academicJournals

Vol. 11(8), pp. 701-708, 25 February, 2016
DOI: 10.5897/AJAR2015.10814
Article Number: C057BB857307
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Soil moisture and water use efficiency in cotton plants grown in different spacings in the Brazilian Cerrado Region

Tonny José Araújo da Silva, Thiago Franco Duarte, Jackelinne Valéria Rodrigues Sousa, Edna Maria Bonfim-Silva*, Adriano Bicioni Pacheco and Helon Hébano Freitas de Sousa

Department of Agricultural Engineering, Federal University of Mato Grosso, Rondonópolis-MT, Brazil.

Received 18 January, 2015; Accepted 10 February, 2016

The aim of this study was to assess soil moisture and water use efficiency in cotton plants (*Gossypium hirsutum* L.) grown in different row spacing in the *Cerrado*, Brazil. The crop was irrigated by drip irrigation, and the amount of supplied water was equal to 90% of crop evapotranspiration (ETc). Spacing of 0.4, 0.7 and 1.0 m between rows were assessed. Soil moisture was assessed up to 1.0 m deep, and water use efficiency for seed cotton and shoot dry matter yield was assessed based on the total water supplied to the crop (rain + irrigation). Soil moisture variations were minimal from 0.6 m deep, regardless of the spacing used. From this same depth, the soil cultivated under the denser system (0.4 m) was drier than the other spacing. In traditional planting (1.0 m), the cotton plant has lower water use efficiency for both seed and shoot dry matter yield. Water use efficiency is optimized in 0.6 m spacing, although the nitrogen dose applied should be observed.

Key words: *Gossypium hirsutum* L., drip irrigation (SDI), moisture profile.

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is the most important textile fiber in the world. It is produced in more than 30 countries, with emphasis to China, in the first position. Brazil is the fifth largest producer and third largest exporter (FAO, 2015). The culture has great economic value and is especially used in regions with irregular rainfall or limited water amounts for irrigation, where it is an important income source for small and large-scale farmers (Papastylianou et al., 2014; Valipour, 2015a).

In Brazil, cotton growth has become common in denser spacing. Traditionally, the culture is seeded at 0.8 to 0.9 m spacing between rows, with final stand ranging from 100 to 120 thousand plants ha^{-1}. In dense cultivation, spacing is typically reduced to 0.45 m between rows, or even smaller. Some preliminary results show that this new system may reduce total yield costs, while increasing yield per area (Belot and Vilela, 2010).

However, if there is economic motivation stimulating the adoption of this planting system on the one hand, there is lack of scientific information on the consequences of this crop management. It is not known, for example, if such management change would affect crop water

*Corresponding author. E-mail: embonfim@hotmail.com.

consumption, consequently reducing soil moisture faster. In addition, the effect of this management on water use efficiency is also unknown.

Moisture profile analysis has provided important information on crop growth. In some cases, moisture along the profile shows little variation (Zhou et al., 2010). However, variations are accentuated in other cases (Hu et al., 2009). Such variations are probably due to uneven vertical root density distribution (Zhao et al., 2010). With respect to water use efficiency, it seems that there is negative correlation with spacing between rows, as shown in different crops (Zhou et al., 2010, 2011).

In this context, this experiment aimed to assess soil moisture and water use efficiency in cotton plants under drip irrigation and different planting spacing in an Oxisol from the Brazilian *Cerrado*.

MATERIALS AND METHODS

The experiment was conducted in field, in the experimental area of the Federal University of Mato Grosso (UFMT), Rondonopolis Campus (-16° 27'45"latitude, -54° 34' 49"longitude, 290 m altitude), between May to September 2015.

The experimental design was of randomized blocks in Box-Behnken design (Box and Draper, 1987). 15 treatments and 4 repetitions were used, totaling 60 experimental units of 30 m². Treatments were, as follows: three cultivation spacing (dense - 0.4 m, intermediate - 0.7 m - traditional - 1.0 m), three nitrogen fertilizer levels, applied throughfertigation as a percentage of the recommended dose (low dose - 20%, intermediate dose - 110% and High dose - 200%) and irrigation three levels, through subsurface drip irrigation (deficit - 30% of ETc; intermediate - 90% of ETc, and water surplus - 150% of ETc).

The irrigation practice has become increasingly common in agricultural systems to achieve high productivity (Valipour, 2014a, b, c). The method adopted was drip irrigation due to greater efficiency of water supply to the plants because, in that system, in addition to located application near the root system, only a portion of soil surface is wet which minimizes losses related to evaporation (Valipour, 2012 a, b, c).

The experimental area soil was classified as Oxiisol (EMBRAPA, 2013). For fertilization and liming recommendation, chemical and particle size characterization was conducted (Table 1) according to EMBRAPA (1997).

Soil acidity was corrected rising base saturation to 50%, and fertilization was carried out with 155 kg ha^{-1}of nitrogen in urea form, 120 kg ha^{-1}of phosphorus (P_2O_5), as Single superphosphate, 100 kg ha^{-1} of potassium (K_2O), in potassium chloride form, and 30 kg ha^{-1}of micronutrients (FTE). Both were conducted according to Sousa and Lobato (2004). Nitrogen was applied by fertigation, with the aid of Dosmatic® MiniDos 1% (Hydro systems, USA) fertilizer injector.

Irrigation management was carried out from reference evapotranspiration (ETo) (Valipour and Eslamian, 2014; Valipour, 2014d,e,f,g,h; Khoshravesh et al., 2015; Valipour, 2015b,c), which was estimated by Penman-Monteith/FAO-56 (Equation 1), using the following meteorological variables: net radiation (MJ m^{-2} d^{-1}), wind speed (m s^{-1}), air temperature (°C) and relative humidity (%). Data were obtained from an automatic weather station installed about 270 m from the experimental area, in which data were stored every 10 min.

Irrigations were carried out on alternate days based on crop evapotranspiration (ETc), according to Equation 2, and the water volume to be applied was corrected by the drip irrigation system efficiency (90%). Three irrigation depths were used: LI30 - water deficit (30% of ETcdemand), LI90 - intermediate (90% of ETc) and LI150 - high water surplus (150% of ETc). Crop coefficients (Kc) for the four plant development stages were chosen as proposed in the FAO 56 (Allen et al., 1998) for cotton crop.

$$ETo = \frac{0.408\Delta\left(Rn - G\right) + \gamma \dfrac{900}{T + 273} u_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34u_2\right)} \quad (1)$$

Where; ETo - reference evapotranspiration (mm d^{-1}),Δ - tangent to the vapor pressure curve (kPa °C^{-1}), Rn - available netsolar radiation (MJ m^{-2} d^{-1}), G - heat flow in the soil (MJ m^{-2} d^{-1}),γ - psychrometric constant (kPa °C^{-1}), u2 - Wind speed at 2 m (m s^{-1}), s - atmospheric water vapor saturation pressure (kPa),e_a - current atmospheric water vapor pressure (kPa) and T - average daily air temperature (°C).

$$ETc = ETo \times K_c \quad (2)$$

Where; ETc - crop evapotranspiration (mm d^{-1}), ETo - reference evapotranspiration (mm d^{-1}) and Kc - crop coefficients.

Treatments related to planting spacing were defined according to the current recommendations of cotton crop productive system in Mato Grosso, Brazil. Sowing was held on May 1, 2015, with IMA 5675B2RF cotton seeds and 8 plants per linear meter. Plant densities, according to crop spacing, were, as follows: E0.4 - 225,000 plants ha^{-1}; E70 - 128,571 plants ha^{-1}and E100 - 90,000 plants ha^{-1}.

Soil profile moisture was continuously observed from 06/06/2015 using Diviner 2000®model (Sentek Pty Ltd, Australia) capacitance probe, with readings at every 0.1 m. For moisture readings, nine access tubes were installed, three for each planting spacing, at 1 m deep in default random plots with intermediate irrigation (90% ETc) in each spacing. Of the three access tubes for each spacing, one was installed in the row-crop, and the other two between the lines (on opposite sides). Soil moisture was a result of the average of the three measuring points.

At 142 days after sowing, experiment harvesting was conducted, and fruits and stems were separated. The collected material was weighed and dried in an oven with forced air at 65°C for 72 h. Subsequently, it was weighed to determine seed cotton and shoot dry matter yield (stem + fruit). Thus, seed cotton (WUE_Y) and shoot dry matter (WUE_{DM}) water use efficiency for yield were calculated. Efficiency was calculated through the ratio between the interest variable and the total water amount supplied to the crop (rain + precipitation).

Water use efficiency for yield and shoot dry matter variables were statistically assessed through response surface analysis, using the SigmaXL® 7.0 software tool to the maximum significance level of 5% for all statistical tests.

RESULTS AND DISCUSSION

Soil moisture distinctly varied for the various soil profile layers in different spacing (Figure 1). It was observed that upper layers (up to 0.4 m) had higher moisture oscillations compared to the deeper layers (0.4 to 1.0 m) in all spacing. This is probably due to higher root density in the upper layers compared to deeper layers. Thus, Zhao et al. (2010), for example, studied the drip irrigation influence on cotton plant root length density, and found

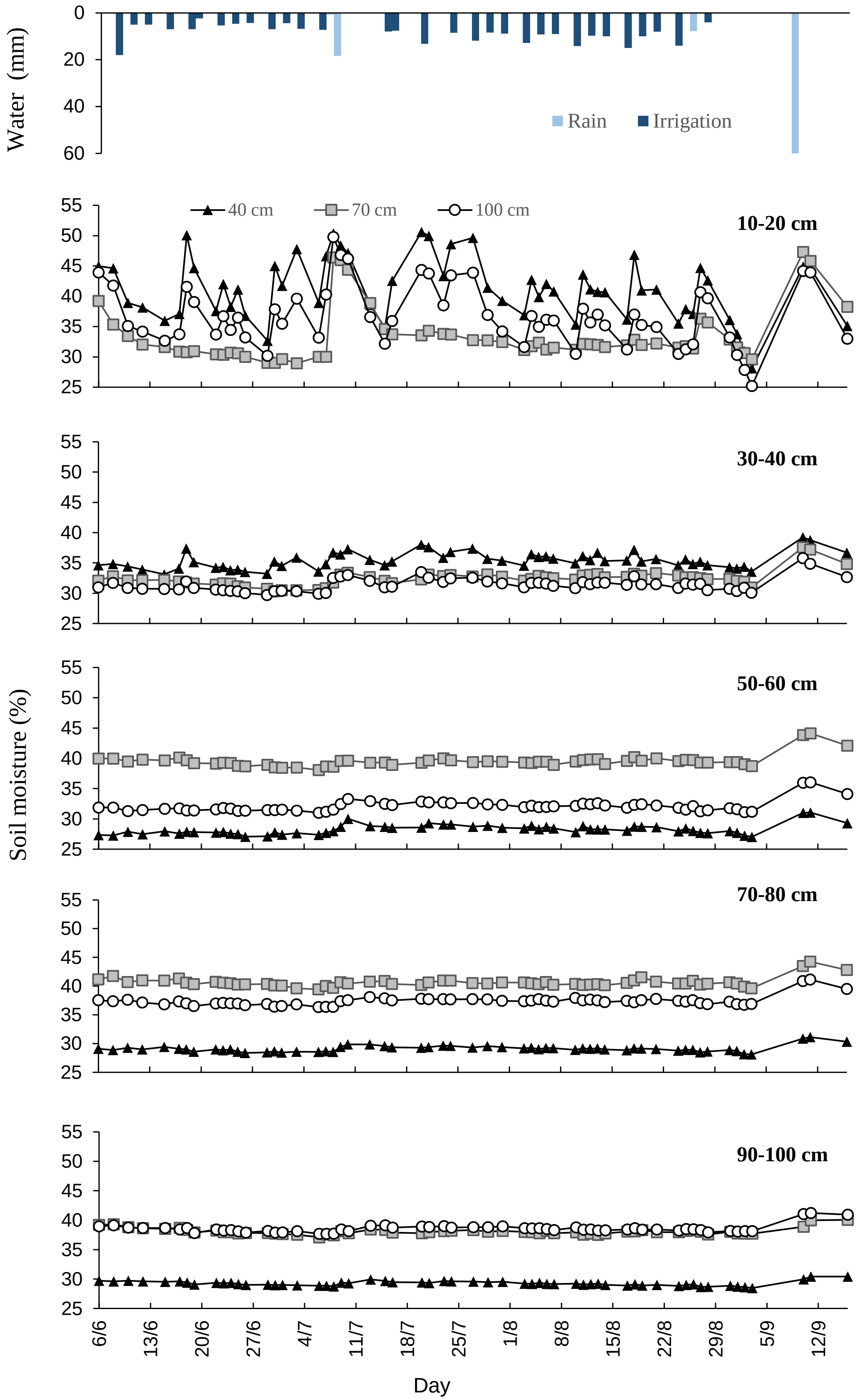

Figure 1. Soil moisture by layers under different spacing between rows and irrigation depths (irrigation + rainfall) for cotton plant grown in a *Cerrado* Oxisol in 2015.

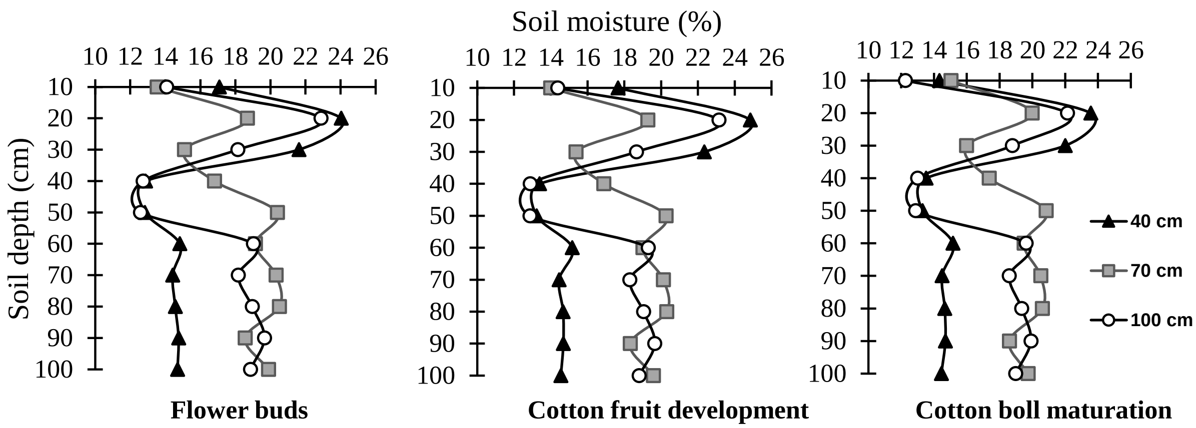

Figure 2. Soil moisture profile (%) until 1.0 m deep in three phenological stages for cotton plant grown under different row spacings in a *Cerrado* Oxisol in 2015.

that most of roots were concentrated until the depth of 0.5 m.

Among spacing assessed, the highest soil moisture values to a depth of 0.4 m were found in the denser crop (Figure 1). From this depth, the situation is reversed, that is, the soil was more dried in the 0.4 m spacing. For other spacing, it was observed that soil moisture in intermediate spacing was initially lower in the first layer (Figure 1). Subsequently, moisture values on the same spacing were higher, up to the depth of 0.8 m, and were identical in the last layer, when compared to the largest crop spacing (Figure 1).

From the 0.5 to 0.6 m layer, soil moisture variation was minimal in all spacing assessed (Figure 1), which could be an indication of maximum plant water extraction depth, according to analysis by Farahani et al. (2008). At the time, Farahani et al. (2008) assessed the moisture profile of a soil cropped with cotton plants, and concluded that most of water extraction occurred up to the depth of 1.20 m. However, it does not explain lower soil moisture values from the depth of 0.5 m to the 0.4 m spacing.

In a similar analysis, Hu et al. (2009) concluded that soil moisture increase in higher depths is the result of higher water supply than what is consumed by the plant. Although the soil had a plastic cover in the study by Hu et al. (2009), which reduces evaporative water loss and favors moisture increase, tendencies found by the authors were, in part, similar to those of this study. It was noted that between the 0.5 and 1.0 m layer, soil moisture was always lower than 30% for 0.4 m planting (Figure 1). For other spacing, soil moisture was kept almost constant at 40% for 0.7 m planting, increasing from approximately 33 to 40% in the largest planting. The reason why the soil was drier at higher depths in denser crops should be further investigated. Probably, vertical root distribution was different between spacing, as shown by Zhao et al. (2010)

The soil moisture profile in the three spacing was similar during flower bud, apple development and boll maturing stages (Figure 2). Moisture initially increased with depth, with subsequent decrease and, finally, little variation was observed in higher depths. Once again, little soil moisture variation was observed in depths higher than 0.6 m, regardless of spacing used. In addition, the lowest soil moisture amounts were observed under 0.4 m spacing.

The total water amount stored throughout the profile was lower under denser row spacing, followed by the large stand later by the intermediate row spacing (Figure 3). Difference between spacing were statistically different among them, with values of 163, 184 and 176 mm for 0.4, 1.0 and 0.7 m spacing (Figure 4). Thus, smaller differences may indicate that the total water consumption of cotton plant grown under denser water system is higher compared to the traditional system. Water use efficiency for seed yield (kg ha^{-1} mm^{-1}) was statistically significant (Figure 5), whose mathematical model was, as follows:

$$WUE_Y = 4.292 - 0.468ET_L + 0.443N_L - 0.677RS - 1.262RS^2 \qquad R^2 = 0.56 \tag{3}$$

Where: WUE_Y: Water use efficiency for seed cotton yield (kg ha^{-1} mm^{-1}), ET_L:crop evapotranspiration level(mm), RS: Row spacing (cm).

Considering the nitrogen dose as fixed (maximum dose) and the water amount applied (≈ETc), in which only the spacing varied (40, 70 and 100 cm), it was noted that the highest water use efficiency was obtained in the intermediate spacing (Figure 6), with a value of 4.7 kg ha^{-1} mm^{-1}. Ranging the spacing between 40 and 100 cm, increasing 10 cm and fitting and deriving a model to the data, as to obtain the maximum point, it was observed that the highest efficiency was achieved for the 60 cm spacing, with a value of 4.83 kg ha^{-1} mm^{-1}. From the WUE_Y point of view, this value is the most suitable

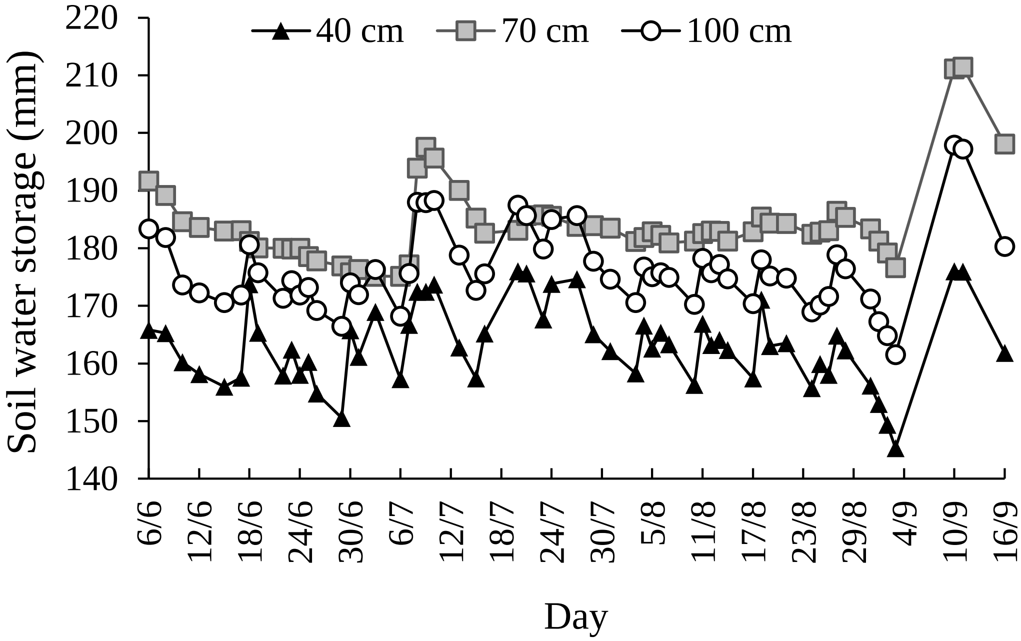

Figure 3. Total soil water (mm) in the 0-1.0m layer for cotton plant grown under different spacing between rows in a *Cerrado* Oxisol in 2015.

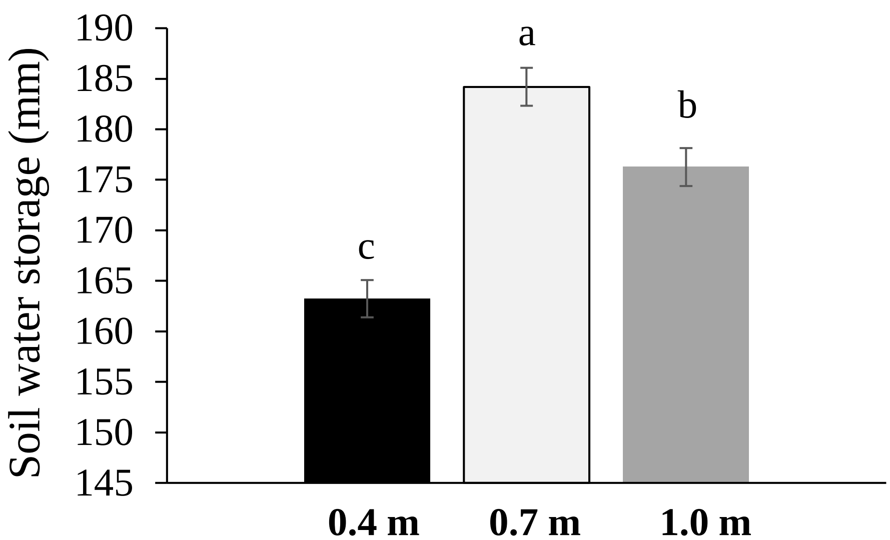

Figure 4. Soil total water mean (mm) in the 0-1.0m layer of cotton plant grown under different row spacings in a *Cerrado* Oxisol in 2015. Bars indicate mean confidence interval (α = 0.05). Means with different letters indicate statistical difference (α = 0.05).

spacing for cotton planting in a condition in which the water amount applied is equal to 90% ETc, considering the fixed nitrogen dose.

The maximum WHE_Y value found was within the limits described by FAO to several cultures (Sadras et al., 2007). For cotton plant, values are of kg ha^{-1} mm^{-1}. Zonta et al. (2015) found values of 6.9 kg ha^{-1} mm^{-1}, considering 100% ETc irrigation. Regarding shoot dry matter (Figure 7), with the same conditions described above, the following model was obtained:

$$WUE_{DM} = 7.967 - 1.351 ET_L + 1.050 N_L - 1.461 RS - 2.136 RS^2 \qquad R^2 = 0.60 \tag{4}$$

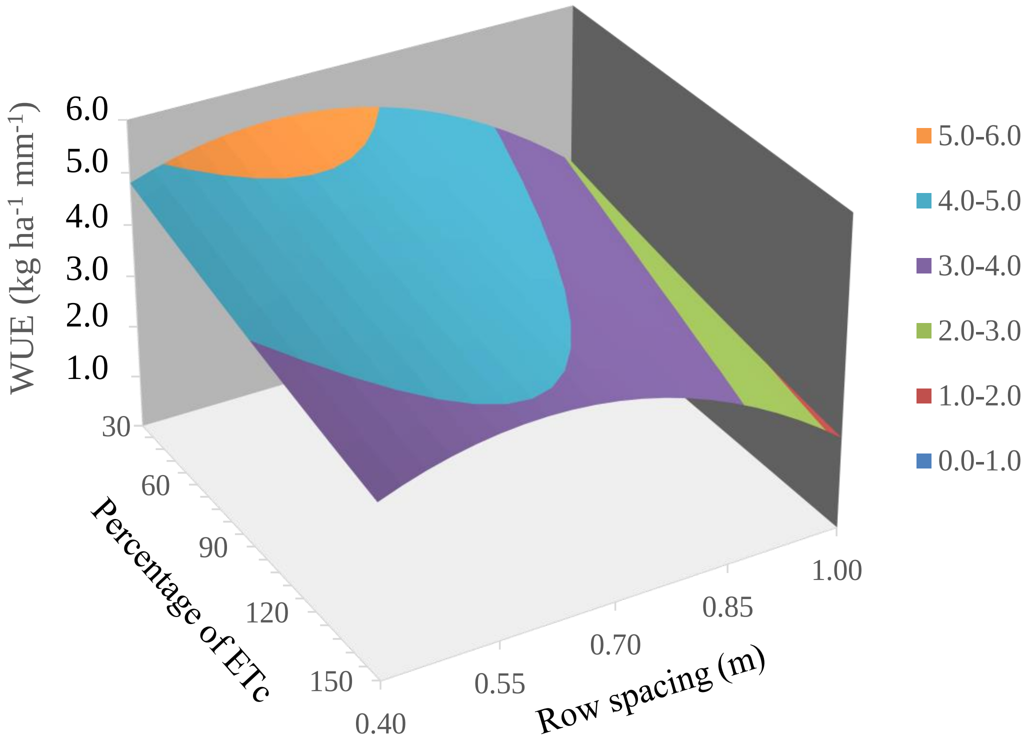

Figure 5. Water use efficiency for seed cotton yield (kg ha^{-1} mm^{-1}) according to crop evapotranspiration levels (mm) and crop spacing, with fixed nitrogen dose a *Cerrado* Oxisol in 2015.

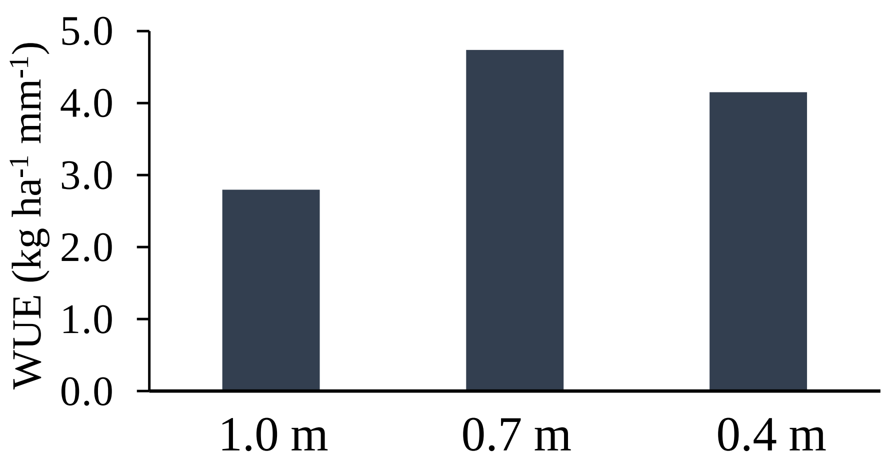

Figure 6. Seed cotton yield water use efficiency (kg ha^{-1} mm^{-1}) according to crop spacing, grown in a *Cerrado* Oxisol in 2015.

Where: WUE_{DM}: Shoot dry matter water use efficiency (kg ha^{-1} mm^{-1}), ET_L: Crop evapotranspiration level (mm), RS: Row spacing (cm).

Considering the same analysis aforementioned, WUE_{DM} values were 8.3, 9.0 and 5.4 ha^{-1} mm^{-1} for spacing of 40, 70 and 150 cm (Figure 8). Adequate spacing was 60 cm again, with 9.6 kg ha^{-1} mm^{-1} WUE_{DM}.

Conclusions

(1) In denser spacing (0.4 m), soil moisture is lower in the soil deeper layers (> 0.6 cm) compared to larger spacing.
(2) Cotton plant grown in conventional spacing (1.0 m) has lower water use efficiency for seed cotton yield compared to the denser system (0.7 and 0.4 m).

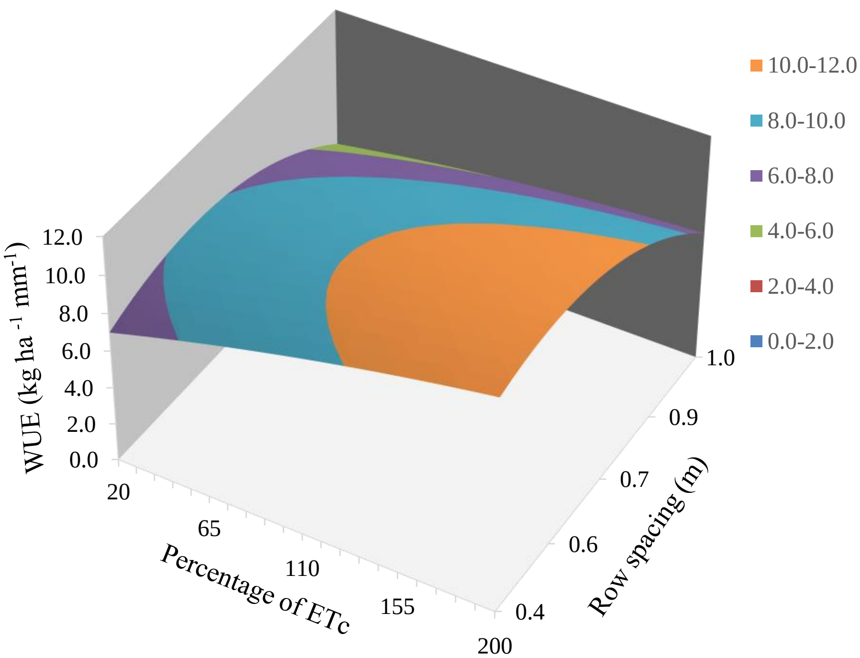

Figure 7. Shoot dry matter water use efficiency (kg ha^{-1} mm^{-1}) according to crop evapotranspiration levels (mm) and crop spacing, with fixed nitrogen dose, in a *Cerrado* Oxisol in 2015.

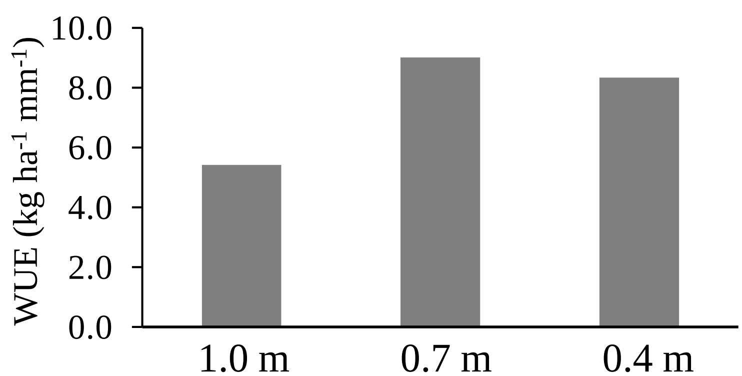

Figure 8. Cotton plant shoot dry matter water useefficiency (kg ha^{-1} mm^{-1}) according to crop spacing grown in a *Cerrado* Oxisol in 2015.

(3) Higher cotton plant water use efficiency can be obtained in intermediate spacing, 0.6 m.

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES

Allen RG, Pereira LS, Raes D, Smith M (1998). Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56. Rome-Italy. 297 pp.

Belót JL Vilela PA (2010). O Sistema de Cultivo doAlgodoeiro Adensado em Mato Grosso: embasamento e primeiros resultados. Cuiabá: Defanti Editora. pp.13-19.

Box GEP, Draper NR (1987). Empirical Model-Building and Response Surfaces. Wiley.

EMBRAPA. EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. (2013). Sistema brasileiro de classificação de solos. Brasília, 353 pp.

EMBRAPA. EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA (1997). Manual de métodos de análise de solo. Rio de Janeiro, 212p.

Farahani HJ, Oweis TY, Izzi G (2008). Crop coefficient for drip-irrigated cotton in a Mediterranean environment. Irrigation Sci. 26(5):375-383.

Food and Agriculture Organization of the United Nations, FAOSTAT database (FAOSTAT, 2015), available at http://faostat3.fao.org/home/E

Hu XT, Chen H, Wang J, Meng XB, Chen FH (2009). Effects of soil water content on cotton root growth and distribution under mulched drip irrigation. Agric. Sci. China 8:709-716.

Khoshravesh M, Sefidkouhi MAG, Valipour M (2015). Estimation of reference evapotranspiration using multivariate fractional polynomial, Bayesian regression, and robust regression models in three arid environments. Appl. Water Sci. pp. 1-12.

Papastylianou PT, Argyrokastritis IG (2014). Effect of limited drip irrigation regime on yield, yield components, and fiber quality of cotton under Mediterranean conditions. Agric. Water Manag.142:127-134.

Sadras VO, Grassini P, Steduto P (2007). Status of water use 877 efficiency of main crops. SOLAW Background thematic report-TR-07.

Sousa DMG, Lobato E (2004). Cerrado: correção do solo e adubação**.** 2. ed. Brasília: Embrapa Informação Tecnológica.

Valipour M (2012a). Sprinkle and Trickle Irrigation System Design Using Tapered Pipes for Pressure Loss Adjusting. J. Agric. Sci. 4(12):125-133.

Valipour M (2012b). Determining possible optimal values of required flow, nozzle diameter, and wetted area for linear traveling laterals. Int. J. Eng. Sci. 1(1):37-43.

Valipour M (2012c). Scrutiny of Pressure Loss, Friction Slope, Inflow Velocity, Velocity Head, and Reynolds Number in Center Pivot. Int. J. Adv. Sci. Technol. Res. 2(5):703-711.

Valipour M, Eslamian S (2014). Analysis of potential evapotranspiration using 11 modified temperature-based models. Int. J. Hydrol. Sci. Technol. 4(3):192-207.

Valipour M (2014a). Variations of irrigated agriculture indicators in different continents from 1962 to 2011. Adv. Water Sci. Technol. 1(1):1-14.

Valipour M (2014b). Handbook of irrigation engineering problems. OMICS Group eBooks, Foster City. http://www.esciencecentral.org/ebooks/handbook-of-irrigation-engineering-problems/handbook-of-irrigation-engineering-problems.pdf

Valipour M (2014c). Handbook of water engineering problems. OMICS Group eBooks, Foster City. http://www.esciencecentral.org/ebooks/handbook-of-water-engineering-problems/pdf/handbook-of-water-engineering-problems.pdf

Valipour M (2014d). Assessment of different equations to estimate potential evapotranspiration versus FAO Penman Monteith method. Acta Adv. Agric. Sci. 2(11):14-27.

Valipour M (2014e). Handbook of hydrologic engineering problems. OMICS Group eBooks, Foster City.http://www.esciencecentral.org/ebooks/handbook-of-hydrologic-engineering-problems/handbook-of-hydrologic-engineering-problems.pdf

Valipour M (2014f). Handbook of hydraulic engineering problems. OMICS Group eBooks, Foster City. http://www.esciencecentral.org/ebooks/handbook-of-hydraulic-engineering-problems/handbook-of-hydraulic-engineering-problems.pdf

Valipour M (2014g). Analysis of potential evapotranspiration using limited weather data. Applied Water Science.

Valipour M (2014h). Application of new mass transfer formulae for computation of evapotranspiration. J. Appl. Water Eng. Res. 2(1):33-46.

Valipour M (2015a). What is the tendency to cultivate plants for designing cropping intensity in irrigated area? Adv. Water Sci. Technol. 2(1):1-12.

Valipour M (2015b). Calibration of mass transfer-based models to predict reference crop evapotranspiration. Appl. Water Sci. pp. 1-11.

Valipour M (2015c). Evaluation of radiation methods to study potential evapotranspiration of 31 provinces. Meteorol. Atmospher. Phys. 127(3):289-303

Zhao C, Yan Y, Yimamu Y, Li J, Zhao Z, Wu L (2010). Effects of soil moisture on cotton root length density and yield under drip irrigation with plastic mulch in aksu oasis farmland. J. Arid Land. 2:243-249.

Zonta JH, Bezerra JRC, Sofiatti V, Brandão ZN (2015). Produtividade de cultivares de algodoeiro herbáceo sob diferentes lâminas de irrigação no semiárido brasileiro. Revista Brasileira de Engenharia Agrícola e Ambiental. 19(8):748-754.

Zhou XB, Yang GM, Sun SJ, Chen YH (2010): Plant and row spacing effects on soil water and yield of rainfed summer soybean in the northern China. Plant Soil Environ. 56:1-7.

Zhou XB, Chen YH, Ouyang Z (2010). Effects of row spacing on soil water and water consumption of winter wheat under irrigated and rainfed conditions. Plant Soil Environ. 57(3):1-7.