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Validation of Aqua Crop model in the simulation of sugar beet production under different water regimes in southeastern Albania

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Abstract— Given the current pressures to reduce irrigation water use, it is important to optimize the use of water in irrigated agriculture. Therefore, the present study evaluates the performance of Aqua Crop, a crop simulation model developed by FAO, in simulating sugar-beet production under three irrigation levels (100%, 75% and 50 % of water requirement) in a semi-arid environment in Korça region (southeastern Albania). During three years (2012–2014), crop physiological measurements and comparisons between simulated and observed soil water content (SWC), canopy cover (CC), biomass production, actual evapotranspiration (ETa) and final tuber yield (TY) were used firstly, to calibrate and subsequently, to validate the AquaCrop model. The results showed that AquaCrop is able to accurately simulate soil water content of root zone, crop biomass, tuber yield, and ETa with normalized root mean square error (NRMSE) less than 10%. Soil water simulated by AquaCrop tends to follow closely the trend in the measured data, but with slight underestimations for full irrigation treatment and significant overestimations for deficit treatments. Statistical indicators in the model's evaluation such as RMSE and Willmot's d-statistics were for tuber yield (0.58 Mg ha−1, 0.92), biomass (0.87 Mg ha−1, 0.95), ETa (33.2 mm, 0.93) and soil water content (24.5–37.6 mm, 0.85–0.90), which suggested that the model can be used to highly reliably assess yield and irrigation water use efficiency. AquaCrop estimated adequately under mild water stress the evolution of soil water content of the sugar-beet crop during the growing season, as well as the spatial distribution of productivity was simulated consistent with the observed values. This makes it very useful for the design and evaluation of deficit irrigation strategies, preventing unnecessary losses from runoff, drainage and soil evaporation, in addition to enhancing water use efficiency.

Index Terms—**Aqua Crop model, canopy cover, sugar beet irrigation, water use efficiency**

I. INTRODUCTION

Modeling can be a useful tool to study and develop promising deficit irrigation strategies (Zairi et al., 2000; Kipkorir et al., 2001; Lobell and Ortiz-Monasterio, 2006; Benli et al., 2007; Heng et al., 2007; Lorite et al., 2007; Pereira et al., 2009; Blum, 2009; Geerts and Raes, 2009). It has been used for decades to analyze crop responses to environmental stresses, and to test alternate management practices (Boote et al., 1996; Sinclair and Seligman, 1996) and promising deficit irrigation strategies (Lobell and Ortiz-Monasterio, 2006; Benli et al., 2007; Heng et al., 2007; Lorite et al., 2007; Pereira et al., 2009). Models allow a combined assessment of different factors affecting yield in order to derive optimal irrigation quantities for different scenarios (Pereira et al., 2002; Liu et al., 2007). Furthermore, They can allow differentiating evapotranspiration between transpiration and evaporation and splitting up crop production in different sub-models (e.g. Raes et al., 2006, 2009a; Geerts et al., 2009; Steduto et al., 2009), which may help elucidate the mechanisms underlying higher water productivity under deficit irrigation. Before any model can be used, calibration, parameterization and evaluation should be performed (Addiscott et al., 1995; Power, 1993; Nain and Kersebaum, 2007). On the other hand, validation is the process whereby the model is run against independent data, without any modification of model parameters or code (Nain and Kersebaum, 2007; Andarzian et al., 2008; Salazar e al., 2009).

Some widely known models are CERES (Jones and Kiniry, 1986) which has been inserted in the DSSAT (Jones et al., 2003) and APSIM (Keating et al., 2003), EPIC (Williams et al., 1989), ALMANAC (Kiniryet al., 1992), CropSyst (Stöckle et al., 2003), and the Wageningen models (van Ittersum et al., 2003), which are based on the crop's physiological response to environmental factors. Most of these models require a very high number of parameters to run, and many of them are not easily available in the field and need to be determined experimentally. For this reason, detailed models maybe less reliable and require more advanced skills than simpler but more robust models (Sinclair and Seligman, 1996).

To overcome these complications, in 2009 the Food and Agriculture Organization (FAO) of the United Nations developed a new water-driven crop simulation model (Steduto et al., 2009; Raes et al., 2009), named AquaCrop, from the basic yield response to water algorithm in Doorenbos and Kassam (1979). It has limited complexity and aims to offer a balance of accuracy, simplicity, and robustness. One of the most important parameters in AquaCrop is the normalized biomass water productivity (WP*), which is typically constant for a given crop species (Steduto et al., 2007, 2009). It uses a relatively small number of explicit and mostly intuitive parameters and input variables, requiring simple methods for their derivation (FAO, 2009). For more details on the conceptual framework of AquaCrop, see Steduto et al. (2009) and for algorithmic and software solutions, see Raes et al. (2009).

The FAO AquaCrop model has been conceived as a tool for simulating, on a daily scale, the canopy cover (CC), biomass and the actual evapotranspiration and for simulating, on a seasonal scale, the final biomass, the harvested yield, the cumulate actual evapotranspiration, and the crop water use efficiency. The performance of the AquaCrop model was been configured and tested in corn (Hsiao et al., 2009), and also subject to validation under irrigated and water deficit conditions (Heng et al., 2009); tested under full and deficit irrigated wheat production (Andarzian et al., 2011) and also performance evaluation for durum wheat (Guendouz et al., 2014); parameterized and tested in irrigated and rain-fed cotton (Farahani et al., 2009; Garcia-Via et al., 2009); compared with other crop models to estimate sunflower growth under different water regimes (Todorovic et al., 2009); in potato to estimate yield variability under field conditions (de la Casa et al., 2013), and to evaluate the quinoa yield response to water availability (Geerts et al., 2009). Because the recent appearance of AquaCrop information about the model performance is relatively scarce, it is not known if the model has been put operative for sugar beet yet.

In this sense, the present study was designed to calibrate and validate the AquaCrop model for soil water content, actual evapotranspiration, plus tuber yield and biomass (2012–2014) under full and deficit irrigation of sugar beet in the semi-arid region of Korça region, southeastern Albania.

II. MATERIALS AND METHODS

A. Model description

AquaCrop crop model is based on FAO method that estimates crop productivity decrease in response to water stress (Steduto et al., 2009). The simulates attainable yields of major herbaceous crops as a function of water consumption under rain-fed, supplemental, deficit, and full irrigation conditions. As compared to other crop models, the AquaCrop model is a user-friendly and practitioner-oriented type of model, as it maintains an optimal balance between accuracy, robustness, and simplicity, and requires a relatively small number of parameters. The AquaCrop model represents an effort to incorporate current knowledge of crop physiological responses into a tool that can predict the attainable yield of a crop based on the water supply available. The model is aimed at a broad range of users, from field engineers and extension specialists to water managers at the farm, district, and higher levels. It can be used as a planning tool or to assist in making management decisions, whether strategic, tactical or operational.

AquaCrop has the following characteristics (Steduto et al., 2009): 1) distinguish evapotranspiration (ET) between crop transpiration (Tr) and soil evaporation (E); 2) considers a simple model of growth and senescence of canopy cover as basis for estimating Tr and to separate it from E; 3) considers that the yield obtained (Y) is a function of bio- mass (B) and the harvest index (HI), and 4) water stress is evaluated separately by four functions affecting growth and senescence of canopy cover, Tr and HI. By splitting the ET in E and Tr the unproductive use of E in biomass production is avoided, which is important especially during the period when the ground cover is incomplete.

The growth engine of AquaCrop is water-driven, in that transpiration is calculated first and translated into biomass using a conservative, crop-specific parameter (Geerts et al., 2009), the biomass water productivity, normalized for atmospheric evaporative demand and air CO_2 concentration. The normalization is to make AquaCrop applicable to diverse locations and seasons. The model uses canopy ground cover instead of leaf area index (LAI) as the basis to calculate transpiration and to separate soil evaporation from transpiration. Crop yield is calculated as the product of above-ground dry biomass and harvest index (HI). Starting at flowering, HI increases linearly with time after a lag phase, until near physiological maturity. Other than for the yield, there is no biomass partitioning into the various organs. Crop responses to water deficits are simulated with four modifiers that are functions of fractional available soil water modulated by evaporative demand, based on the differential sensitivity to water stress of four key plant processes: canopy expansion, stomatal control of transpiration, canopy senescence, and HI. The HI can be modified negatively or positively, depending on stress level, timing and stress duration. AquaCrop uses a relatively small number of parameters (explicit and mostly intuitive) and attempts to balance simplicity, accuracy, and robustness. The model is aimed mainly at practitioner-type end-users such as those working for extension services, consulting engineers, governmental agencies, nongovernmental organizations, and various kinds of farmers associations. It is also designed to fit the need of economists and policy specialists who use simple models for planning and scenario analysis (Steduto et al., 2009).

As in other crop models, AquaCrop structures the soil-plant-atmosphere system by including 1) the soil, by incorporating water and nutrients budgets; 2) the plant, through their processes of growth, development and yield, and 3) the atmosphere, with its thermal regime, rainfall, evaporative demand and carbon dioxide concentration. While it is a generic model, presents specific parameters for different crops, and some of them have a conservative character (Steduto et al., 2009). Additionally, some management aspects are explicit, with emphasis on irrigation, but also the levels of soil fertility as they affect crop development, water productivity, and crop adjustments to stresses, and therefore final yield. Pests and diseases are not considered.

B. Field experiment site conditions

Experimental site (15 ha) is located in Libonik County (Vertisol soil-FAO). Sugar beet is one of the main crops in this region. Experiments on sugar beet were conducted in three consecutive seasons from 1012 to 2014. The growing season for sugar beet is from middle of March to end of September. Date of sowing and date of emergence was recorded. The planting densities was 8 plants m^{-2}. Fifteen 5 m × 10 m plots were created and divided by concrete walls. Sugar beet was sown by hand. Before sowing, each plot was irrigated with about 100 mm water containing 300 kg ha^{-1} ammonium phosphate and 150 kg ha^{-1} urea. Weeds were effectively controlled using herbicides, and no pests or disease infestations were observed during the plant growing seasons.

Three kinds of irrigation schedules were tested for sugar beet based on growth stages: A - Full irrigation; B - 75% of full irrigation and C - 50% of full irrigation.

The area of the tuber yield (GY) measurement was a 5 m × 6 m portion in the heart of each plot, and a 1000-kernel weight was determined from the harvested tubers. For dry matter, samples of aboveground biomass were harvested on a 10 days basis from 1 m^2 area and were dried in a forced-air drier at 70^0C for 3 days to document biomass production (Ehdaie and Waines, 2001). The harvesting of experiment was accomplished manually 10 days after physiological maturity and above-ground dry biomass and tuber yield were measured.

Soil water content was measured gravimetrically in each 0.3 m layers down to 1.2 m depth every 10 days. Measurements were performed in two replications per treatment. Volumetric water content was obtained from gravimetric content and bulk density.

C. Weather and soil data

The experimental site is characterized by a Mediterranean climate, with rainfall confined mostly to the period from October to late March, and totaling 765 mm per year as an average for the past 30 years. An automated weather station inside the research center measured daily values of minimum and maximum air temperature and relative humidity, precipitation, solar radiation, sunshine and wind speed at 2 m height. Daily reference evapotranspiration

(ET_0) is computed using the FAO 56 Penman–Monteith approach (Allen et al., 1998), with data of daily solar radiation, minimum and maximum temperature, wind run, and maximum and minimum relative humidity. Actual evapotranspiration (ETa) was calculated by the water balance method.

The rainfall does not meet the needs of sugar beet for normal growth, especially during the dry, windy summer season. Table 1 shows the distribution of precipitation during sugar beet seasons in the years of the experiment.

TABLE 1. PRECIPITATION (IN MM) DURING SUGAR-BEET GROWING SEASONS FROM 2012 TO 2014, AT LIBONIK COUNTY

Year	Month							Total
	March	April	May	June	July	August	September	
2012	59.3	30.8	33.6	29.3	16.5	9.1	22.3	200.9
2013	55.4	38.7	22.6	10.5	9.7	6.6	21.0	164.5
2014	57.4	45.8	34.3	22.5	12.2	11.3	21.8	205.3

In Table 2 are shown irrigation amount during field experiments for sugar beet.

TABLE 2. IRRIGATION AMOUNT DURING FIELD EXPERIMENTS (2012–2014).

Years	Treatment A	Treatment B	Treatment C
	Amount (mm)		
2012	329.5	247.1	164.8
2013	367.1	275.3	183.6
2014	330.1	247.6	165.1

The soil parameters of experimental site that were determined include soil texture, bulk density, and hydraulic properties. Some selected soil properties of experimental site are shown in table 3.

TABLE 3. SOME SELECTED SOIL PROPERTIES OF EXPERIMENTAL SITE

Sampling depth (cm)	Texture (ISSS) (g kg^{-1})			Hydraulic properties m^3 m^{-3}			Hydraulic conductivity (m d^{-1})	Bulk density (g/cc)
	Clay	Silt	Sand	θ_{sat}	θ_{FC}	θ_{PWP}		
0-30	517	221	262	0.57	0.50	0.13	0.612	1.25
30-60	532	245	223	0.59	0.52	0.15	0.478	1.32
60-90	614	217	169	0.58	0.51	0.14	0.329	1.39
91-120	652	245	103	0.57	0.51	0.14	0.230	1.43

D. Input data and calibration of the Aqua Crop model

Aqua Crop uses six input files for simulation: climate file, crop file (time to emergence, maximum canopy cover, start of senescence, maturity), soil file, management file, irrigation file, and initial soil water conditions; all these are user specific. The climate file consists of three sub-files: (i) minimum and maximum air temperature, (ii) ETo, and (iii) rainfall, all with daily values as described by Raes et al.(2009). The crop file contains both conservative parameters (that do not change with location) and user-specific parameters (non-conservative). The parameters used for the AquaCrop model were measured or estimated using experimental data; some were based on field experience, and some used the default values given in the model, regardless of the year.

The AquaCrop model was calibrated using the values observed from the field experiment during 2012 for tuber yield, biomass, ETa and soil water content (0–120 cm). Measured soil water content was only available for this year, and was the reason this year was selected. Treatment A was used for the model calibration, and the model's default values were used for stress treatments. The difference between the simulated model and the experimental data was minimized by using a trial and error approach.

E. Data analysis

Since no single measure can indicate how well a simulation model performs, a combination of statistical indices are generally used to evaluate the model (Caton et al., 1999; Kobayashi and Gauch et al., 2003). The agreement between the measured and simulated values was assessed using the following six statistics: RMSE (root mean square error), NRMSE (normalized root mean square error), MBE (mean bias error), MAE (mean absolute error), d (index of agreement (Willmott, 1982). Percentage difference was determined using the following equation, where S_i; indicates simulated values and M_i; indicates measured values in all statistical indices.

$$\mathrm{NRMSE} = \sqrt{\frac{\sum_{i=1}^{n}(S_i - M_i)^2}{n}} \times \frac{100}{M}$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(S_i - M_i)^2}{n}}$$

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}\left|S_i - M_i\right|$$

$$\mathrm{MBE} = \frac{1}{n}\sum_{i=1}^{n}(S_i - M_i)$$

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(S_i - M_i)^2}{\sum_{i=1}^{n}(|S_i| - \overline{M}) + (|M_i| - \overline{M})}\right]$$

$$\text{Percent deviation} = (\text{simulated} - \text{measured}) \times \frac{100}{\text{measured}}$$

Normalized RMSE calculated according to Loague and Green (1991) gives a measure (in %) of the relative difference of simulated versus observed data. The simulation is considered excellent with a normalized RMSE of less than 10%, good if the normalized RMSE is greater than 10 and less than 20%, fair if the normalized RMSE is greater than 20% and less than 30%, and poor if the normalized RMSE is greater than 30% (Jamieson et al., 1991). According to the d-statistics proposed by Willmott et al. (1985), the closer the index value is to one, the better the agreement between the two variables that are being compared and vice versa. A value of 1.0 indicates excellent agreement between measured and simulated values. A value of RMSE close to zero indicates better model performance. The MBE reveals the long-term performance of the model. A positive value of MBE gives the average amount of overestimation in the estimated values and vice versa. Lastly, The MAE measures the weighted average magnitude of the absolute errors. All these statistics were computed using the IRENE statistical software (Fila et al., 2003).

III. RESULTS AND DISCUSSION

A. AquaCrop model calibration

Table 4 show the simulation results for sugar-beet on the Korça Plain using the calibration data set (treatment A) for tuber yield, biomass, ETa and soil water content up to 0–120 cm depth.

TABLE 4. MEASURED VERSUS SIMULATED RESULTS FOR CALIBRATION UNDER FULL IRRIGATION FOR SUGAR-BEET

Year	Variables	Measured	Simulated	Deviation (%)	RMSE	NRMSE (%)	d	MAE	MBE
2012	**Biomass (Mg ha^{-1})**	9.8	9.9	1.0	0.65	9.78	0.98	0.84	− 1.06
	Tuber yield (Mg ha^{-1})	45.1	46.4	2.9	0.43	7.89	0.91	0.34	− 2.09
	ETa (mm)	456.7	440.1	−3.7	23.9	8.76	0.97	12.6	− 6.25
	Soil water content (mm)	283.6	264.9	−6.6	32.7	8.74	0.83	29.4	−24.7

The minimum difference was simulated for biomass (1%) while the highest difference was observed in water content (6.6%). Araya et al. (2010a) simulated the highest deviation for biomass, at 8.5%. Differences in tuber yield and ETa were 2.9% and − 3.7%, respectively. The calibration results show a reasonably close match between the measured values and those simulated by the model.

B. AquaCrop model validation

Validation is an important step in model verification (Addiscotet al., 1995; Power, 1993), and is done by comparing independent field measurements (data) with the outputs created by the model. Soil water content over the root depth, ETa, above-ground dry biomass and tuber yield were considered in this study for model validation. The crop parameters obtained from the model calibration were used in the validation. Table 5 shows the measured and simulated results for the validated data sets for tuber yield, biomass and ETa from 2013 to 2014 years in the Libonik County.

TABLE 5. MEASURED VERSUS SIMULATED RESULTS FOR VALIDATED DATA SETS OF SUGAR-BEET FROM 2013 TO 2014 IN THE LIBONIK COUNTY

Year	Treatment	Yield (Mg ha^{-1})			Biomass (Mg ha^{-1})			ETa (mm)		
		Measured	Simulated	Deviation (%)	Measured	Simulated	Deviation (%)	Measured	Simulated	Deviation (%)
2013	**A**	48.5	46.7	−3.7	3.8	4.1	7.9	375.2	353.7	−5.7
	B	40.9	44.8	8.7	3.9	4.2	7.7	391.6	351.3	−10.3
	C	42.2	38.2	−9.5	4.4	4.0	−9.5	390.4	369.3	−5.4
2014	**A**	52.7	50.4	−4.4	4.5	4.4	−2.2	381.0	403.3	5.9
	B	50.9	52.7	3.5	4.4	4.5	2.3	419.5	418.0	−0.4
	C	47.8	43.3	−9.4	4.6	4.2	−8.9	386.5	4030.	4.2

C. Tuber yield

The simulated tuber yields showed a good agreement with their measured (Table 5). The simulated sugar-beet yield varied from 38.2 to 52.7 t ha^{-1}, while the measured yield varied from 40.9 to 50.9 t ha^{-1} for full and deficit irrigation treatments in all of cropping seasons. The results in Table 5 show that no significant deviation (−3.7% to −9.5%) was observed between the measured and simulated values of AquaCrop for the year 2013, as this year was relatively dry, and the cropping season depends mainly upon irrigation.

In the second year (2014), the greatest deviation was simulated for tuber yield in the case of treatment C (−9.4%, underestimated). This could possibly be due to the fact that the senescence of the canopy accelerates under severe water stress, and the underground root system may be restricted and prevented from extracting more deeply stored soil water, thereby limiting its water uptake. Several authors (Heng et al., 2009; Araya et al., 2010a,b; Zeleke et al., 2011; Abedinpour et al., 2012) reported much greater deviations under severe water stress, as compared to well-watered treatments for maize, teff and canola crops simulated by AquaCrop.

Table 6 shows the statistical assessment of the AquaCrop model for two experimental years under deficit irrigation. The results of RMSE (0.34 Mg ha^{-1}), MAE (0.43 Mg ha^{-1}), MBE (−0.02 Mg ha^{-1}), d (0.93) and NMRSE (9.87%) are comparable with those obtained by others (Mkhabela and Paul, 2012).

TABLE 6. SIMULATION ERROR STATISTICS OF VALIDATED AQUACROP MODEL

Model output parameters		Mean		RMSE	NRMSE	d	MAE	MBE	r^2
		Measured	Simulated						
Biomass (Mg ha^{-1})		4.3	4.2	0.78	8.97	0.96	0.71	− 0.07	0.94
Tuber yield (Mg ha^{-1})		47.2	46.1	0.34	9.87	0.93	0.43	− 0.02	0.93
ET$_a$ (mm)		390.8	383.1	23.5	6.78	0.94	18.8	− 4.26	0.98
Soil water content (mm)	**Treatment**								
	A	409.2	370.8	34.6	9.74	0.89	12.8	− 10.7	0.91

	B	384.3	359.8	25.8	8.85	0.93	21.5	− 6.09	0.88
	C	347.1	333.6	31.4	9.62	0.92	26.4	− 15.2	0.95

The results of this study therefore suggest that the AquaCrop model can be used with a considerable degree of accuracy for deficit irrigation scheduling, considering crop growth stages or timing of irrigation for modeling sugar beet tuber yield on the Korça Plain.

D. Final aboveground biomass

Table 5 shows a validation of the AquaCrop model for final aboveground biomass. There are generally a good agreement between the model predictions and measured aboveground biomass data (Table 5). The highest negative deviations (−9.5%, −8.9%) were simulated for the year 2013, and for 2014 in treatment C, as in the case of tuber yield. This is due to severe water stress experienced in the cropping season, as already explained for tuber yield. A similar trend was observed in the validation of the AquaCrop model for tuber yield.

The model predicted biomass values at harvest quite well. The calculated values of statistic indices, RMSE, NRMSE, d-index, MAE, MBE and r^2 were 0.78 Mg ha^{-1}, 8.9%, 0.93, 0.71 Mg ha^{-1}, -0.07 Mg ha^{-1}, 0.94, respectively.

E. Actual evapotranspiration (ETa)

Table 5 shows the validation of the AquaCrop model for actual evapotranspiration from 2013 to 2014 in the experimental years. AquaCrop simulated the largest negative deviation (−10.3%) for treatment C in the year 2013 – a relatively dry year when the crop water requirement depended mainly on irrigation. Other deviations between the measured and modeled ETa were smaller (−0.4 to 5.9%). It has already been explained in the literature, and is supported by the findings for tuber yield and biomass in this study, that the AquaCrop model cannot provide satisfactory results under severe water stress conditions. Other deviations between the measured and modeled ETa were smaller (−0.4 – 6.9%).

Table 6 contains all the model evaluation criteria from 2013 to 2014, with RMSE (23.5 mm), MAE (18.8 mm), MBE (−4.26 mm), d (0.94) and NMRSE (6.67%). Normalized RMSE for ETa is in the excellent range. Farahani et al. (2009) evaluated the AquaCrop model for cotton, and calculated a deviation for ETa of between 2.1% and −10.2%. Henget al. (2009) presented total measured and simulated ET. Deviations were calculated in the range of −1.23% to −8.4%. The model acceptably simulates the value of ETa under deficit irrigation for sugar beet in the semi-arid conditions of southeastern Albania. These results thus confirm that the AquaCrop model can be used to study water balance, further estimate water consumption, and for planning sugar beet in the Korça District.

F. Soil water content

The AquaCrop model was validated for the soil water content of the total profile (0–120 cm), and the results are shown in Table 6. Data were available for a single sugar beet season (2012). The results show that the model performed well for simulating water dynamics. Statistical parameters such as RMSE ranged from 25.8 to 34.6 mm, NRMSE from 8.85 to 9.74%, d varied from 0.89 to 0.93, MAE was in the range of 12.8 to –26.4 mm, and MBE from −6.09 to −15.2 mm under different irrigation treatments. Thus treatment A was used in the model calibration, and the rest of the two treatments were used for validation. The highest deviation was simulated by the AquaCrop model, as compared to the measured soil water content (−9.3%) for treatment D, while other deviations were smaller (−6.4% to −3.90%). In general, the total soil water content simulated by the AquaCrop model closely follows the trend of the values observed, although there are some slight mismatches with the measured data. The modeling of the soil water content revealed a common trend in this study: i.e. a slight underestimation – but initial soil water content was well simulated, except in the case of the C treatment. This trend coincides with grain yield, biomass and ETa in this study, indicating that mismatches largely occur in the model's performance under conditions of severe soil water deficit. Farahani et al. (2009) and Hussein et al.(2011) reported that the AquaCrop satisfactorily simulated the soil water content of the whole profile; however it consistently tended to overestimate total soil water content, particularly in the deficit irrigation plots. Hsiao et al. (2009) also found that the AquaCrop model overestimated the soil water content by a significant amount– about 80 mm – although the general trend of the measured dataset was captured for deficit irrigation. Araya et al. (2010b) verified the underestimation of the soil water content simulated by the AquaCrop model under severe water stress conditions, although overall there was a perfect match between the simulated and measured data sets. Zeleke et al. (2011) also confirmed that AquaCrop acceptably simulated both the amount and trend of soil water content, but tended to overestimate in the cropping season.

Despite the slight mismatching, the overall results of this study suggest that the AquaCrop model can be used with a reliable degree of accuracy to simulate soil water content in sugar beet on the Korça Plain under deficit irrigation.

IV. CONCLUSION

In this study, the AquaCrop model successfully predicted BY and TY in sugar beet. The crop parameters are adjusted to simulate BY and TY for sugar beet under different irrigation treatments. These adjustments were made to obtain more stable and closer relationships between the simulated values and the measured values.

The evaluation of the AquaCrop model illustrated that the model was able to simulate soil water content of root zone, crop biomass and tuber yield accurately. Moderately satisfactory agreements were obtained for tuber yield, biomass, ETa and soil water content in the validation process. The model prediction slightly underestimated soil water content.

The simplicity of AquaCrop due to its required minimum input data, which are readily available or can easily be collected, has made it user-friendly for users. We can conclude from this study that the AquaCrop model can be used with a reliable degree of accuracy under mild water stress to determine the least sensitive and stress-tolerant stages of the growing period. This makes it very useful for the design and evaluation of deficit irrigation strategies, preventing unnecessary losses from runoff, drainage and soil evaporation, in addition to enhancing water-use efficiency. The particular feature that distinguishes AquaCrop from other crop models is its focus on water, especially under water limiting conditions.

One important application of AquaCrop would be for use in yield gap analysis, and to identify the constraints limiting crop production and water productivity. Its application could also be evaluated under climate-change scenarios for regional or national food and water security.

We can conclude from this study that the AquaCrop model can be used with a reliable degree of to determine the least sensitive and stress-tolerant stages of the growing period. This makes it very useful for the design and evaluation of deficit irrigation strategies, preventing unnecessary losses from runoff, drainage and soil evaporation, in addition to enhancing water-use efficiency.

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