productivity simulation programs [6]. For the same authors, these models make it possible to predict the impact of climate change and, if the meteorological events behave within the historical range of variation, indicate the best planting harvest for each region.

Thus, [7], emphasize that any and all tools that help the decision-making process are of great value to the agricultural sector. The best understanding of the meteorological requirements of the crop and the water relations in the soil-plant-atmosphere system can contribute to the reduction of the risks of failure in agricultural production [8].

Considering the relevance of the soybean crop to the Brazilian agribusiness, and the need to have information that allows to estimate in advance the risks that involve the activity aiming at greater profitability, the present work had as objective to evaluate the effects of the meteorological conditions in the yield of soybean crop in an area in the municipality of Campo Verde, Mato Grosso, Brazil.

2. MATERIALS AND METHODS

2.1 Experimental Site Description

The work was carried out with data collected in two agricultural years (2013/14 and 2014/15) at Santa Luzia Farm, located in the municipality of Campo Verde, Mato Grosso, Brazil, T (15º42'28 "S, 55º19'59" W, 736 m). The M7739 IPRO soybean variety from Monsoy was used, with an early cycle of 105 days. Sowing was carried out in a field of 210 hectares at the beginning of October and the harvest took place at the beginning of the month of February. The meteorological data of the region were obtained through the 9th district of meteorology (9th DISME) of the National Institute of Meteorology (INMET).

The amount of available water was calculated by the ratio of the field capacity (FC) to the permanent wilting point (PWP), obtaining a value of 72.8 mm; These variables were obtained through a pedotransfer, obtained through the located, a texture that is considered to be loamy-clayey.

Through the meteorological data of precipitation and temperature the water balance was proposed by Thornthwaite and Mather [9] in order to obtain the water availability during the development of the crop. From the water balance, potential evapotranspiration (PET), real evapotranspiration (ETr) data were extracted.

The response factor of the crop (Ky) was obtained through the formula proposed by Doorenbos and Kassam [10], which indicates the response of the water supply to the yield, being quantified through the relation between the relative yield and the relative evapotranspiration deficit, as shown in the formula below.

$$ky = (1-Yr / Ym) / (1-ETr / ETm)$$

On what,

ky = yield response factor;
Yr = actual yield of the crop;
Y m = maximum yield of the crop;
ETr = actual evapotranspiration;
ETm = maximum evapotranspiration.

The maximum evapotranspiration (ETM) was defined following the methodology of Doorenbos texture of the soil where the production area is and Pruitt (1977), where it follows the following formula:

$$ETM = kc.ETo$$

On what,

Kc = coefficient of culture
ETo = Reference evapotranspiration (Table for tropical humid climate with moderate climate, being considered 4.5 mm/day).

The coefficient of culture (kc) was defined following the development stages of the culture by Doorenbos and Kassam [10] according to Table 1.

ETo data were obtained following a Table presented by Doorenbos and Kassam [11], where ETo is related to the climate of the region, with an ETo between 4 and 5 mm/day for the study region.

The estimated values of grain yield and precipitation over the years studied can be visualized in Fig. 1.

The maximum or potential yield (Yp) was generated by the relation of annual water excess, which in the study area was between 750 and 1000 mm/year, and the duration of the wet period in the region of Campo Verde - MT is between

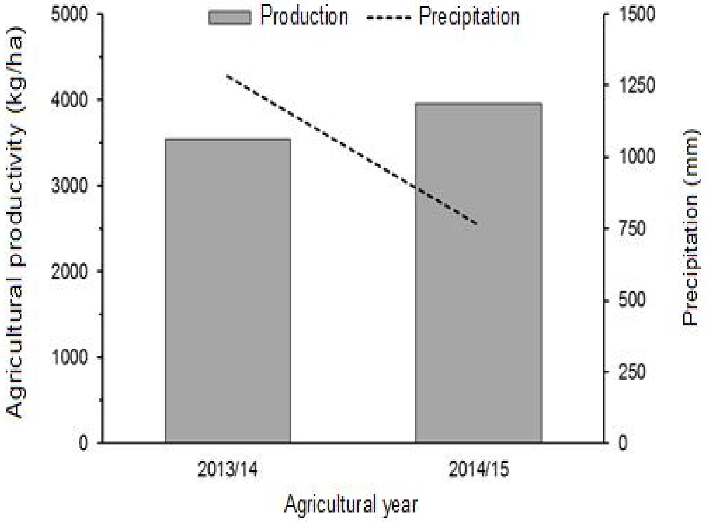

Fig. 1. Soybean yield and precipitation along two agricultural crops in the 210-hectares field at Santa Luzia Farm, Campo Verde, Mato Grosso, Brazil

Table 1. Coefficient of soybean (*Glycine max (L.)* in the development stages of the crop

Development phase	Period (in days)	Coefficient of culture (kc)
Initial	0 a 20	0.350
Development of culture	21 a 45	0.750
Intermediate	46 a 70	1.075
End of cycle	71 a 110	0.75
At harvest time	111 a 120	0.45

240 and 270 days; being the soybeans cultivated between October and May, the maximum or potential yield was in the range of 5.78 to 5.97 t/ha, being considered an average value of 5.87 t/ha.

3. RESULTS AND DISCUSSION

Table 2 presents the farm production data, showing an increase in yield of the 2013/14 crop for the 2014/15 crop, from 3,540 kg.ha^{-1} in the first crop evaluated to 3960 kg.ha^{-1} in the next harvest. The production showed an inverse behavior to the rainfall behavior, with higher production in the year with lower rainfall volume, but sufficient to guarantee a good production for the crop.

Table 2. Productivity of soybean during the study period at the Santa Luzia Farm, Campo Verde, Mato Grosso, Brazil

Agricultural year	Productivity (Kg.ha^{-1})
2013/2014	3,540.00
2014/2015	3,960.00

To obtain the maximum yield, the total water requirement in the soybean crop ranges from 450 mm/cycle to 800 mm/cycle, depending on climatic conditions, crop management and cycle duration. The need of water in the crop increases with the development of the plant, reaching the maximum during flowering-filling of grains (7 mm/day to 8 mm/day) and decreasing after this period [12].

For the cultivation of cotton, the highest productivity is achieved by applying slides between 600 mm and 800 mm of water [13]. According to the authors, the low water levels in the soil cause a decrease in the yield of the cotton, as well as the excess of water in the soil can negatively influence the development of the crop. In cotton cultivation, adequate water availability provides increased productivity and improved fiber qualities, while deficiency decreases fiber strength and fineness, stem diameter, plant height, and therefore productivity. The crop yield potential (Yp) or yield potential with limited water (Yw) are site specific because they are determined by several factors such as time, management, growing harvest duration and soil management. Both can be estimated from research plots, in which the crop is grown without limitations, or by crop simulation models. The use of crop simulation with a long-term time database provides a more robust estimate of Yp and Yw than the survey lots because the simulation best represents the impact of temperature variation, solar radiation and precipitation over the time [14].

Corroborating with the authors, [15] argue that information on water productivity is often made available only from experiments in a single field, so results are limited to local (environmental) conditions that can vary from year to year and to the soil, specific crops and practices of water management. However, yield, water use, and water productivity can be obtained in an integrated manner through the combination of crop production models and remote sensing, recognized as a powerful tool for estimating yields of crops at various spatial scales.

In almost all periods when soybean remained in the field, the real evapotranspiration (ETr) was equal to potential evapotranspiration (PET), evidencing that there was no water restriction for the crop in the referred periods. In this sense, the water availability for the crop was met, without there being a production penalty.

The water balance was realized in the harvest 2013/2014 and 2014/2015, as can be seen in Figs. 2 and 3.

Based on the values of ETr and ETp, as well as Yr and Yp, the values of Ky were estimated for the agricultural years 2013/14 and 2014/15 at Santa Luzia Farm, according to Table 3. The values of Ky estimated in the different agricultural years were less than 1, indicating no sensitivity to water deficits. Despite the low values of Ky found in the present study, there was little difference found between the

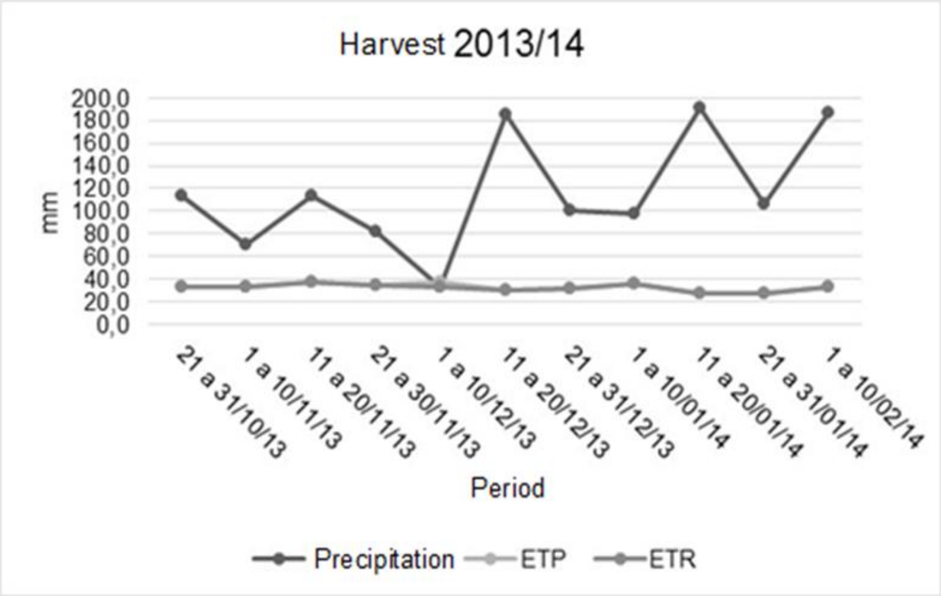

Fig. 2. Sequential water balance (P: precipitation; ETP: potential evapotranspiration and ETr: real evapotranspiration) during the 2013/14 harvest in the 210-hectare farm at Santa Luzia Farm, Campo Verde, Mato Grosso, Brazil

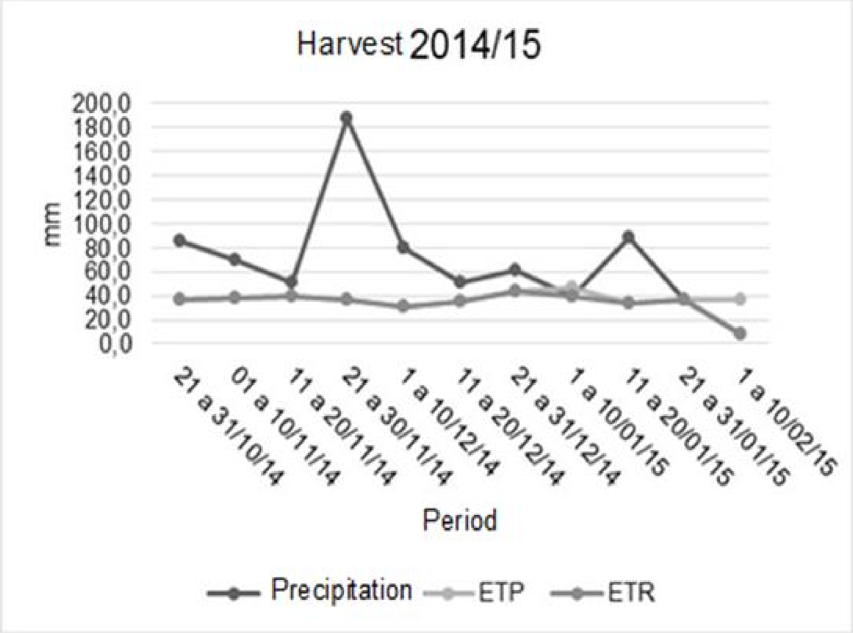

Fig. 3. Sequential water balance (P: precipitation, ETP: potential evapotranspiration and ETr: real evapotranspiration) during the 2014/15 harvest in the 210-hectare farm at Santa Luzia Farm, Campo Verde, Mato Grosso, Brazil

values of ETr and ETp in the evaluated agricultural years.

The values of crop evapotranspiration (Etc) and crop coefficient (Kc) vary according to the energy availability of the plant, soil, planting system, density, variety and age of the plant [12].

According to Zwirtes et al. [16] verified higher yield of sorghum grains (6,285.4 kg ha^{-1}) was

Table 3. Mean values of [1-ETr / ETp)] and [1- (Yr / Yp)] and the sensitivity factor ky of soybean crop, in the agricultural years from 2013/14 to 2014/15 in the field of 210 hectares at Santa Luzia Farm, Campo Verde, Mato Grosso, Brazil

Ano	ET_r	ET_p	ET_r/ET_p	$(1-ET_r/ET_p)$	Y_r	Y_p	Y_r/Y_p	$(1-Y_r/Y_p)$	K_y
2013/14	32.62	32.96	0.99	0.01	3,540	5,870	0.6	0.4	0.02
2014/15	34.53	37.96	0.92	0.08	3,960	5,870	0.67	0.33	0.26

ETr, ETp: Actual and potential evapotranspiration, in mm day^{-1}, respectively, considering only the months of cultivation of the crop, from October to February. Yr, Yp: Actual and potential production, in kg ha^{-1}, respectively

obtained with plants maintained with 100% replacement of crop evapotranspiration, while each of 25% decrease in water application in evapotranspiration replenishment of the crop resulted in a decrease of 1,113 kg ha^{-1} in grain yield.

According to Oliveira et al. [12] conditions of air temperature, relative air humidity and wind speed did not affect the development of non-irrigated soybean in the Cerrado in the rainy season and with late cultivar. During this period, the highest daily evapotranspiration demand was 6.4 mm, and rainfall during this period was able to meet this need.

According to Carvalho et al. [17] evaluated the effect of different irrigation slides on productivity, water use efficiency and yield response coefficient (Ky) of the carrot and observed reference evapotranspiration (ETo) and crop (ETc) totaling 286,3 and 264.1mm in 2010, and 336.0 and 329.9 mm in 2011, respectively. Root productivity ranged from 30.4 to 68.9t ha^{-1}, as a response to treatments without irrigation and with 100% replenishment of the soil water slide, respectively, the mean Ky (0.82) was obtained for the carrot crop in response to the water deficit. Being that values of Ky lower than 1.0 indicating that the culture showed some adaptability to the water deficit.

The influence of irrigation water management on crop yield increase (CYI), deficit irrigation practices were investigated to quantify the effect on yield and to find the best CWP values. It has been found that in rainfall systems without CYI irrigation it is low, but that CWP increases rapidly when a small irrigation water is applied. Water stress during different growth stages affects CYI differently. The optimal values for CYI are reached in approximately 150 and 280 mm of applied irrigation water, besides rainfall, in wheat and corn, respectively [18].

For [12] the quantification of water used by soybean plantations in the Cerrado and its relationship with meteorological elements are important data for studies of water use in this crop and planning of irrigation management. The determination of yield in soybean planting in the Cerrado is of fundamental importance the use of coefficient of regional culture.

We understand that the data (two agricultural years) are insufficient to prove whether the weather conditions of these years include the entire range of the region's climate, or whether they have been exceptional years. In addition, the meteorological data of the region were collected in the 9th district of meteorology (9th DISME) located in the municipality of Cuiabá - MT, located 137 km away from where the production data were collected.

According to Ferreira et al. [19] the consistency of the data, the location and the distance from the meteorological stations to the place of interest are determining factors of precision of grain yield estimates based on meteorological data, mainly precipitation data. In their studies, soybean water balance was calculated with data recorded in three meteorological stations where they proved variability in rainfall distribution, which resulted in soybean yield discrepancies, estimated at the regional level.

According to the authors, it is recommended 15 years of time data for rainfed crops, while in fully irrigated systems 5 years may be sufficient for productivity estimates. In addition, a high degree of caution is required in the use and choice of a single climate station to represent a municipality or region, particularly in countries such as Brazil, with multiple regions of agricultural and environmental importance.

4. CONCLUSION

The methods used in this study do not prove whether the meteorological conditions of the years studied include the entire range of the region's climate, or whether they were extravagant years. The values of ky and estimated in the two years of agricultural evaluation showed that despite the difference in production there was not enough water deficit to interfere in the soybean production at Santa Luzia farm.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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