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USING AQUACROP TO SIMULATE TRANSPIRATION VARIABILITY UNDER WATER STRESS CONDITIONS

UTILISATION DU LOGICIEL AQUACROP POUR LA SIMULATION DE LA TRANSPIRATION SOUS UNE IRRIGATION DEFICITAIRE

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ABSTRACT

The objective of the present study was to calibrate and validate Aquacrop model under the semi arid condition of central Tunisia. Field experiments from two consecutive years were considered to test the efficacy of a preliminary calibration procedure in simulating water contents (Ɵv), canopy cover (CC) and transpiration. Statistical indicators for root mean square error (RMSE), Mean Bias Error (MBE), Nasch coefficient (E) and evidenced that model predictions were good under non stressed plots and acceptable for stressed treatment in simulating the temporal dynamic of the canopy cover. Soil water contents and transpiration varied in the same range of measured values. However, the model in general underestimated the measured values of cumulative transpiration. This underestimation was accentuated in the end of the growth season and for higher values of reference transpiration. Results allowed describing basic calibration procedure for Aquacrop model in order to determine accurate estimation of the dynamic of water status on soil and the plant, allowing by the fact to avoid high sophisticated monitoring and high costly tools measurements.

Keywords: Deficit irrigation, Potato, modeling, semi-arid climate, transpiration, modeling, water balance.

RESUME

L'objectif de la présente étude était de calibrer et de valider le modèle Aquacrop sous un climat semi-aride du centre de la Tunisie. Des expériences menées sur deux années consécutives ont été considérées pour tester l'efficacité d'une procédure préliminaire de calibration, pour la simulation des teneurs en eau, des couvertures végétales et de la transpiration. Les indicateurs statistiques pour l'erreur quadratique moyenne, la marge moyenne d'erreur et le coefficient de Nasch ont montré que les prédictions du modèle étaient bonnes pour les traitements non stressées et acceptables pour les traitements stressés. La teneur en eau du sol et la transpiration variaient dans la même gamme des valeurs mesurées. Cependant, le modèle sous-estime généralement les valeurs mesurées de transpiration cumulative. Cette sous-estimation s'est accentuée à la fin de la saison de croissance et pour des valeurs élevées de transpiration de référence. Les résultats ont permis de décrire une procédure de calibration basique du modèle Aquacrop afin de reproduire la dynamique du statut hydrique dans le sol et le tissu végétal. Cette calibration permet d'éviter des mesures coûteuses et complexes pour le suivi de l'état hydrique dans le continuum sol plante atmosphère.

Mots clés : irrigation déficitaire, pomme de terre, climat semi-aride, transpiration, modélisation, bilan hydrique

INTRODUCTION

In Most of arid and semi-arid countries, the problem of water scarcity is in a continuous accentuation since drought events are longer and more frequent (Douh et al., 2012). Future projections prédict even a deeper effect of water stress in the coming years (Bhouri Khila et al., 2015). However, irrigation is compulsory to intensify the production and to meet the food needs of a growing population (Zella et al., 2007). With the incresing pressures on non agricultural water, it is crucial to increase water use efficiency of strategic crops (Bhouri Khila et al., 2016) so to produce more with less water. Because of their superficial roots, potatoes are quite high sensitive to water stress (Fulton, 1970). Producing a drought sensitive plant with limited water availability was the interest of many scientific researches, especially with the increasing scarce availability of water resources. According to Rijtema and Aboukhaled (1976), small water deficits lead to a stomata closure, inducing a reduction of the transpiration. Many reports indicated that the relatively shallow root system of potatoes plays an important role in that sensitivity (Van Loon, 1981, Fulton, 1970, Boone et al., 1978). The rooting depth or intensity determines the depth and the volume in which potatoes can extract water from the soil. In Tunisia, considerable efforts are implemented to produce more with less water. However, deficit irrigation was not yet experimentally tested for the semiarid climate of the Tunisian environment. Moreover, several researchers consider deficit irrigation difficult to manage because of the rapid effect of water stress on tuber yield (Eldredge et al., 1996; Shock et al., 1993, Wright and Stark, 1990). In that context, model simulations after being calibrated and validated could be adopted as a management tool for testing the impact irrigation strategies, avoiding real field stress effects (Droogers and Hunink, 2012). The AquaCrop model allows investigating the effect of a biotic stress on transpiration and crop yield (Farahani et al., 2009). Several researchers have found satisfactory results with Aquacrop when simulating the effect of different soil humidity on plant growth and production for many crops like sunflower, beans, winter wheat and tomato (Karunaratne, 2009). According to Farahani et *al.* (2009), Aquacrop is a simple model for calibration and validation. Therefore, it does not need skilled researchers. This procedure is considered easier especially with the existing set of default parameters by hsiao et *al.* (2009). These default parameters overcome the influence of geographical site and crop cultivar (Steduto et *al.*, 2009). Some researchers suggested even to not adjust these parameters since their modulation is dependent on the stress function. Aquacrop transpiration predection have been used for many crops including potato. Both Heng et al. (2009) and Hsiao et al. (2009) suggested that Aquacrop is able to simulate crop development and transpirationss under non stressed conditions. However, other studies like the one of Katerji et *al.*, 2013concluded that model performance decreases in case of environmental stress conditions. The main objective of this paper is to assess the calibration and validation of Aquacrop model to simulate transpiration variability under full and deficit irrigation. In that context, the values of the input parameters are retrieved from literature for water stress functions and from measurements for root dynamic, canopy cover and soil characteristics.

MATERIAL AND METHODS

Field experiments and irrigation management

Field Experiments were conducted at the High Agronomic Institute of Chott Meriem, Sousse, Tunisia (longitude 10.5632° W; latitude 35.9191° N, altitude

19.0 m a.s.l.). The climate of the study area is classified as semi-arid, with hot and dry summer and mild-rainy winter seasons. In 2014 and 2015, tuber seeds of the same potatoes cultivar (Solanum Tuberosum L., cv. Safran), were planted on January, 15th and on January, 22nd, respectively, at distance of 0.40 m along the row and 0.80 m between the rows, in an experimental plot, 25 m length and 7 m wide. The experimental plot was divided in two subplots (treatments T1, T2) subjected to similar seasonal management, except for irrigation doses. Figure 1 presents the cumulated values of irrigation for treatment T1 and T2 for the experimental season of 2014 and 2015. This figure shows also cumulated value of precipitation and reference evapotranspiration. Values of precipitation were recorded from a climatic station, allowing also the measurements of maximum and minimum temperature, solar radiation, wind speed and relative humididty. From these values, reference evapotranspiration ET0 were calculated based on the FAO- Penmen Monteith equation (equation 1).

$$ET = \frac{\Delta(R_n - G_0) + 86400 c_p \rho_a \frac{(e_s - e_a)}{r_a}}{\lambda\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \quad (1)$$

Where ET [mm day^{-1}] is the evapotranspiration from a vegetated surface , λ [MJ kg] is the latent heat of vaporization , Δ [kPa °C^{-1}] is the slope of the saturated vapor pressure curve , R_n [MJ m^{-2} day^{-1}] represents the flow of net radiation, G_0 [MJ m^{-2} d^{-1}] is the flow of soil heat, e_s-e_a [kPa] is the air deficit pressure, γ [kPa °C^{-1}] is the psychrometric constant of air and, finally, $r_s$and r_a [s m^{-1}] are respectively the surface and aerodynamic resistances.

Tuber seeds were irrigated with a subsurface drip irrigation system characterized by a single 710 distribution pipe per plant row, installed at 0.20 m depth. Co-extruded drip emitters, spaced 0.40 m, discharged a flow rate of 3.5 l/h at nominal pressure of 100 kPa. Volumetric counters installed on the field allowing determining the exact provided irrigation doses. During the investigated growth season, values of water contents in the two treatments were monitored at different depths and positions from the emitter. Crop agronomic parameters mainly leaf area index, rooting depth and yield productions, were measured on three different plants in 2015 collected at different crop stages, from randomly chosen locations of each subplot, approximately every week and from one plant every two weeks in 2014. Leaf area index was converted to CC using the following formula (Heng et al., 2009):

$$CC = 1.005[1 - exp(-0.6LAI) \ ]^{1.2} \quad (2)$$

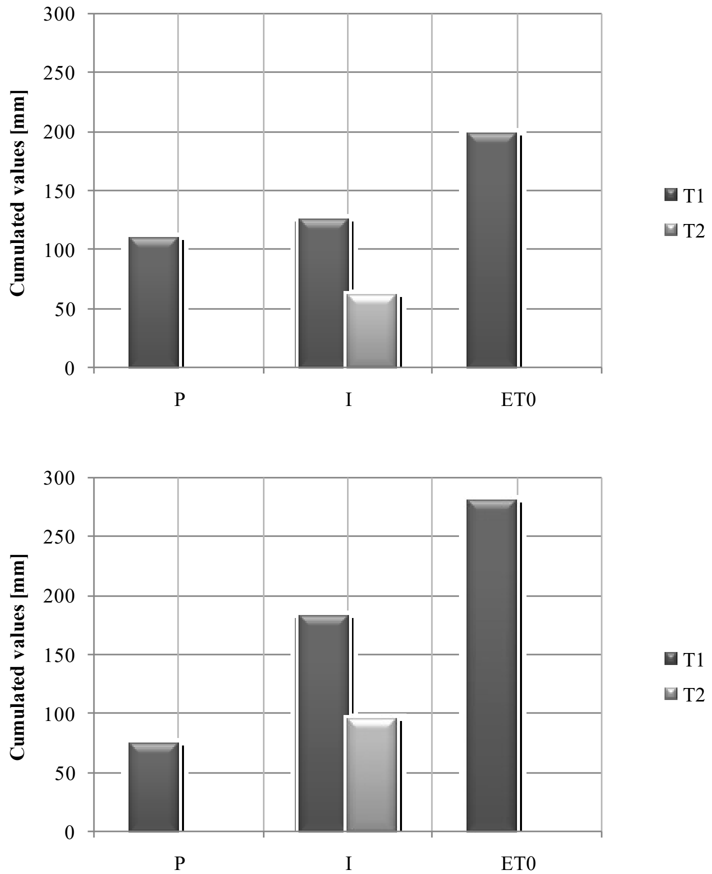


Figure 1 : Cumulated values of precipitation, P, irrigation, I, and reference evapotranspiration, ET0, for the experiments of 2014 and 2015

Calibration Procedure

The performance of Aquacrop for simulating field conditions was assessed taking into account. No fertility and salinity stress were considered. This late assumption was considered because the electrical conductivity of the irrigation water was equal to 1.4 $ds.m^{-1}$. Hence, simulations were restricted to investigate on the effect of two irrigation doses on canopy development, water contents and evapotranspiration fluxes. As sampling was more intensive in 2015, data from this year was used for Aquacrop calibration. However, data from 2014 was considered during the validation. For a first time, the calibration started with a comparison between simulated and measured canopy cover, *CC,* and water content *Θv* for full irrigation treatment. In a second time, a comparison between simulated and measured evapotranspiration were examined. For the days on which water contents were monitored, measured evapotranspiration were retrieved from the equation of water balance. Finally, the procedure involved a comparison between simulated and observed *CC*, *Θv* and transpiration for the deficit treatment. In general, measured data of crop growth and conservative parameters for potato (Hsiao, 2009) were assumed during this first step. An iterative process of simulations were investigated in order to adjust the most sensitive parameters, starting by testing the non conservative parameters and to leave unchangeable as much as the result of the absolute error, conservative parameters of Aquacrop. Operating as described, it was possible to calibrate the model mainly on the conservative parameters of Hsiao et al. (2009).

RESULT AND DISCUSSION

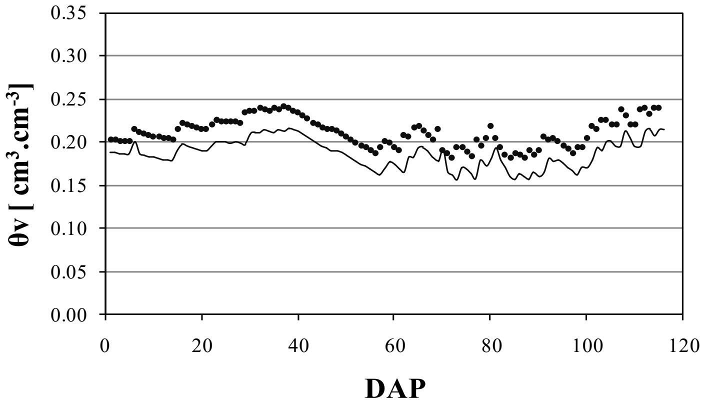
Simulation of soil water contents

For soil calibration, soil water characteristics including water content at field capacity, θ*fc* , water content at permenant wilting point, θ*pfp* and saturated hydraulic conductivity, K*s*, were introduced into the soil file according to values indicated on the table 1.

Table 1: Parameters of soil water retention curves according for the entire soil profile

Prameters	Values
θ*fc* [$cm^3.cm^{-3}$]	0.27
θ*pfp* [$cm^3.cm^{-3}$]	0.08
K*s* [$cm.h^{-1}$]	7.06

Figure 2 and Figure 3 present the dynamic of average water contents during the experimental seasons of 2015 and 2014. These data bases were used for the calibration and the validation of the temporal dynamics of soil water contents.



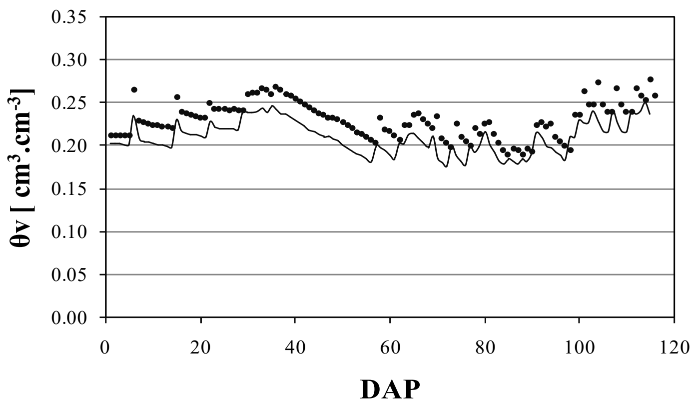


Figure 2: Dynamic of soil water contents for the experimental season of 2015 used for the calibration for treatments T1 (a) and treatment T2 (b)

As can be observed, simulated values of soil water contents followed the same trend of the measured ones. When comparing T1 and T2 treatments, it was observed that greater irrigation doses determined always higher water availability. However because of the lower atmospheric demand, observed on 2014, water contents resulted quite higher than 2015. In fact, for the first period, approximately till DAP 90, values ranged between 0.25 and 0.30 $cm^3.cm^{-3}$ for T1 compared to 0.20 and 0.30 $cm^3.cm^{-3}$ in the same period of same treatment during the experimental year of 2015.

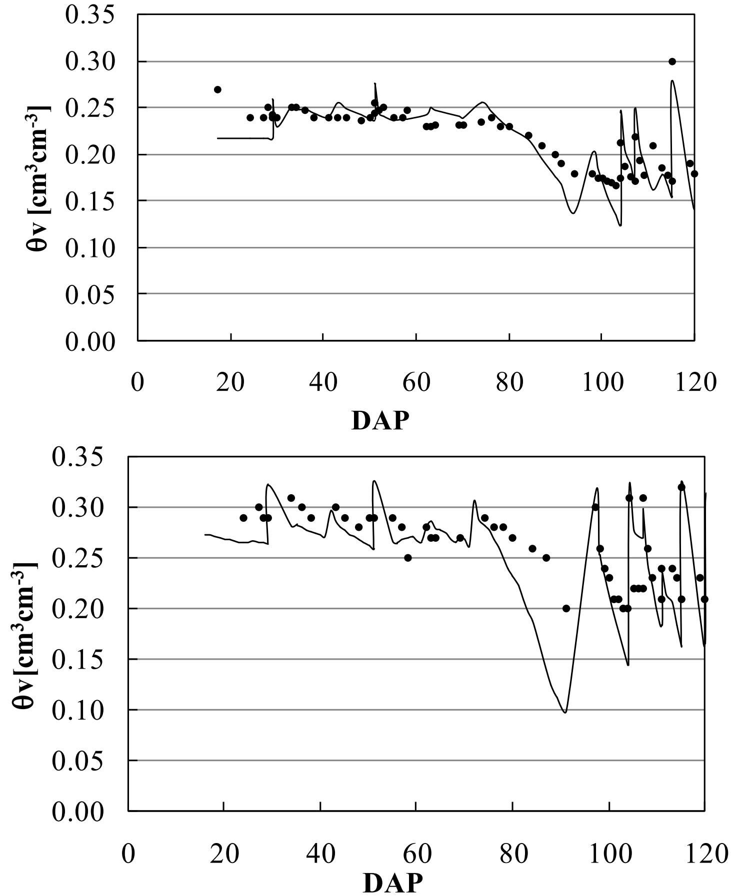


Figure 3: Dynamic of soil water contents for the experimental season of 2014 used for the calibration for treatments T1 (a) and treatment T2 (b)

Simulation of vegetative growth

Table 2 shows the parameters used for the vegetative growth simulations. These values were introduced into the crop file in order to reproduce the temporal dynamic of the canopy cover development. The rest of parameters in this function were introduced in accord to the default values of Aquacrop.

Table 2: Parameters for crop phenology

Crop phenology	Value	Sources
Time to emergence, GDD ^{NC}	322	m
Time to maximum rooting depth, GDD ^{NC}	956	m
Time to start tuber formation, GDD^{NC}	553	m
Time to harvest, GDD^{NC}	2324	m
Time to maximum canopy cover GDD^{C}	967	m
Time to tuber formation GDD^{C}	1748	m

m: measured; C: conservative; NC: non conservative; GDD: growing degree days

Table 3 shows the statistical indices of simulated canopy cover development used for the calibration and the validation process.

Moreover, when analyzing results from statistical indicators of the canopy cover predetions are presented in table 2. Based on that indicators, it depicts that simulated canopy cover could be retained to a certain extent acceptable since RMSE were in general lower than 6%. Moreover, RMSE values were higher under T2 than it was under T1 showing a better performance under full irrigation. Results from E were almost equal to one, confirming the aibility of the model to predict the vegetation development under the study area. These results are in agreement with the findings of Katerji et al. (2013) who found that Aquacrop model was able to reproduce field measurement of crop stress. According to these authors, better predictions were obtained under moderate stress level than it was under high stress level.

Table 3: Statistical indices of simulated canopy cover development for the calibration and validation dataset

	N	RMSE	E
		CALIBRATION	
T1	16	3.84	0.98
T2	16	5.54	0.95
		VALIDATION	
T1	8	5.86	0.96
T2	8	7.90	0.86

Simulation de la transpiration

Table 4 summarizes used the parameters used for the calibration of the stress function on Aquacrop. Figure 4 shows the trends of simulated and measured transpiration during the growth season of 2014 and 2015. As can be observed, for both investigated years, the model was able to reproduce the evolution of cumulated transpiration values with some underestimation. Similar to the Findings of Katerji et al. (2013), AquaCrop systematically underestimated the seasonal ET.

Table 4: Parameters for crop water stress

Water stress	Value	Sources
Upper threshold for canopy expansion [C]	0.41	CA
Lower threshold for canopy expansion [C]	0.21	CA
Upper threshold for stomata closure [C]	0.41	CA
Shape factor for stomata closure [C]	3.5	CA
Upper threshold for canopy senescence [C]	0.41	CA

CA: calibrated, C: conservative

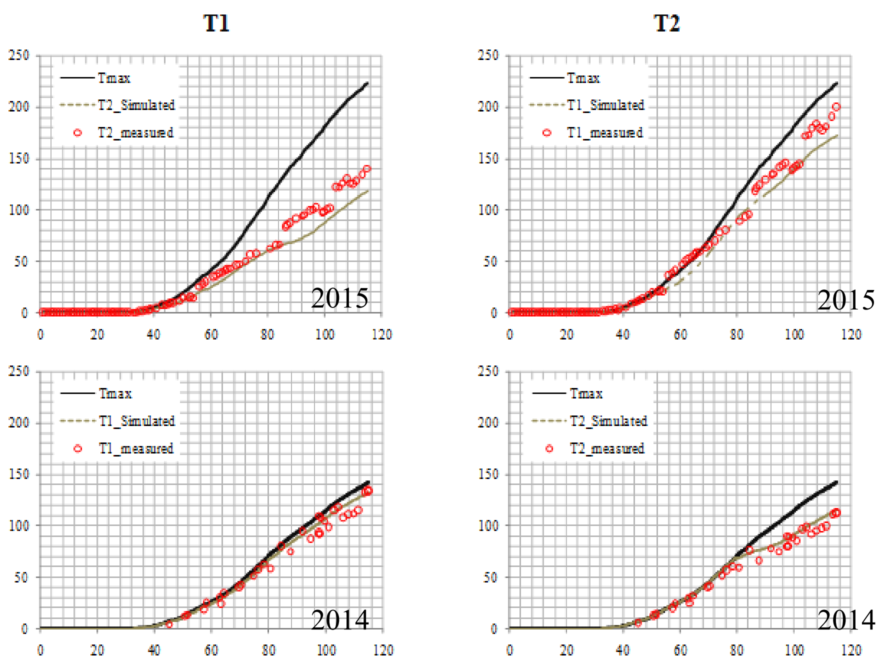


Figure 4: Simulated and measured transpiration for treatment T1 and T2 during the experimental years of 2015 and 2014.

Moreover, it is also remarkable that the deviations between simulated and measured cumulated transpiration generally increased as during the end of the vegetative growth. This result could be explained by the fact that, under semi-arid conditions, atmospheric demand widely increases from mid march till the end of august, so that the stress levels intensified. This observation is confirmed by the higher transpiration reduction observed on 2015 compared to 2014, in which reference evapotranspiration resulted lower. Katerji et al. (2013) reported that Aquacrop performance in reproducing field conditions is articulated on three factores; the species the stress level and the output variable. Results from that authors confirmed that Aquacrop showed poor aptitude in simulating the daily actual transpiration, when the plant was subject severe stress level. Heng et al. (2009) concluded also based on a comparison with field measured that Aquacrop showed good agreement only under fully irrigated treatment.

CONCLUSION

This study investigated on the calibration and validation of Aquacrop model to reproduce field measurement of canopy cover, soil water contents and transpiration fluxes. The followed calibration procedure is articulated around a set of values used as default parameters on Aquacrop. So the aim of the calibration procedure was to fix values that should be changed from the default set according either to field measurement or calibration to reproduce field measurement. Statistical indicators for root mean square error (RMSE), Mean Bias Error (MBE), Nasch coefficient (E) and evidenced that model predictions were good under non stressed plots and acceptable for stressed treatment in simulating the temporal dynamic of the canopy cover. Soil water contents and transpiration varied in the same range of measured values. However, the model in general underestimated the measured values of cumulative transpiration. Results allowed describing basic calibration procedure for Aquacrop to accurately describing water status on the soil and the plant. This procedure allows reproducing the temporal dynamic of soil and plant water status resulting on a better irrigation management.

REFERENCES

BHOURI KHILA S., DOUH B., MGUIDICHE A., BOUJELBEN A. (2015). Effet de la contrainte hydrique sur la productivité du blé dur en conditions climatiques semi arides de Tunisie, Larhyss Journal, No. 23, pp. 69-85.

BHOURI KHILA S., DOUH B., MGUIDICHE A., BOUJELBEN A. (2016). Efficience d'utilisation de l'eau de la culture de blé dur en conditions pluviales et irriguées en Tunisie, Larhyss Journal, No. 27, pp. 137-152.

BOONE F.R., BOUMA J., de SMET L.A.H. (1978). A case study on the effect of soil compaction on potato growth in a loamy sand soil: Physical measurements and rooting patterns. Netherland Journal of Agricultural Sciences, Vol 26, Issue 1, pp. 405–420.

DOORENBOS J., PRUITT W.O. (1977). Crop water requirements. In: FAO Irrigation and Drainage. FAO, Rome, Paper no. 24 (rev.)

DOUH B., CHEHAIBI S., ZOUAGHI M. (2012). Analyse diagnostique du maintien en état de fonctionnement des systèmes d'irrigation mécanisée par aspersion, Larhyss Journal, No. 11, pp. 47-61.

ELDREDGE E.P., HOLMES Z.A., MOSLEY A.R., SHOCK C.C., STIEBER T.D. (1996). Effects of transitory water stress on potato tuber stem-end reducing sugar and fry color. American Potato Journal, Vol 73, Issue 2, pp. 517-30.

FARAHANI H.J., IZZI G., OWEIS T.Y. (2009). Parameterization and evaluation of the AquaCrop model for full and deficit irrigated cotton. Agronomy Journal, Vol.101, Issue 2, pp. 469–476

FULTON J.M. (1970). Relationship of root extension to the soil moisture level required for maximum yield of potatoes, tomatoes and corn. Canadian Journal of Soil Sciences, Vol 50, Issue 2, pp. 92–94.

HENG L.K., HSIAO T., EVETT S., HOWELL T., STEDUTO P. (2009). Validating the FAO AquaCrop model for irrigated and water deficient field maize. Agronomy Journal, Vol. 101, Issue 1, 488–498.

HSIAO T.C., HENG L., STEDUTO P., ROJAS-LARA B., RAES D., FERERES E. (2009). AquaCrop-The FAO crop model to simulate yield response to water: III. Parameterization and testing for maize, Agronomy Journal, Vol. 101, Issue 3, pp. 448–459.

KATERJI N., CAMPI P., MASTRORILLI M. (2013). Productivity, evapotranspiration, and water use efficiency of corn and tomato crops simulated by AquaCrop under contrasting water stress conditions in the Mediterranean region, Agricultural Water Management, Vol. 130, Issue 1, pp. 14–26

RIJTEMA P.E., ABOUKHALED A. (1976). Crop water use. In: Research on Crop Water Use, Salt-affected Soils and Drainage in the Arab Republic of Egypt. FAO Regional Office, Cairo, 92 p.

SHOCK C.C., HOLMES Z.A., STIEBER T.D., ELDREDGE E.P., ZHANG P. (1993). The effect of timed water stress on quality, total solids and reducing sugar content of potatoes, American Potato Journal, Vol 70, Issue 3, pp. 227-41.

VAN LOON C.D. (1981). The effect of water stress on potato growth, development and yield, American Potato Journal, Vol 58, Issue 4, pp. 51-69.

WRIGHT J.L., STARK J.C. (1990). Potato. In: B.A. Stewart and D.R. Nielsen, eds. Irrigation of Agricultural Crops - Agronomy. Monograph No. 30, Madison, Wisconsin, United States of America, ASA-CSSA-SSSA.

ZELLA L., SMADHI D. (2007). Evolution de l'irrigation, Larhyss Journal, No. 06, pp. 65-80.