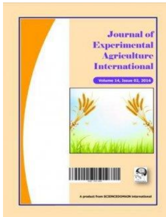

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Yield Response Factor to Water (Ky) of FMX 993, FMT 701 and FMX 910 Cotton Varieties in Campo Verde, MT

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Authors' contributions

This work was carried out in collaboration among all authors. Authors PMCC, SHV, MF and HMO collected and manipulated the data and wrote the first draft of the manuscript. Authors AB and JHCJ discussed the results, correct and improve the writing of the manuscript in Portuguese and English versions. All authors read and approved the final manuscript.

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ABSTRACT

Production of herbaceous cotton in rainfed is subject to water-deficit risks due to climatic variations, such as precipitation with non-homogeneous spatial-temporal distribution. In this sense, the objective of this study was to evaluate the yield response factor to water of FMX 993, FMT 701 and FMX 910 cotton varieties, in Campo Verde County, Mato Grosso State, Brazil. Real yield data of the 2009/10 and 2010/11 seasons of the three varieties were obtained. Meteorological data were used to estimate the maximum yield and to calculate the daily water balance for each variety and

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seasons. From these values the yield response factor to water (Ky) was obtained. Ky values ranged from 0 to 0.9, with the lowest and highest values for FMX 910 for the 2009/10 and 2010/11 seasons, respectively. These values obtained from Ky indicate that all varieties studied present increasing tolerance to water-deficit. The FMX 993 variety had a lower variation in Ky values between 0.3 and 0.5 for the 2009/10 and 2010/11 seasons, in that order. Therefore, among the cotton varieties evaluated in this study, recommend FMX 993 for the conditions of Campo Verde County, Mato Grosso State, due to its greater tolerance to the water-deficit.

Keywords: Evapotranspiration; maximum yield; rainfed agriculture.

1. INTRODUCTION

The cotton production in Brazil was 3.84 Mt in the 2016/17 season, with 67.2% of this in the Mato Grosso State, with an average productivity of 4,183.0 kg ha^{-1} [1]. These yields are influenced by the climatic, genetic, phytosanitary and agronomic crop management factors that prevent maximum yield.

The maximum yield (Ym) is that obtained by a highly productive variety and well adapted to climatic conditions, with adequate water availability, good nutrition, pest and disease free, and wide use of agricultural inputs [2]. Ym can be calculated for different weather and climate conditions, allowing long-term identification of areas more conducive to production and, in the short term, the effect of water availability on yield under rainfed conditions.

The water deficit, product of the water balance, occurs when the total water entering the system through precipitation is less than the total amount of evapotranspirated water [3]. In these environmental conditions, the plant physiological response to water deficit (stomatal closure, acceleration of senescence, lower aerial biomass, etc.) is aimed at the conservation of water in the soil [2,4]. In addition, estimates of reference evapotranspiration (ET_0) and crop coefficients (Kc) are widely used to estimate crop and vegetative water use and water requirements and these are necessary and important for irrigation scheduling, planning and cultural management.

Under rainfed conditions crop yields are highly dependent on the interactions between the phenological phases of the crop and climatic variations. The intensity, regularity and distribution of rain during the vegetative period of the plant significantly interfere with yield. In cotton, the phenological period between flowering and seed filling are the most sensitive to water stress [5]. The water supply to a crop results from interactions that are established throughout the soil-plant-atmosphere system [6]. Cotton productivity linked to climate change varies for each variety, some of which are more tolerant to water deficit than others.

The crop sensitivity to water deficit can be assessed by the ratio between the relative reduction of production and the relative reduction of water consumption (Ky), that the larger it is, more sensitive is the crop [7]. Values of Ky minor than 1 indicate increasing tolerance. In the case of cotton, the expected values of Ky were estimated between 0.46 and 0.99 [8].

There is still little information on the effect of water deficit on cotton in rainfed conditions in Mato Grosso State. Considering that the production of Mato Grosso cotton is the most important in Brazil, having this information is relevant, since it would allow better management of time and resources in the planning of cultural practices, bringing greater efficiency, with better perspectives of productivity and income to the farmer. In the present work, the objective was to evaluate the response to the water deficit of the FMX 993, FMT 701 and FMX 910 cotton varieties, from the 2009/10 and 2010/11 season, at Mourão Farm, Campo Verde County, Mato Grosso State.

2. MATERIALS AND METHODS

2.1 Edaphoclimatic Conditions

Rainfed cotton productivity and yield data of FMX 993, FMT 701 and FMX 910 varieties was used, from Mourão Farm, Campo Verde County, Mato Grosso State, Brazil, located at 15° 29 'S, 54° 50' W, at 650 masl. The climate of the region is Aw, according to the climatic classification of Köppen [9], tropical humid, rainy season in summer and dry in winter, with rainfall concentrated in the months of November to April, annual averages of precipitation 1726 mm and mean temperature of 22.3°C. The soil was classified as Red Latosol, with clayey texture (45-55%), medium organic matter content (3%), base saturation 50-60 ($cmol_c\ dm^{-3}$), and phosphorus 12 mg L^{-1}.

The yields of the 2009/10 and 2010/11 seasons were considered, with crop cycles of 200 days after sowing (DAS), between the sowing-harvest dates of Dec. 6, 2009 – Jun. 24, 2010 and Dec. 20, 2010 – Jul. 07, 2011 respectively. The plant density was 8 plants m^{-1} and row spacing of 0.90 m (88,888.88 plants ha^{-1}). In the cultural managements, planting fertilization consisted of 120 kg ha^{-1} of N, 65,6 kg ha^{-1} of P_2O_5 and 150.8 kg ha^{-1} of K_2O, 63 kg ha^{-1} of SO_4; urea, potassium chloride, sulfur and triple superphosphate were used as the source. Both weed control and pest management were made according to technical recommendations [10]. Furthermore, the period of the mains vegetative stages of the cotton varieties were: V_0-emergence (4-9 DAS), B_1-first floral bud (38-44 DAS), F_1-first flower (60-65 DAS), M_1-first boll (67-73 DAS), C_1-first crocked boll (113-120 DAS).

Planting typically begins when soil temperature reaches 16°C at 0.10 m depth in more temperate zones or 18°C at 0.20 m depth in warmer regions. Though seeds germinate down to 12-14°C, the optimum air temperature ranges from 31 to 33°C, but the germination limiting temperature maximum is 40-42°C. Emergence is optimal at 32-34°C. Cotton plants form a strong tap-root, down to nearly 3 m on good soil. Suitable soil varies widely, but favored soils are loamy to clayey, deep, well drained and with good water-holding capacity. On soils with hard pans, subsoiling is common to facilitate drainage and root deepening. Water requirements vary widely depending on growing season length, climate, cultivar, irrigation method, and production goals, but may range from 700 to 1,200 mm [7].

2.2 Reference (ET_0), Maximum Crop (ETm) and Real Crop (ETr) Evapotranspiration

The reference evapotranspiration (ET_0, in mm day^{-1}) was calculated using the FAO Penman-Monteith method [11], with the help of the ET_0 Calculator Version 3.2 software from the FAO Land and Water Division [12], based in the equation 1:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where: R_n is the net radiation at the crop surface, in MJ m^{-2} day^{-1}; G is the soil heat flux density, in MJ m^{-2} day^{-1}; T is the mean daily air temperature at a height of 2 m, in °C; u_2 is the wind speed at a height of 2 m, in m s^{-1}; e_s is the saturation vapour pressure, in kPa; e_a is the actual vapour pressure, in kPa; Δ is the slope of the vapour pressure curve, in kPa $°C^{-1}$; and is the psychrometric constant. The soil heat flux is ignored (G=0) in daily applications.

In order to determine the ETm of the cotton varieties, in Equation 2 the coefficient of cultivation (Kc) was adopted in the initial stage 0.4, in development 0.8, intermediate 1.1, final 1.3 and in the harvest 0.9 [2].

$$ETm = ET_0 \times Kc \quad (2)$$

Where: ETm is the maximum crop evapotranspiration, in mm day^{-1}; ET_0 is the reference evapotranspiration, in mm day^{-1}; Kc is the coefficient of cultivation, dimensionless.

In order to determine the real evapotranspiration (ETr), a daily water balance was performed according to Thornthwaite and Mather [13], considering soil water storage capacity of 140 mm.

2.3 Maximum Yield (Ym)

In the determination of the Ym (Equation 4), the agroecological zones method adapted by Doorembos and Kassam [2] was used, assuming that all crop, phytosanitary and nutritional needs of the crop were met and its yield was conditioned by the genetic potential, solar radiation and temperature of the study site.

For the estimation of the Ym it was necessary to calculate the dry matter production for the cotton crop (Yo, in kg ha^{-1}), corrected to the crop and temperature (25°C) (Equation 3), according to the recommendations of Doorembos and Kassam [2]:

$$Yo = F(0.8 + 0.01\ ym)yo + (1 - F)(0.5 + 0.025ymyc \quad (3)$$

Where: F is the fraction of the day-time when the sky is overcast (calculated by F=(Ac-0.5Rg)/0,8Ac, where Ac is the mean amount of photosynthetically active radiation on clear days at latitude cultivation, and Rg is the mean measured total short-wave global radiation); ym is the maximum rate of dry matter yield of leaves, in kg ha^{-1} h^{-1}, for mean temperature of cultivation days of cotton crop; yo is the crude dry matter production rate of the standard crop produced on a cloudy day, in kg ha^{-1} day^{-1}; and c is the crude dry matter production rate of a standard crop produced on a clear day in kg ha^{-1} day^{-1}.

Thus, the Ym of a highly productive variety will be given according to Equation 4:

$$Ym = cL.cN.cH.G.Yo \qquad (4)$$

Where: Ym is the maximum yield, in kg ha^{-1} $period^{-1}$; cL is the correction due to the crop and leaf area development; cN is the correction for dry matter production; cH is the correction for cotton yield index of fiber; G is the total growth period of the crop, in days.

2.4 Yield Response Factor to Water (Ky)

The relation between the relative yield drop and the relative evapotranspiration deficit was determined according to Equation 5.

$$\left[1 - \frac{\mathrm{Yr}}{\mathrm{Ym}}\right] = \mathrm{Ky}\left[1 - \frac{\mathrm{ETr}}{\mathrm{ETm}}\right] \qquad (5)$$

Where: Ky is the yield response factor to water for the cotton crop, dimensionless; Yr and Ym is the real and maximum crop yield, respectively, in kg ha^{-1}; ETr is the real crop evapotranspiration, mm day^{-1}; ETm is the maximum crop evapotranspiration, in mm day^{-1}.

2.5 Weather Data

In the estimation of ET_0 and Ym, daily meteorological data of maximum and minimum air temperature (°C), wind velocity at 2 m above the surface (m s^{-1}), radiation (cal cm^{-2} day^{-1}) and mean relative humidity (%), precipitation (mm day^{-1}). The meteorological data were obtained from the National Aeronautics and Space Administration Langley Research Center [14].

These climatic data, whether measured or estimated, are necessary to estimate ET_0 by the Penman-Monteith method (Equation 1). Furthermore, for the estimation of Ym it was necessary to calculate the real evapotranspiration (ETr), using daily precipitation data (mm day^{-1}) through a water balance.

3. RESULTS AND DISCUSSION

Fig. 1 shows the distribution of precipitation during cotton cultivation. Using the classification of phenological growth stages for the cotton described by Araújo et al. [15] it was observed in the 2009/10 season, that from 35-40 DAS (Fig. 1A) in the B1, F1, M1 and C1 stages, the ETr and ETm are larger than the precipitations, occurring water deficit in this period, and that the culture responded with greater root growth, as a strategy to dispose of water and maintain productivity, as Yeates [16] indicates. These results corroborate with Zonta et al. [17] who observed that when the water deficit occurs during the crop cycle, productivity losses are only significant if it occurs at 15 days after the F1/M1 stages.

In the 2010/11 crop season, ETr and ETm are higher than precipitations from 110 DAS (Fig. 1B), with a water deficit occurring between the M1/C1 stages, with a low risk of affecting productivity.

It is observed that the evapotranspiration reached the maximum, in the vegetative and reproductive phases crop transition, and then decreasing, which is in accordance with what was observed by Bezerra et al. [18].

In Table 1, it was observed that Ym was higher than Yr in all varieties and in the two seasons evaluated. This shows that these varieties have a higher production potential and this has not been fully exploited. For the 2009/10 season, the FMX 910 variety presented the largest Yr, with 2,057.3 kg ha^{-1}, constituting the closest to Ym, followed by FMX 993, with 1,923.5 kg ha^{-1} and FMT 701 with 1,637.2 kg ha^{-1}. In the 2010/11 season the three varieties presented similar Yr between them, however with a smaller difference between Ym and Yr for the variety FMX 993.

Similar results were obtained by Guimarães et al. [19] in the 2011/12 season for the Tangará de Serra County (MT) climatic conditions, in which the FMX 993 variety showed higher cotton productivity when compared to FMT 701. The differences in climatic conditions and agronomic management caused a yield lower among cultivated varieties in Tangará da Serra County, MT than those cultivated in Campo Verde County, MT. Also, for FMX 993 and FMX 910 varieties, Anselmo et al. [20] found respectively 3,997.5 and 4,266.0 kg ha^{-1} of average cotton productivity, being lower than those used in this study.

On the other hand, Silva et al. [21] obtained 4,485.0 kg ha^{-1} cotton productivity for the FMT 701 variety for the 2007/08 season in Mineiros

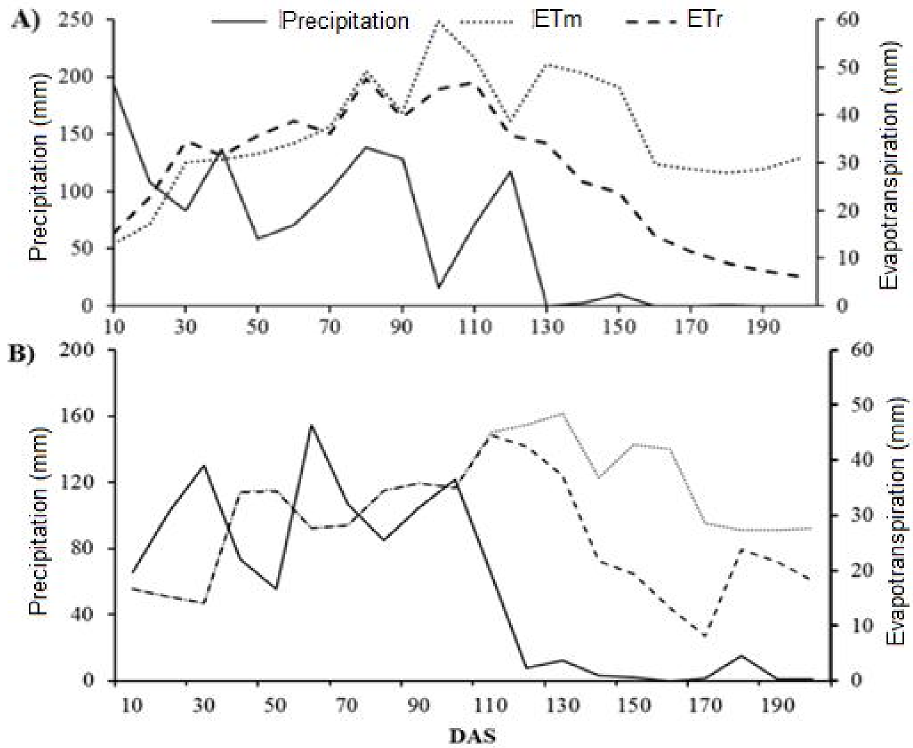

Fig. 1. Distribution of precipitation, maximum crop evapotranspiration (ETm) and real crop evapotranspiration (ETr) in the cotton crop of the 2009/10 (A) and 2010/11 (B) season. DAS: days after sowing

Table 1. Cotton productivity (Yc), real yield (Yr), maximum yield (Ym), maximum evapotranspiration (ETm), real evapotranspiration (ETr) and yield response factor (Ky) of varieties FMX 993, FMT 701 and FMX 910 in the 2009/10 and 2010/11 seasons

Season	Varieties	Yc	Yr	Ym	Fiber yield	ETm	ETr	Ky
		……… kg ha^{-1}	…………..		…….%.......	…... mm….		
2009/10	FMX 993	4,880.0	1,923.5	2,052.0	39.5	727	563	0.3
	FMT 701	4,184.0	1,637.2	2,052.0	39.1	727	563	0.9
	FMX 910	5,178.0	2,057.3	2,065.0	39.7	727	563	0.0
2010/11	FMX 993	4,552.0	1,766.2	1,957.0	38.8	648	525	0.5
	FMT 701	4,246.0	1,673.7	1,990.0	39.4	648	525	0.8
	FMX 910	4,292.0	1,645.7	1,986.0	38.1	648	525	0.9

County, Goiás state, showing close to those obtained in this study. In the north of Minas Gerais state, Coutinho et al. [22] obtained 1,255.36 kg ha^{-1} and 1,071.45 kg ha^{-1} cotton yield in the FMT 701 and FMX 910 varieties, respectively; being the yield conditioned by low water availability (436 mm), due to an inadequate rainfall distribution during the growing season.

In a study of maximum yield of eleven cotton varieties cultivated in the 2008/09 season in Chapadão do Sul County, Mato Grosso do Sul State, the FMT 701 variety showed the highest productivity, with 4,683.0 kg ha^{-1}, higher than those obtained in the region of Campo Verde County.

These reported productivities and yields show that the development of the varieties is strongly influenced by the region and its edaphoclimatic characteristics and also that under adequate precipitation conditions for the region, it may be that the variety does not express its maximum potential in relation to another region for which it has been improved.

The Fiber yield (%) variable, which refers to the percentage of fibers present in relation to cotton yield, showed similar average values between varieties and seasons (between 38.10 and 39.7%). These results were lower than those obtained by Vilela et al. [23] with 43.7% and 45.3% of fiber yield for the FMT 701 and FMX 993 varieties, respectively, for the Campo Verde County. The difference could be made by the volume of rain that occurred during these periods for 2005/06, 2009/10 and 2010/11 seasons. The importance of the fiber yield is in the price paid by the cotton fiber yield, on average, 3.5 times superior to the one paid by the cotton productivity, when it is not benefited. Therefore, the fiber yield, for the cotton producer, is the characteristic of greater interest, constituting approximately 90% of the production value.

The accumulated rainfall in the 2009/10 and 2010/11 seasons was 1,043.0 and 1,106.35 mm respectively, indicating an increase in the amount of water available, but there was a general reduction in the yield of cotton varieties (Table 1). This is because, despite the greater amount of rain, rainfall availability was lower for the subsequent season, which is proven with ETm and ETr, since they had to reduce their evapotranspiration as a consequence of the smaller amount of available water.

Therefore, the yield of a crop is determined not only by the total amount of water supplied to the crop during the whole cycle, but mainly by the availability of this (spatial-temporal distribution) at the critical moments of water requirement for the optimal vegetative and reproductive development of the crop. Silva et al. [24] demonstrated that the cotton crop is highly sensitive to climatic changes, mainly water deficiency combined with abrupt increases in mean air temperature, since this environmental variable significantly affects phenology, foliar expansion, elongation of the internodes, production of biomass and the partition of assimilates in different parts of the plant.

In the estimation of yield response factor to water (Ky) different values were obtained depending on the varieties and corresponding seasons. In the 2009/10 season the variety FMX 910 presented Ky=0; which indicates that in this season despite the water deficit, the yield was not affected, presenting values of Yr very close to Ym. Contrary to the 2010/11 season, the estimated value of Ky was 0.9, showing a high sensitivity to water deficit. However, the FMX 993 variety shows similar values close to zero (Ky=0.3 and 0.5) in the two seasons, while the FMT 701 variety indicates values closer to 1 (Ky=0.9 and 0.8). Therefore, the values of Ky in the total period of crop development for the FMX 993 variety in the two seasons and the FMX 910 variety in the 2009/10 season were below the value estimated by the FAO for the total period of growth (Ky=0.85) [2]. Araújo et al. [25] obtained values of Ky less than 1 for the cotton crop, thus agreeing with the results of this study indicating a low sensitivity of the crop to water stress. In addition, Ertek and Kanber [26] evaluated the Ky of the irrigated cotton and obtained a value of Ky of 0.7.

These results suggest that FMX 910 is a highly productive variety in comparison to the others studied, due to a greater efficiency in the use of water for the yield; however, it is highly sensitive to the inadequate spatial-temporal distribution of rainfall when grown in areas with irregular rainfall conditions and prone to drought. On the other hand, the FMX 993 and FMT 701 varieties presented a Ky more constant in the different environmental conditions.

4. CONCLUSION

The FMX 993 variety presented low and constant values of Ky for the two seasons studied, having a better response to the adverse climatic conditions when compared to FMX 910 and FMT 701 varieties.

Therefore, among the cotton varieties studied in this work, recommend FMX 993 for the conditions of Campo Verde County, MT, due to its greater tolerance to the water deficit.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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