USING AQUACROP FOR CROP BEAN ACCORDING TO DIFFERENT DEPTH IRRIGATION

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SUMMARY: The simulation software of growing crop and its development have been used by technician and researches aiming to avoid loses on the field and for studying how improve crop yield. The crop bean is very cultivated and consumed in Brazil that generates opportunity to simulate its growing using the AquaCrop in Brazilian climate and soil. The aim of this study was to analyze the response of AquaCrop when it was set for conditions of planting, environment and irrigation. We observed that the simulated results were statistically close to results taken in the field, but biomass and hydric balance showed bigger differences than the observed results. In the present study, the resemblance between simulated and observed results for most of the analyzed variables showed that AquaCrop fits satisfactorily the growth of crop bean. However, we suggest that more studies should be conducted to endorse the results in Brazilians climate and soil conditions. In conclusion, AquaCrop can be used to simulate the growth of crop bean in Brazilian environmental conditions.

KEY-WORDS: management, water use efficiency, production function.

UTILIZAÇÃO DO AQUACROP PARA A CULTURA DO FEIJÃO DE ACORDO COM DIFERENTES REGIMES DE IRRIGAÇÃO

RESUMO: A simulação do crescimento e desenvolvimento de plantas em softwares tem sido usada por técnicos e pesquisadores em busca de evitar perdas no campo e como fonte de estudo para melhorar produtividade. A cultura do feijão é muito cultivada e consumida no Brasil, gerando assim a necessidade de simular o crescimento desta usando o AquaCrop de acordo com as condições de clima e solo brasileiros. O objetivo deste estudo foi analisar a resposta do AquaCrop quando configurado para a condições de plantio, ambiente e irrigação locais. Observamos que os resultados simulados foram estatisticamente próximos dos resultados obtidos no campo, mas a biomassa e o balanço hídrico mostraram uma maior diferença entre

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os resultados observados e os simulados. No estudo presente, a semelhança entre os resultados observados e simulados para a maioria das variáveis analisadas mostraram que o AquaCrop foi satisfatório na simulação do crescimento do feijão. No entanto, sugerimos que mais estudos sejam conduzidos para maior provimento das informações. Em conclusão, o AquaCrop é uma ferramenta adequada para simulação do crescimento do feijão sob condições ambientais brasileiras.

PALAVRAS-CHAVE: manejo, eficiência do uso da água, função de produção.

INTRODUCTION

The AquaCrop is a software used to simulate growth and productivity of a crop in particular conditions. Computational model is based on an equation proposed by Doorenbos & Kassam (1979) for estimating crop development according to transpiration, presenting a direct relationship among factors evolved in the process (Steduto et al., 2012).

The equations used in the program are significant on studying outcome of growth under different conditions, involving food security, planning and management of crop, risks on productivity loses due to nutritional stress, or pest or disease (Holzworth et al., 2015).

For simulating growth process of a crop, some variables are required by the software (e.g., field capacity, permanent wilting point, hydraulic conductivity at saturation, readily evaporable water) as well as minimum deep evaporation without restriction (Allen et al., 1998). Additionally, some crop indexes are used, like KcTR, that is the transpiration coefficient when canopy cover is full, which means the last stage before senescence; CCo that represents canopy cover when 90% of the crop are emerged; CGC that represent crop growth after CCo and before the flowering; and, CDC, which is used when senescence takes place (Steduto et al., 2012).

The crop bean is economically important to Brazil, because it is consumed in whole country. It has a growth period nearly by 90 days (Heinemann et al., 2009), and it needs so much water and nutrients (Santos et al., 2015). Also, crop bean has social importance in Brazil, since it is more cultivated by smaller and medium farmers than the bigger ones.

Thus, the aim of this study was simulating the growth of crop bean using the software AquaCrop as well as analyzing the coefficients were observed, and compare the simulated yield with data observed on the field.

MATERIALS AND METHODS

Crop bean was cultivated between July and October 2015 at the Experimental Farm of Coimbra – MG, Brazil, of Federal University of Viçosa, located at Zona da Mata of Minas Gerais, at coordinate 20° 45’ S 42° 5’ W, with 698 m of altitude.

The soil had clay texture. The field capacity was 0.435 cm^3 cm^{-3}. Permanent wilting point was 0.228 cm^3 cm^{-3} and hydraulic conductivity was 236.1 mm day^{-1}. For AquaCrop simulations, we considered two soil layers, ranging between 0.20 and 0.40 m, which is considered as effective zone of deep root. REW was 12 mm. The soil and water did not have issues of salinity, once electrical conductivity was 0,058 dS m^{-1}.

The planting method was direct sowing, using 14 seeds per meter. On seeding, we used NPK fertilizing (nitrogen, phosphorus, and potassium) in a proportion of 8-28-16, and in a dosage 348 kg ha^{-1}. Before the flowering, urea was used in dosage of 200 kg ha^{-1}.

We applied four different depth irrigations during crop cycle: D1 = 239 mm; D2 = 310 mm; D3 = 322 mm e D4 = 386 mm. The irrigation was behind the central pivot that had an intensity of application of 2 mm h^{-1}. We did not observe run-off during the irrigations.

The management of needed water by crop bean was determined using local climate and the evapotranspiration math presented by Allen et al. (1998). The moisture was periodically observed.

The climate data was obtained by a meteorological station disposed in the experimental field for recording maximum, average, and minimum daily temperatures (°C) as well as solar radiation (W m^{-2}), average relative humidity (%), speed wind (m s^{-1}), and rain (mm).

The leaf index area and dry biomass was periodically measured. The Equation 1, which was proposed by Hsiao et al. (2009), was used for math canopy cover using the leaf index area data.

The simulation was made on software AquaCrop, version 4.2 of June 2012. For the input climate data on software during the crop, we used another software, EToCalculator. On data of management crop, soil have been covered with 90% of organic mulches.

For culture data, minimum root deep was 0.10 m and maximum of 0.40 m; base temperature was 10°C and maximum of 30°C; Kc_{TR} was 1.10; effect of high temperature on pollination was 32°C as a maximum limit; and there was no problem with salinity on experimental field. Initially, we do not take any adjust in productivity index and culture grow.

The conservative parameters that we do not know was estimated on simulation using the method of trying and error having as a support the data observed on field of biomass, canopy cover and productivity.

Additionally, we evaluated two types of water productivity index that do the ratio between yield and water supply. The first one was IWP (Irrigation Water Productivity), that mean the ratio between productivity and irrigation. The second was EWP, the ratio between productivity and evapotranspiration (Ali & Talukder, 2008). To the statistical analysis, we used the modelling of efficiency (Ef), root mean square error (RMSE) by Loague & Green (1991), and agreement index (d), proposed by Willmott (1982).

RESULTS AND DISCUSSION

The average maximum temperature for August, September and October 2015 was, respectively, 26.4, 28.3 e 31.4°C; the average minimum temperature, at the same order, was 11.5, 15.8 e 17.1°C; the average solar radiation for August was 120.3 W m^{-2}, in September was 126.2 W m^{-2} and in October was 157.8 W m^{-2}. The values of solar radiation for the first two months are low for the crop.

The crop evapotranspiration of August, September and October, according to Allen et al. (1998) method, presented average of 2.28 mm day^{-1} to August, 2.68 mm day^{-1} in September and 3.65 mm day^{-1} in October.

On Table 1 is observed the quantity of water supply in each deep applied, including rain that run off (ineffective rain) and the rain that can be used by plants on soil (effective rain).

The soil moisture was observed in each treatment and compared with the AquaCrop estimated, as showed in Figure 1.

The treatment D4 presented higher efficiency and agreement index, and the D2 showed lower error with simulated data, being closer of value estimated by software and agreeing with the AquaCrop data. The treatment D4 presented greater variation between observed and simulated data because higher deep water applied and then evapotranspirometric demand.

Adjusts made about local conditions of the field and of each irrigation on AquaCrop resulted index presented on Table 2. They were different than observed values of productivity and yield crop, knowing crop had a differential response for each deep irrigation treatment.

The ratio of potential biomass with real one varied in 86 and 77%. Notice biomass and productivity was according water applied in each treatment.

The growing degrees observed on software were 980°C (Table 2) because of relative low temperatures in two of the three months. Renato (2013) showed growing degree for crop bean 1300°C for the same experimental field that this experiment was realized, but in another season of the year with higher temperatures.

The transpiration was different among treatments because the quantity of water applied and available to the plants. In D4, besides received higher deep water, have lower transpiration than D3, because the plant have a maximum capacity of transpiration according irrigation. The average daily transpiration agreed with showed by Ogindo & Walker (2004), where was evaluated transpiration efficiency in bean.

The water was infiltrated and drained, had greater retention in D4 treatment. This is reflected on water productivity index when irrigation (IWP) and irrigation plus rain (WP) (Table 3) are considered, having a balance between observed productivity and water applied.

The EWP was proportional to deep irrigation, because the water available on soil supports the transpiration and evaporation, however, this is a linear ratio. When the plant is in your maximum grow stage, more water applied is exceeded and it is not used by plant, even in other cases can favor the vegetative grow plant and this flowering late, doing greater biomass production but less grain production (Ali & Talukder, 2008).

The yield of the plants observed on this study agrees with Hegab et al. (2014). Those authors observed high productivity index in plants with low water available.

The crop bean has a positive response when the water stress is applied in correct moment. Depending how the stress is applied, the plant could have a positive response when the stress is made gradually or can be negative when it is made suddenly (Ali & Talukder, 2008). The plants on D1, which suffered water stress, did not present great productivity compared to other treatments (D2 and D3), but the plants consumed water as high as the other treatments.

The productivity index (WP) showed greater values on D3 and D4, the crop presented high yield according to high deep water applied water.

The bean flowering stage required high amount of water for effective yield. However, if the stress occur on vegetative stage close to flowering, the answer could be positive for the plant and for enjoying water applied, because on that stage, the plant do not suffer so much with low water available on soil (Santos et al., 2015).

The CCo and CGC were similar between the treatments because, in the beginning of the grow crop, we applied the same quantity of water until appear the “real leafs” (when the cotyledons leave) and the rain occurred on this phase. The plants grew equally until we applied the differential deep irrigations.

The CGC and biomass was greater than Yuan et al. (2013) but the grain production showed lower results. The CDC was smaller than simulated value. The bean study by this authors had the CDC lower than the CDC simulated, consequently the bean had a maturity and senesce longer than bean studied on this research.

The comparison of crop growth using simulated and observed data of canopy cover of each treatment is showed on Figure 2.

The observed biomass presented different behavior from simulated ones. The program considers accumulation and crescent biomass but the biomass decreased because some leafs fell and some parts of plant became dry, including the grains.

CONCLUSION

The AquaCrop is helpful on study of crop grow on field according to different conditions, in this case, for crop bean.

For canopy cover, we observed agreement between estimated model growths, proposed by the program, and observed on field through the equation tested.

For the soil moisture, we observed more variance between observed results and simulated ones by the program.

To Brazilian conditions, it is needed more studies and adjusts of AquaCrop to another culture and climate conditions.

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Table 1. Quantity irrigation applied, ineffective rain, effective rain, and total water supplied.

Deep Irrigation	Water applied by irrigation (mm)	Ineffective Rain (mm)	Effective rain (mm)	Total water supply (mm)
D1	175.8	83.7	63.2	322.7
D2	256.0	93.5	53.4	402.9
D3	272.3	97.3	49.6	419.2
D4	345.9	106.9	40.0	492.8

Table 2. AquaCrop index for simulation adjust of grow and productivity crop bean in local field conditions and in each deep irrigation.

Parameters	D1		D2		D3		D4	
	Obs.	Est.	Obs.	Est.	Obs.	Est.	Obs.	Est.
Biomass (kg ha^{-1})	4976	4968	5033	5062	6620	6641	6699	6687
Potential Biomass		6413		5879		7712		8284
Productivity (kg ha^{-1})	2160	2137	2437	2427	3355	3340	3421	3454
GD (°C)[1]		980.2		980.2		980.2		980.2
Evaporation (mm day^{-1})		38.3		45		38.3		38.3
Transpiration (mm day^{-1})		116.8		141.3		150.5		141.7
Deep Irrigation (mm)		312.6		383.6		401.6		464.6
Drainage (mm)		167.6		196.2		210.1		276.5
EWP (kg m^{-3})[2]		1.38		1.40		1.77		1.93
WP (g m^{-2})[3]		11.0		9.9		12.0		12.8
HI (%)[4]		43.0		48.4		50.3		51.7
CCo (%)[5]		1.32		1.21		1.25		1.29
CGC (% day^{-1})[6]		15.2		15.4		15.0		15.3
CDC (% day^{-1})[7]		20.3		17.9		12.0		12.2

[1]GD: growing degrees; [2]EWP: evapotranspiration water productivity; [3]WP: yield grain per water applied to the field; [4]HI: harvest index; [5]CCo: canopy size of the average seedling at 90% emergence; [6]CGC: canopy grow coefficient; [7]CDC: canopy decline coefficient.

Table 3. Productivity index of quantity water supplied on irrigation (IWP) and irrigation plus rain (WP).

Treatments	IWP (kg ha^{-1} mm^{-1})	WP (kg ha^{-1} mm^{-1})
D1	13.03	6.90
D2	13.56	9.90
D3	14.58	8.89
D4	12.33	8.05

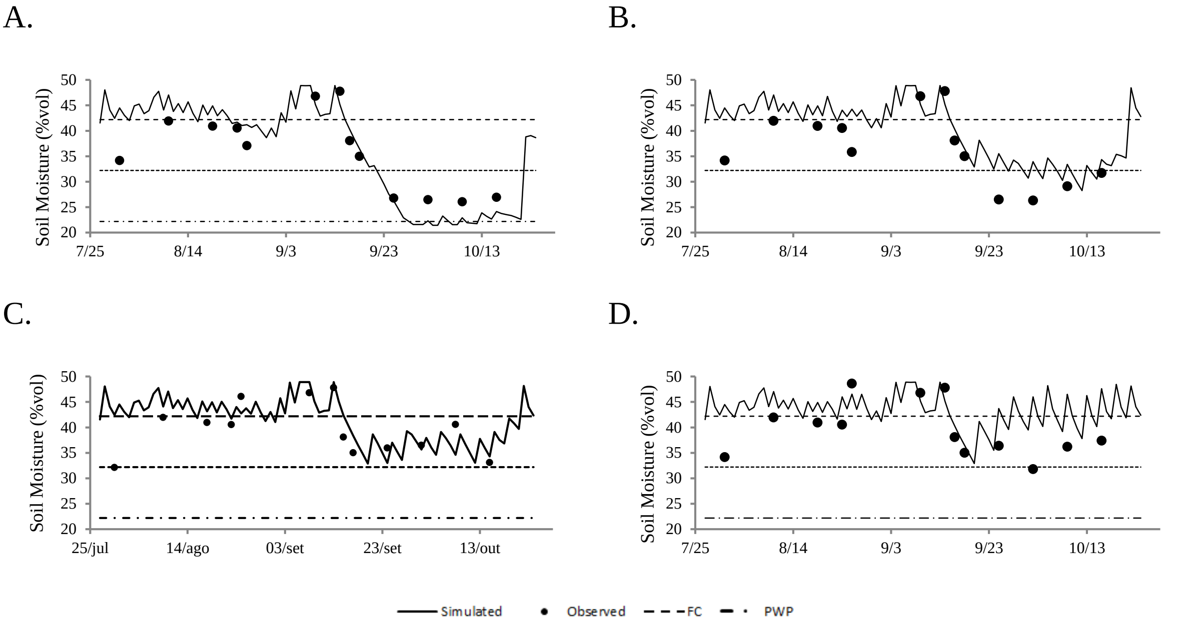

Figure 1. Soil moisture observed and simulated by AquaCrop on different deep irrigation D1 (A), D2 (B), D3 (C) e D4 (D).

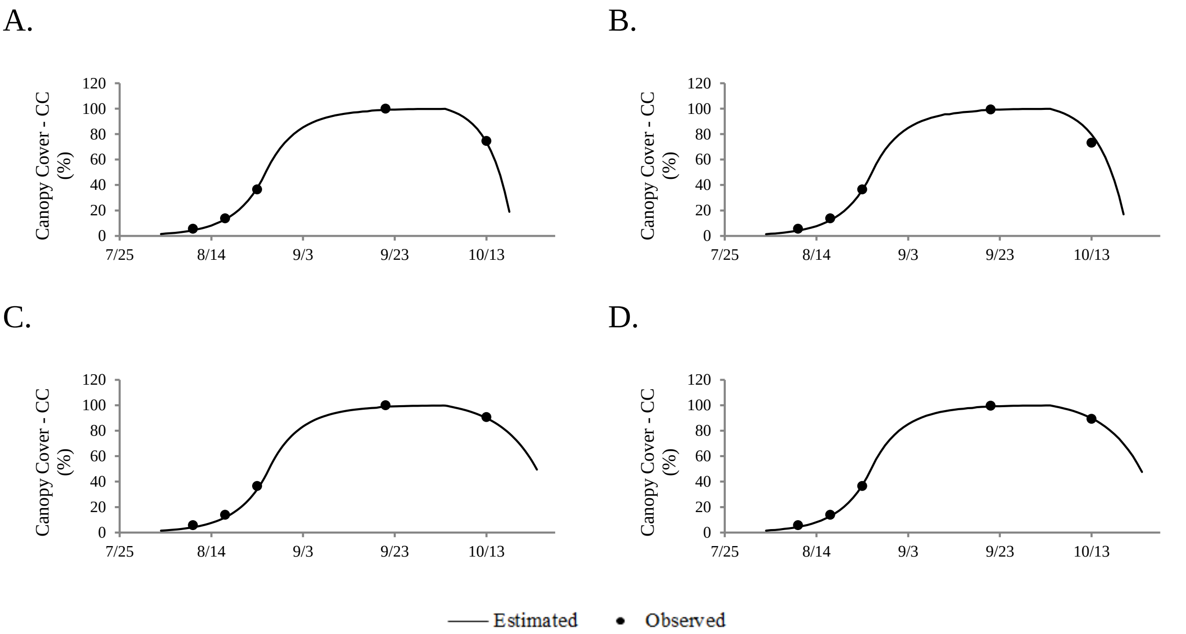

Figure 2. Canopy cover simulated and observed on deep irrigation D1 (A), D2 (B), D3 (C) and D4 (D).