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DEFICIT IRRIGATION UNDER WATER STRESS AND SALINITY CONDITIONS: FAO-AQUACROP MODEL

ABSTRACT

In this research, estimation potential of Aquacrop model under deficit irrigation and salinity conditions were evaluated for winter wheat grown under arid and semi-arid climates. Five different irrigation strategies and irrigation water salinity levels (0.5, 5, 7.5, 10, 15 dS m^{-1}) were taken with the model to estimate deficit irrigation and salinity scenarios. Wheat grain yield, biomass production and canopy cover were simulated under deficit and salinity stresses. According to estimation of the model; the deficit irrigation with water reduction of more than 75 % of full irrigation was applied at growth stages of wheat, revealed the significant reduction in grain yield, biomass and canopy cover as compared with full irrigation practice. The increase in irrigation water salinity caused a significant decrease in grain yield and biomass value. It was compared to the 0.5 dS m^{-1} salinity level, a low value of 3% was obtained for the 5 dS m^{-1} salinity level. Yield loss of 7.5, 10 and 15 dS m^{-1} salinity levels were found to be 18.97%, 42.5% and 85.6% respectively. Also, increasing irrigation water depth in saline treatments resulted in increased grain and biomass yield. For sustainable water management in agriculture area, using simulation model such as Aquacrop is useful tolls to estimate effect of applied water depth and quality of irrigation water on crop yield.

Keywords: *Aquacrop, Crop yield, Deficit irrigation, Salinity, Wheat*

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INTRODUCTION

World population is estimated to reach approximately ten billion people in the next thirty years, according to the United Nations, and global water and food demands can also be foreseen to increase accordingly. The agricultural sector uses seventy percent of the world's fresh water. Water is a limited resource and climate change has accelerated the depletion of the natural resource. The growing population has also increased per capita water use, compounding the global situation of freshwater scarcity (Maysoun et al., 2021). Due to the increasing water demand and scarce fresh water resources, using saline water for irrigation is inevitable. In order to tide over this problem, field management strategies such as choosing appropriate planting method planting salt resistance genotypes and fertilization are suggested as feasible solutions (Dastranj and Sepaskhah, 2020).

Wheat is *one* of the *most important* strategic crops in Turkey. Turkey's wheat cultivation area constitutes 3.2% of the world wheat cultivation area as of 2019/20 production season (SGB, 2021). According to 2020 United States Department of Agriculture data, Turkey ranks 9th in world wheat exports and its self-sufficiency level is between 95-100% over the years about wheat production. Wheat being the winter season crop (vegetation period; 270 days) needs about 350 to 500 mm irrigation water throughout the growing period in Central Anatolia Region of Turkey.

The decrease in freshwater resources and winter precipitation due to the effect of climate change makes it even more necessary to determine irrigation strategies in wheat. In determining the effects of irrigation strategies and irrigation water qualities on crop yield, computer models are a very useful tool to see the results that may arise in the future.

The FAO's AquaCrop model is one of the most used models to simulate the effects of different irrigation practices and water quality parameters on crop yields since the last 10 years (Steduto et al., 2012). The model requires several parameters and input data to simulate yield response to water for most of the major field crops cultivated worldwide (Steduto et al., 2009).

The model has been calibrated and validated for semi-arid climate in Turkey and could be simulate winter wheat yield, biomass and water productivity values (Kale Çelik et al., 2018). The model was used to simulate to effects of deficit irrigation and irrigation water salinity level on winter wheat yield and biomass in this study.

MATERIAL

A field research project was conducted in Ankara Murted Plain (40º 04’ N and 32º 36’ E, elevation 831 m) of Turkey-Central Anatolia region to calibrate and validate the Aquacrop model between 2008 and 2012 (Kale Çelik et al., 2018). With this project, the prediction accuracy of the model for arid and semi-arid regions was found to be statistically acceptable. In this study, the field data of this project were used as an input in the Aquacrop (Ver. 6.1) model and the model was run according to different scenarios.

Experimental field soils are mostly silty clay and clay textures. Average field capacity on the volume basis of soil is 36%, wilting point 21% and bulk density 1.22 gr cm^{-3}. A locally adapted major wheat variety (*Bayraktar-2000*) was grown during the experimental studies.

The research area is far from the sea and surrounded by mountains, so the climate is typical continental climate. Summers are hot and dry, winters are cold and rainy. The daily temperature differences are quite high. The lowest temperature measured in the region is -4.7 °C, the highest temperature is 34.3 °C, and the annual average temperature is 9.1 °C. The average annual total precipitation is 398.6 mm, most of which falls during the winter months.

AquaCrop version 6.1 was used in this study and it was obtained from the official website of FAO via http://www.fao.org/aquacrop/software/software-download link. AquaCrop is a crop simulation model which describes the interactions between the plant and the soil. From the root zone, the plant extract water and nutrients. Field management (e.g. soil fertility) and irrigation management are considered since it affects the interaction. The described system is linked to the atmosphere through the upper boundary which determines the evaporative demand (ETo) and supplies CO_2 and energy for crop growth. Water drains from the system to the subsoil and the ground water table through the lower boundary. If the groundwater table is shallow water can move upward to the system by capillary rise (Raes et al., 2012).

METHOD

In order to simulate effects of drought and salinity stress on wheat yield and biomass with AquaCrop model, five irrigation strategies and five different irrigation water salinities scenarios were created. Five different irrigation strategies (S_{100} - S_{75} - S_{50} – S_{25} and S_0) were taken with the model to estimate deficit irrigation. Irrigation water was applied each growth stage (the stem elongation, heading and milk stages), on the same day with the full irrigation and 75, 50 and 25% of full irrigation was applied in the deficit-irrigation treatments. Water depletion in 90 cm soil profile was considered while calculating irrigation water requirements. Initial soil moisture contents during model run were taken from the project carried out between 2011-2012. In the project, soil moisture was measured with a neutron meter in every 30 cm layer at a depth of 120 cm. The moisture in the 0-30 cm section was measured by gravimetric method. For salinity scenarios

5 different irrigation water salinity levels were T_1 = 0.5 dS m^{-1}, T_2 =5 dS m^{-1}, T_3 = 7.5 dS m^{-1}, T_4 = 10 dS m^{-1}, T_5 = 15 dS m^{-1}.

Input data for AquaCrop (Ver. 6.1), included climate file (minimum and maximum air temperature, ET_o, rainfall and CO_2), crop file (time to; emergence, start of flowering and duration of flowering, maximum canopy cover, canopy senescence, and physiological maturity), soil file (field capacity, permanent wilting points, saturated hydraulic conductivity), management file (irrigation, field management practices) and initial condition file (initial soil water content, initial soil salinity) (Steduto et al., 2012). Crop and soil inputs used in the model are presented at Table 1 and 2.

Table 1. Crop input parameters

Conservative parameters	**Value**	**Nonconservative parameters**	**Value**
Base temperature °C	0.**0**	Sowing rate, kg seed /ha	170
Cut-off temperature °C	27.**0**	1000 seed mass, g	33.50
Canopy cover at 90% emergence %	6.47	Germination rate, %	85.0
Maximum canopy cover, %	90.**0**	Cover per seeding, cm^2/plant	1.50
Canopy growth coefficient %	2.**68**	Plant density, plants/m^2	431.3
Canopy decline coef. at senescence %,	0.34	Sowing date	20 Oct.
Leaf growth threshold p-upper	0.20	sowing to emergence time	31 Oct.
Leaf growth threshold p-lower	0.65	Time to reach max canopy cov.	12 May
Leaf growth stress coeff. curve shape	5.0	Time from sowing to max. root d	16Marc.
Stomatal conductance threshold p-upper	0.65	Time to start senescence	10 June
Stomata stress coefficient curve shape	2.5**0**	Time sowing to reach maturity	20 July
Senescence stress coefficient p-upper	0.70	Time to reach flowering	15 May
Senescence stress coefficient curve shape	2.5**0**	Duration of flowering stage	25 May
Harvest index, %	36.**0**	Min. effective root depth, m	0.30
WP normal. for ET_o and CO_2, g m^{-2}	15.0	Maxi. effective root depth, m	1.50

Table 2. Soil inputs used in AquaCrop model for winter wheat

Depth	Moisture content				Bulk density	K_{sat}
(m)	FC (%)	WP (%)	Sat (%)	TAW	(g cm^{-3})	(min day^{-1})
0.0 – 0.3	33.8	17.4	45.0	164	1.24	220
0.3 – 0.6	36.2	22.1	47.0	141	1.27	175
0.6 – 0.9	36.9	22.2	47.0	147	1.21	125
0.9 – 1.50	37.4	23.0	50.0	144	1.20	125

FC, field capacity; WP, wilting point; TAW, total available water; Sat, water content at saturation; Ksat, saturated hydraulic conductivity

Applied irrigation water amount according to irrigation treatments were 230 mm, 172,5 mm, 115 mm, 58 mm 0 mm for S_{100} - S_{75} - S_{50} – S_{25} and S_0 respectively.

RESULT AND DISCUSSION

Effect of deficit irrigation treatments on yield and biomass of wheat

Irrigation treatments results showed that, the lowest average grain yield was found in S_0, which did not apply irrigation water during the growing period (rainfed), with a value of 4950 kg ha^{-1}. The highest average grain yield and biomass values of 7560 kg ha^{-1} and 16250 kg ha^{-1} were obtained in S_{100} respectively, which was fully irrigated during the stem elongation, heading and milk stages. Grain yields were 7350 kg ha^{-1} for S_{75}, 6590 kg ha^{-1} for S_{50}, 5640 kg ha^{-1} for S_{25} and 4950 for rainfed (S_0) treatments. According to variance analysis there is significant negative relationship between treatments (Figure 1).

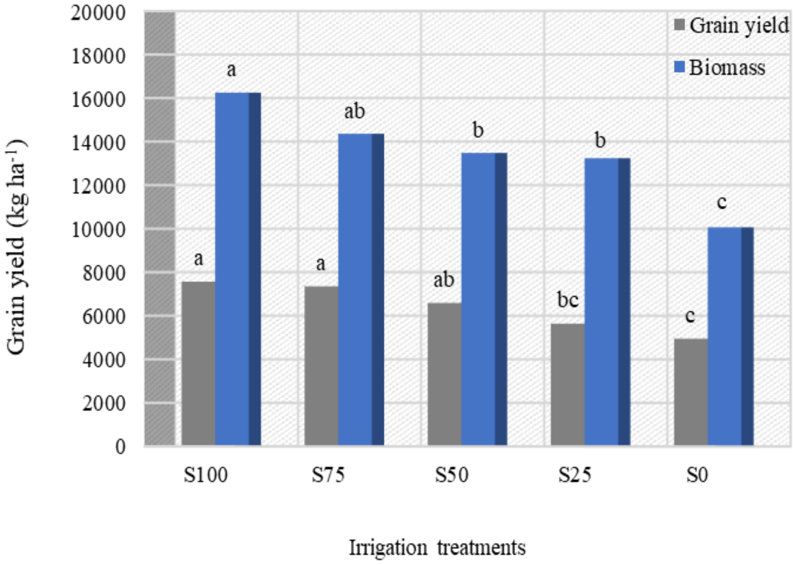

Figure 1. Estimated grain yield and biomass for irrigation treatments

There is a positive and significant relationship between grain yield and biomass with the correlation coefficient (R^2) 0.88 (Figure 2).

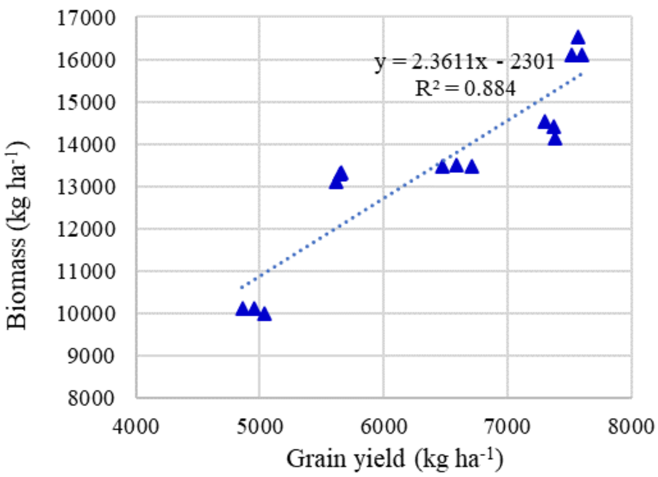

Figure 2. Grain yield and biomass relationship

Effect of irrigation water salinity on yield and biomass of wheat

The grain yields and biomass values for different irrigation water salinity levels were given in Figure 3.

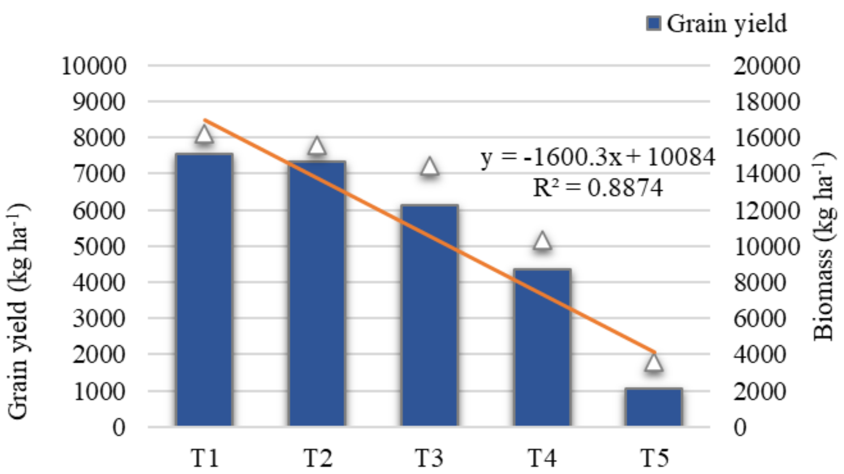

Figure 3. The grain yields and biomass values for different irrigation water salinity

The increase in irrigation water salinity caused a significant decrease in grain yield and biomass value. It was compared to the T_1 (control) treatment, a low value of 3% was obtained for the T_2 treatment. Yield loss of T_3, T_4 and T_5 salinity treatments were found to be 19%, 43% and 86%, respectively. Similar results regarding the decrease in yield as a result of the increase in the salinity of the applied irrigation water were also obtained by Tekin et al. (2014), Mostafazadeh-Fard et al. (2009), Gowing et al. (2009) and Kumar (2020), Hammami et al. (2020).

Effect of water deficit and irrigation water salinity on canopy cover (CC) of wheat

Hammani et al. (2020) was reported that the maximum and minimum CC were 85% and 30% in the sub-humid and arid areas, respectively. The canopy cover values of all treatments showed the same trend until early spring. The highest CC value was obtained as 82.5% on S_{100} treatment. The S_0 treatment was about 10-15% lower than the S_{100} treatment. Figure 4 shows that water deficit stress effects on canopy cover of winter wheat.

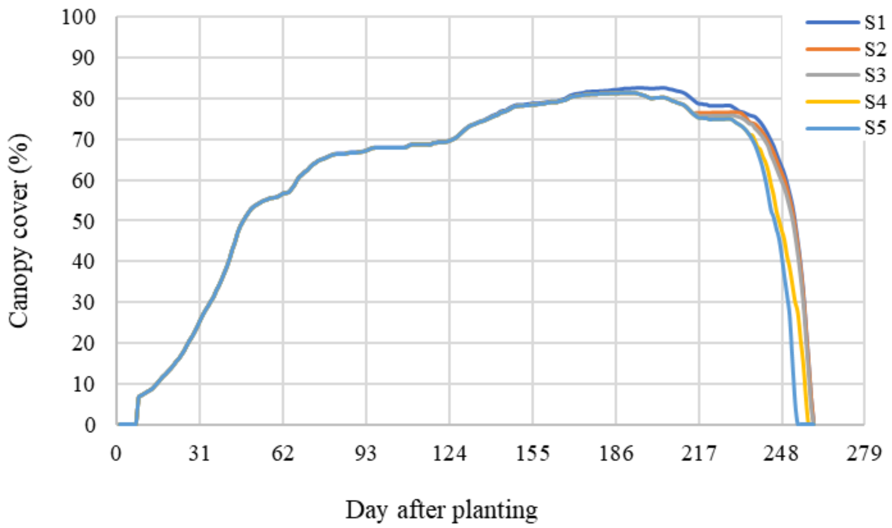

Figure 4. Canopy cover of wheat under different irrigation water amount

Simulation results indicated that salinity reduction a 18.8 % in the CC for Central Anatolia conditions (Figure 5). Similar result was obtained by Hammani et al. (2020) such as the salinity induces a 10% reduction in the CC in the sub-humid environment and 5–30% in the dry climate condition.

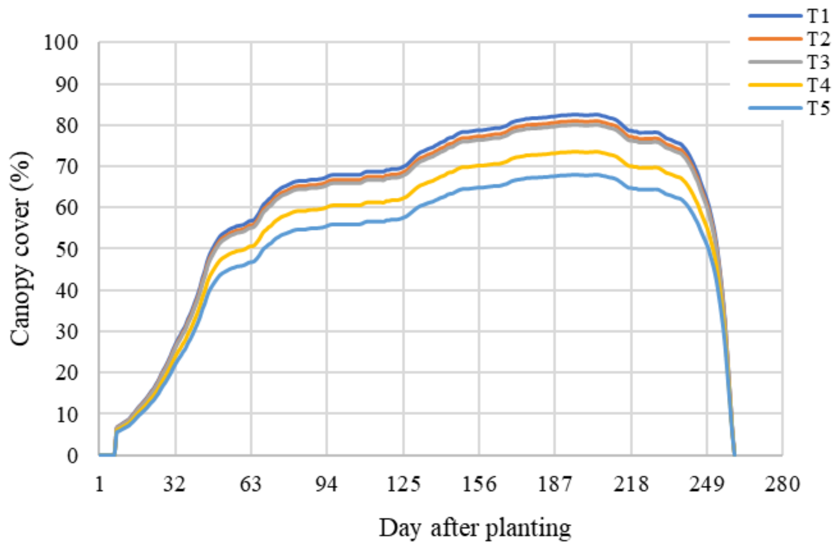

Figure 5. Canopy cover of wheat under different irrigation water salinity

Deficit irrigation water irrigation water salinity interactions

When all treatments were evaluated together, it was observed that the yield increased proportionally as the amount of irrigation water applied increased. On the other hand, the lowest yield was obtained at all salinity levels in S_0 treatment, where no irrigation water was applied. When both the decrease in the amount of irrigation water and the increase in the salinity level come together, more significant decreases were observed in the yield.

Interaction between irrigation water salinity and irrigation water amount on wheat grain yield were found to be statistically significant at the level of 1%. Statistical evaluation were given in Table 3.

Table 3. Variance analysis table of grain yield

Sources	SD	SS	AS	F values	F Table	
					0.05	0.01
Salinity	4	204497904	215909047	155.40**	0.42	3.32
Irrigation	4	130111354	130111354	93.65**	0.56	2.40
Salinity * Irrigation	16	14.80	0.30	23.68**	0.32	2.34
Error	65					
Total	73					

**; significant level of 0.01, SD; Standard deviation, SS; Sum of square, AS; Average of square

The change in the amount of irrigation water also changed the effects of irrigation water salinity on crop yield. The interaction effect of irrigation water salinity and deficit irrigation on wheat yield have been found by Jiang et al. (2013). Also, Gowing et al. (2009), reported that there were small but statistically significant effects of the interaction between the salinities of the irrigation and water use of wheat.

CONCLUSION

The deficit irrigation with water reduction of more than 75 % of full irrigation was applied at growth stages of wheat, revealed the significant reduction in grain yield, biomass and canopy cover as compared with full irrigation practice. Irrigation water salinity is one of the most important factors in limiting crop growth and reducing crop yield in arid and semiarid regions. In this study results showed that highest irrigation water salinity caused highest crop yield reduction. Also, increasing irrigation water depth in saline treatments resulted in increased grain and biomass yield. For sustainable water management in agriculture area, using simulation model such as Aquacrop is useful to estimate effect of applied water depth and quality of irrigation water on crop yield.

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