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MANAGEMENT PRACTICES ASSESSMENT USING AQUACROP MODEL FOR GROWING BARLEY UNDER SALINE CONDITIONS OF THE ARID REGIONS OF TUNISIA

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ABSTRACT

FAO's Aquacrop is one of the most suited models to water limited and saline conditions. It can help to assess management practices and allows developing better informed decisions concerning management and environmental factors that affect crop production. In this study, Aquacrop was used to determine the acceptable threshold of initial soil salinity and the suited period for sowing barley. Three initial soil salinity levels (3, 6 and 8 dS m^{-1}) were evaluated under different initial soil water content for full (FI) and deficit irrigated barley and two contrasting seasons. Barley yield was predicted also for 8 consecutive sowing dates including the sowing dates used by famers. The model simulations were evaluated using statistical indicators (Root Mean Square Error (RMSE), Mean Bias Error (MBE), Mean Absolute Error (MAE) and the coefficient of determination (r^2) and the three season's experimental data. Results show that grain yield and final biomass decrease with delay of sowing date and these reductions were accentuated with high initial soil salinity and the variability of rainfall events. The most suitable period for sowing barley ranging between end of November and the beginning of December. Initial conditions affect yield while the yield reduction started to be considerable (30%) only with the relatively higher level of soil salinity (8 dS m^{-1}) and for dry season and deficit treatment. The comparison between measured and simulated yield and biomass under varied sowing dates and initial soil salinity shows good agreement with RMSE ranging between 0.36 and 1.6 t ha^{-1}, MAE ranging between 0.29 and 1.48 t ha^{-1}, r^2 about 0.77 and 0.81 for yield and final biomass, respectively. Aquacrop could be a useful tool to determine the optimum barley yield for different restricted factors.

Key words: Barley, irrigation, Aquacrop, saline water, sowing date, management practices, arid environment.

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INTRODUCTION

Barley (*Hordeum vulgare*L.), considered as a tolerant crop to water and salt stress (Jamshidi and Javanmard, 2017), is one of the cereal crops most grown by farmers in the arid regions of southern Tunisia due to its importance for human consumption and for animal feed. Despite its importance, the productivity remains poor with a national average yield of 1.21 t ha^{-1} (World Bank, 2014). Many field management factors can affect barley production such as irrigation, soil salinity and sowing time.

The improvement of barley yield requires the choice of the suitable irrigation method and the better management of the irrigation timing and amount to control salinity. Therefore, efficient use of saline water for irrigation is to undertake appropriate management of irrigation to conserve water resources and prevent the development of excessive soil salinization that affects crop production (Fisher, 1980; Munns, 2002). Effective irrigation scheduling and the use of micro-irrigation systems are two possible options to improve water productivity in arid regions of Tunisia. Previous experiments conducted on barley in southern Tunisia by El Mokh and Nagaz (2014), and El Mokh and Nagaz (2015) demonstrated the potential of irrigation management practices in reducing the effect of salinity on both yield and soil salinization.

Sowing date is an important determinant of crop yield especially for rainfed crops or for saline conditions where natural leaching has an important role in reducing soil salinization and then improving crop production. Xinglong *et al*. (2017), Askar *et al*. (2013), and Ahmed *et al*. (2020) have reported decreasing crop yield in delayed sowing date. Latiri *et al*. (2010) reported better wheat yield with early sowing was obtained for years with no stress at germination in the semi-arid environment of Tunisia. Wheat yields were reduced by 4.2 to 10% for each week of any delay in sowing in autumn in Mediterranean environment (Asseng *et al.,* 2008). Under arid conditions, optimization of seeding time is a key measure to match plant demand with water availability and desirable environmental conditions (Gernot Bodner *et al*., 2015). Planting date has a considerable effect on grain yield by influencing the yield components resulting in a remarkable reduction in grain yield (Alam *et al*., 2015). Soil water conditions at sowing can also be important for crop production, particularly in low rainfall regions (Heng *et al*., 2007; Asseng *et al*., 2008). Initial soil water can affect the crop establishment and can contribute to water use and yield later in the season, in particularly in low rainfall seasons (Fereres *et al*., 2012).

Environmental factors greatly affect plant growth and yield. Therefore, better control of these factors may improve plant production. The study of the impact of each factor on the crop production and the determination of the acceptable threshold of yield reduction needs lengthy and expensive field experiments, especially with a high number of treatments. Over the years, simulation models have been successfully built to observe the behavior of the crops under their environmental conditions. In fact, crop models are biophysical process-based simulation tools that predict crop growth and yield for a range of soil, climate, and management conditions (Hwang *et al*., 2017). Another application of crop models is as decision support tools for system management. Simulation model can be a useful tool to study and develop scenarios for farmers for enabling local end users to evaluate and optimize crop yield, irrigation water use, sowing time, etc. (Heng *et al*., 2007 ; Liu *et al*., 2007 ; Raes *et al*., 2009). According to Olutobi *et al*. (2017), the validation of optimum and adapted practices such as planting date, water and salinity management needs useful simulation tool capable of representing a range of field conditions at different spatial and temporal scales.

The purpose of this work is to develop better adapted management plan that could be applied at a large scale for barley crop irrigated with saline waters. In fact, the already proven model for arid conditions of southern Tunisia (El Mokh *et al*., 2017) was used to assess the impact of sowing date and the initial water content and salinity on barley yields under different seasonal conditions.

MATERIALS AND METHODS

Experimental site and crop management: Field experiments were conducted over 3 years (2012-2015) in a commercial farm situated in Bedoui in the region of Medenine, South east of Tunisia (33°27’ N, 10°31’ E; altitude 55 m) characterized by a typical Mediterranean climate. No rainfall was received during 2012-2013 while 120 and 80 mm of rainfall were registered during 2013-2014 and 2014-2015, respectively (Fig. 1).

The soil at the experimental site is sandy with 80.6% sand, 12.6% silt and 6.8% clay. Average water content values for field capacity (FC) and permanent wilting point (PWP) are, respectively, 0.165 and 0.092 m^3 m^{-3} and organic matter content is less than 0.8%. The total soil available water, for an assumed root depth of 800 mm, was 72 mm.

Barley (cv. Ardhaoui) was planted on 30 November, 4 and 20 December, respectively, in 2012-2013, 2013-2014 and 2014-2015 with sowing density about 80 kg ha^{-1}, in a randomized complete block design with three replicates and two irrigation treatments. Each plot (treatment) included six lines with 30 m length and 70 cm rows space. Each row was equipped with a dripline including emitter spaced 40 cm and a mini-valve placed at the beginning of each row to control the irrigation time of each treatment. Water meter and gate valves were placed to control water supply in each block. All plots were drip irrigated with well waters having an electrical conductivity (ECi) of 6 dS m^{-1}. Each dripper has a flow rate of 4 L h^{-1}.

Irrigation was scheduled to replenish the water depleted in the root zone through the crop evapotranspiration (ETc) to field capacity (FI) and the crop ET was estimated based on soil water balance model developed on Excel using the FAO 56 guidelines (Allen *et al*., 1998). Full treatment (FI) was irrigated with an amount equal to 100% of cumulated ETc. DI-TM treatment consisted in irrigation water restriction of 50% during both tillering and maturity stages. Every year, barley was harvested in the fourth week of May.

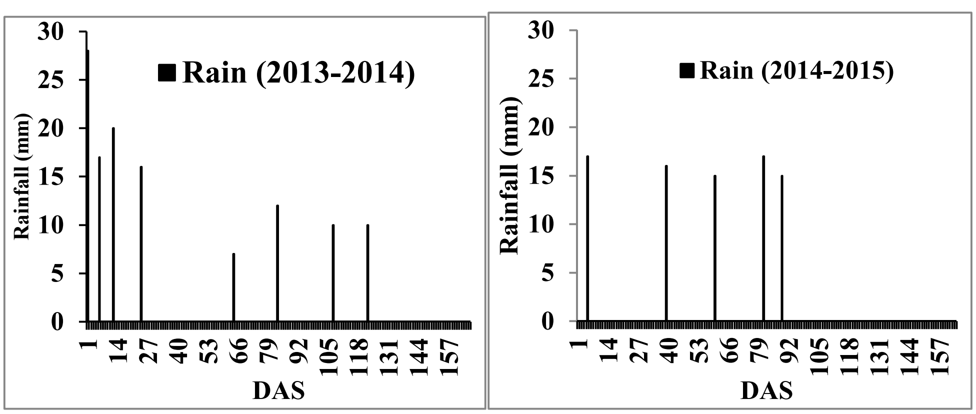

Figure 1. Rainfall data with day after sowing (DAS) during barley growing seasons (2013-2014 and 2014-2015).

AquaCrop simulation model: AquaCrop is a crop water productivity model especially suited in arid and semi-arid regions where water is a key limiting factor for crop production. It relates soil-crop-atmosphere components. This model simulates yield response to water and recently in its version 4.0 added the yield response to salinity. It integrates the salt balance component, which uses the calculation procedure presented in BUDGET (Raes *et al*., 2006; Raes *et al*., 2002) to simulate salt movement and retention in the soil profile. Steduto *et al*. (2009) and Raes *et al*. (2006) have reported the detailed description of AquaCrop parameterization. Many studies were conducted to evaluate the model performance in simulation of yield response to water availability, while there is a lack of works that test its accuracy under saline conditions. El Mokh *et al*. (2017) have previously tested the model for barley crop cultivated in saline conditions in the arid climate of southern Tunisia. Based on the previous calibrated parameters, the model was used as tool to predict yield under different scenarios of initial soil conditions and sowing dates in order to determine the suitable period for growing barley. The data of the three contrasting seasons conducted in farmer field were used to evaluate the model simulations.

Initial conditions: The initial soil conditions in terms of water content and salinity are an important factor that affecting the crop germination and establishment and later the biomass and yield. The irrigation with water having relatively high salinity may cause an increase in the soil salinity. To this end, the combined effect of initial soil salinity and water content was tested in the absence of rainfall (2012-2013) and in rainy season (2013-2014). Three initial soil salinity levels (3, 6 and 8 dS m^{-1}) were tested under different initial soil water content. Five levels of initial soil water content were tested between PWP and FC (9, 11, 13, 15 and 17%). The initial soil salinity was started from the low value observed in the field up to a maximum that could be achieved in the field. Both seasons (2012-2013 and 2013-2014) used to test model simulation were started with different initial conditions (Table 1).

Sowing dates: Different sowing dates were selected over the period from 30 November until 5 January. The first sowing date was defined referring to the common farmers' practices in the region. These dates include three sowing dates tested in field experiments. The simulation started with the date 30 November and 5 days' time step was used to evaluate the effect of the sowing date delay on the crop yield and biomass. The effect of rainfall events could also be crucial in determining the optimal planting date because of high level of ECi (6 dS m^{-1}). For that reason, the model was run for the three seasons having different amounts and distribution of rainfall to evaluate the impact of sowing date on the barley yield. Depending on the amount of rainfall received before sowing, the initial condition of seasons is different (Table 1).

Table 1. Initial soil conditions for the three seasons and sowing dates.

Seasons	Initial water content (m^3m^{-3})	Initial ECe (dS m^{-1})	Sowing dates
2012-2013	0.168	4.0	30/11/2012
2013-2014	0.126	3.0	05/12/2013
2014-2015	0.168	6.0	25/12/2014

The first and the third seasons start with initial water content at field capacity, while for the second season farmer rely on the first rainfall received. Thus, in the absence of rainfall before sowing, irrigation is applied by farmer before sowing to avoid germination failure and crop development. Raes *et al*. (2004) and Mhizha (2010) indicated the necessity to bring soil to field capacity in order to sustain germination.

Analysis of simulation results: Analysis of variance was performed to evaluate effects of irrigation treatments using the Statgraphics (www.statgraphics.com). The LSD test at 5% level was used, to evaluate the difference between treatment means.

To evaluate the model performance, the experimental data of the seasons 2012-2013, 2013-2014 and 2014-2015 were used. Evaluation includes the comparison between simulated final biomass, grain yield, soil water content and salinity and observed values under two irrigation strategies. The root means square error (RMSE), mean absolute error (MAE) and mean bias error (MBE) (Eqs. 1, 2 and 3) and the coefficient of determination (r^2) were used to evaluate the agreement between the measured and simulated values:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(S_i - O_i\right)^2} \quad (1)$$

$$MAE = \frac{\sum_{i=1}^{n}\left|S_i - O_i\right|}{n} \quad (2)$$

$$MBE = \frac{\sum_{i=1}^{n}\left(S_i - O_i\right)}{n} \quad (3)$$

Where Si and Oi are simulated and observed values, respectively, and n is the number of observations.

RESULTS AND DISCUSSION

Barley yield under different initial soil water content and salinity levels: Three salinity levels were used mainly relatively low salinity value (3 dS m^{-1}), moderate (6 dS m^{-1}) and high value (8 dS m^{-1}) which are frequently attained in irrigated areas in the region. The salinity levels were tested for two contrasting seasons 2012-2013 and 2013-2014 which are considered dry and rainy seasons, respectively, and for both full and regulated deficit irrigation strategies.

Relatively low Initial soil salinity (3 dS m^{-1}): Figure 2 presents the combined effect of five levels of initial soil water content and initial soil salinity in both seasons (2012-2013 and 2013-2014). In the absence of rain, the effect of initial soil salinity start to be felt when the soil water content drop to 13%. The grain yield and biomass reductions were more pronounced with the regulated deficit irrigation strategy (DI-TM) where the reduction was about 17% compared to 5 % for FI with the most low initial water content (9%).

For the rainy season, results show that the soil salinity level of 3 dS m^{-1} doesn't affect the crop yield even with low water content conditions (Fig. 2). The amount of rainfall received in the beginning of season could compensate the dry initial soil condition. Referring to the field experiment, the initial condition used for this season (Table 1) resulted in yield with a good correlation with the model simulation (Table 2).

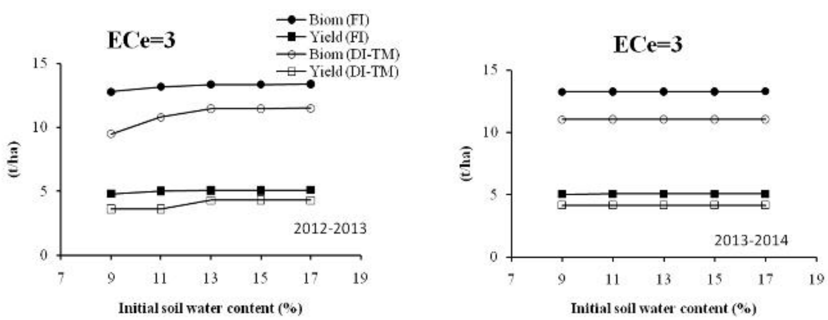

Figure 2. Grain yield and biomass under different initial soil water content levels and initial soil salinity of 3 dS m^{-1} for Full (FI) and deficit irrigation (DI-TM) strategies.

Moderate Initial soil salinity (6 dS m^{-1}): For the rainy season, the effects of soil salinity increase remain insignificant due to the rainfall events. In dry season, the yield reductions increase with the increase of the soil salinity especially with low initial soil water content approaching the wilting point humidity. In fact, the yield reduction for FI strategy raises to 17% and for the regulated deficit strategy (DI-TM) increase to 23% (Fig. 3). Thus, the salinity level of 6 dS m^{-1} has a moderate effect on the yield reduction especially with application of water restriction strategy. Hammami *et al*. (2020) reported that in the arid regions with low or absence of rainfall the irrigation of barley with high salinity (10-15 dS m^{-1}) resulted in considerable yield reduction compared to that under rainfed conditions.

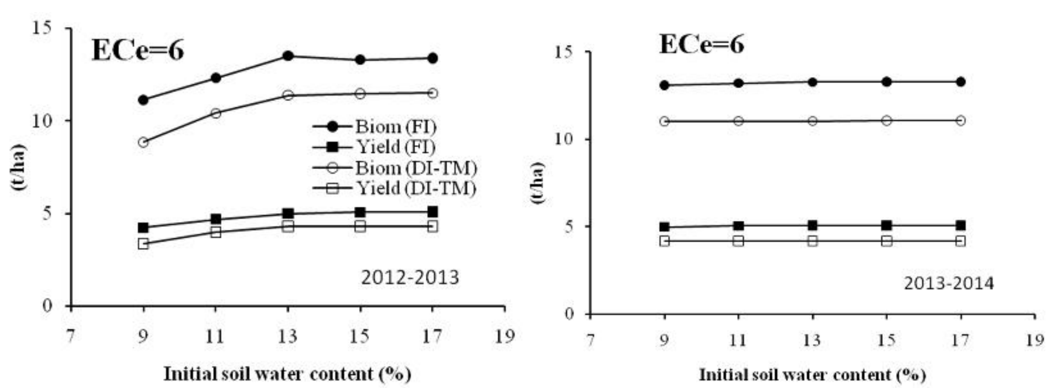

Figure 3. Grain yield and biomass under different initial water content levels and moderate initial soil salinity of 6 dS m^{-1} for full (FI) and deficit irrigation at (DI-TM) strategies.

Relatively high initial soil salinity (8 dS m^{-1}): A slight reduction of yield was observed under the second season (Fig. 4) where the well distribution of rainfall could maintain the soil salinity at acceptable level for barley crop. In the absence of rainfall, a yield reduction was noted even with relatively high initial water content. Therefore, the yield reduction was about 30% under the deficit strategy (DI-TM) and could be considerable under more water restriction. Bagues *et al*. (2020) have singled the important effect of combined drought and soil salinity on barley yield reduction in the arid regions. Whereas, the relatively high initial salinity haven't a considerable effect on yield reduction starting with soil at field capacity, that's can be attributed to the salt tolerance of this cultivar. Hammami *et al*. (2020) confirmed the low reduction of yield about 40% for tolerant verities compared to sensitive varieties with 72%.

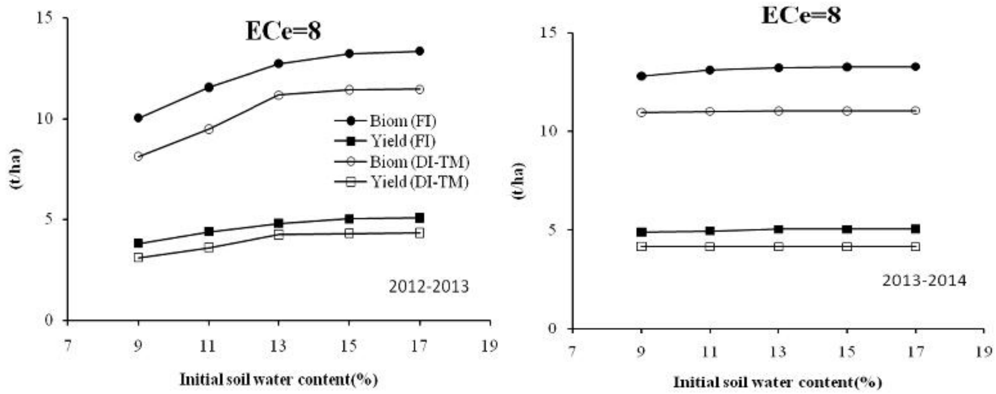

Figure 4. Grain yield and biomass under different initial water content levels and high initial soil salinity of 8 dS m^{-1} for full (FI) and deficit irrigation (DI-TM) strategies.

Despite barley has been classified as a relatively tolerant crop to salinity (Maas and Hoffman, 1977), it's considered more salt sensitive at emergence and early growth stages than in their later growth stages (Porter, 2012). Thus, starting with relatively high soil salinity and low humidity caused important yield reductions.

Initial soil water content is an important factor that affecting crop development especially in saline conditions. Based on model simulations, we could note the importance of initial rainfall event on alleviating the effect of high initial salinity on barley yield. The initial soil conditions may have significant effect on the rate of germination and crops establishment. Therefore, farmers should take care more about this factor practically for saline conditions to assure optimum yield. Results show that even with irrigation amount applied to meet the crop water requirements (FI), yield was affected starting with initial dry soil in addition to its higher salinity. The impact was doubled with regulated deficit irrigation (DI-M) and can contribute to crop development failure with continuous water restriction. Many other studies based on simulations and field experiments revealed the importance of sowing cereals with the first rainfall and the positive effect of starting with wet soil profile on the yield (Raes, 2012; Mhizha, 2010; Abrha *et al*., 2012).

Impact of sowing dates on yield and final biomass: The final biomass and grain yield for both seasons 2012-2013 and 2013-2014 decreased slightly with the delay of sowing date (Fig. 5), while a considerable decrease in yield was registered in the third season (2014-2015). In fact, in the third season the initial soil salinity was relatively high (6 dS m^{-1}) and most of rainfall events were received in the first part of the season (between 39 and 89 DAS). Thus, with the delay of sowing date the occurrence of leaching may decrease then the impact of salt stress on yield could be higher. Ankur *et al*. (2017) reported that the reduction of barley grain yield ranging between 7.6 and 18.6% with the delay of sowing date. However, Ram *et al*. (2010) and Ankur *et al*. (2017) were attributed these reductions to the shorter of growing period in vegetative phase and steep rise in temperature at the grain filling stage.

The yields reduction were relatively important under deficit treatment (DI-TM) with 16 to 20% compared to full irrigation (FI) with 11 to 13%, except for the third year where the reductions are comparable and ranging between 20 and 35%. This difference may be due to the shortening of growing period as result of water and salt stress during development and later stages, which can reduce the time for biomass accumulation as a result of osmotic adjustment (Ali and Abustan, 2013).

The model simulations were evaluated based on measured data of final barley yield, soil water content and salinity for the three seasons (Table 2).The measured grain yields were ranging between 4.1 and 4.7 t ha-1, and 4.2 and 5.2 t ha^{-1}, respectively, for DT-TM and FI and the difference between both treatment was not significant ($p<0.05$).

The values of statistical parameters indicated an acceptable agreement between simulated and measured yield and biomass where the RMSE ranges from 0.36 to 1.6 t ha^{-1}, MBE between 0.02 and 0.35 t ha^{-1}, and MAE from 0.29 to 1.4 t ha^{-1}. In addition, the values of r^2 about 0.77 and 0.81 (Fig. 6), respectively, for grain yield and biomass ensure that the model simulated barely yield with reasonable accuracy.

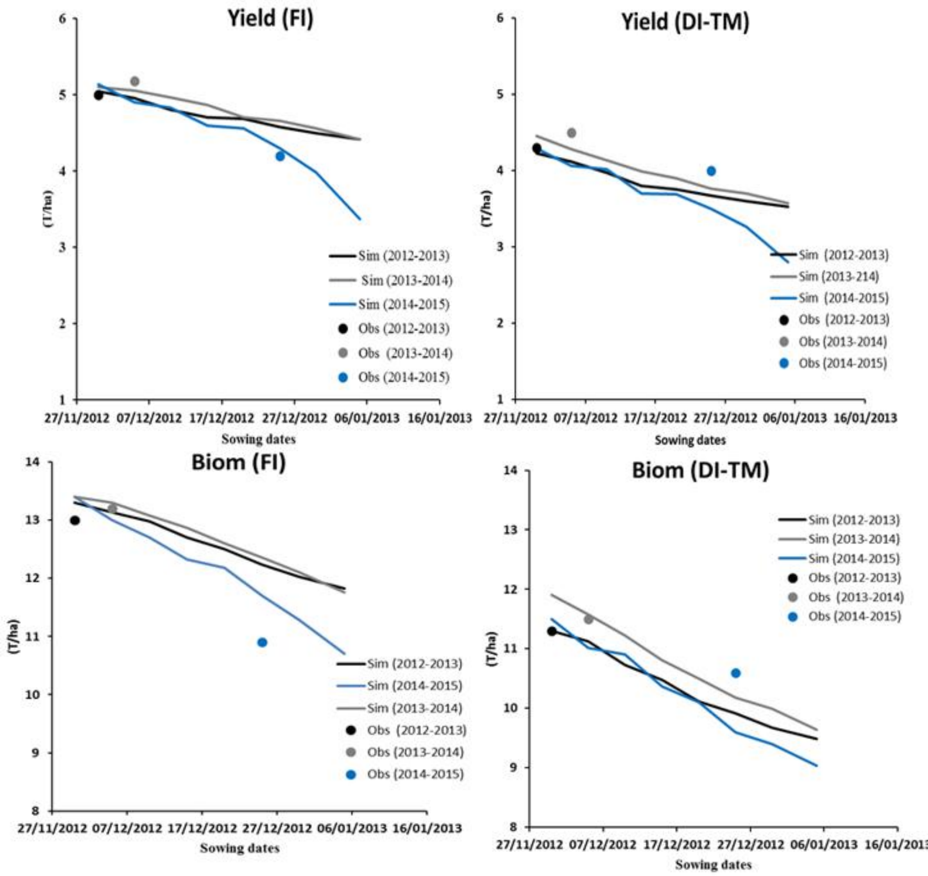

Figure 5. Simulated barley yield and final biomass under FI and DI-TM treatments for 8 sowing dates versus observed yield and final biomass for three experimental seasons (2012-2013, 2013-2014 and 2014-2015).

Table 2. Statistical parameters for evaluation of model performance for the three seasons.

Variable names	n	RMSE	MBE	MAE
	2012-2013			
Yield (t ha^{-1})	6	0.36	**0.02**	0.29
Biomass (t ha^{-1})	6	1.62	0.22	1.48
	2013-2014			
Yield (t ha^{-1})	6	0.47	-0.35	0.38
Biomass (t ha^{-1})	6	0.94	-0.29	0.74
SWC (mm)	6	18.9	18.06	18.06
ECe (dS m^{-1})	6	1.62	1.29	1.29
	2014-2015			
Yield (t ha^{-1})	6	0.64	-0.46	0.49
Biomass (t ha^{-1})	6	1.13	-0.36	1
SWC (mm)	6	27.2	26.5	26.5
ECe (dS m^{-1})	6	2.45	2.13	2.16

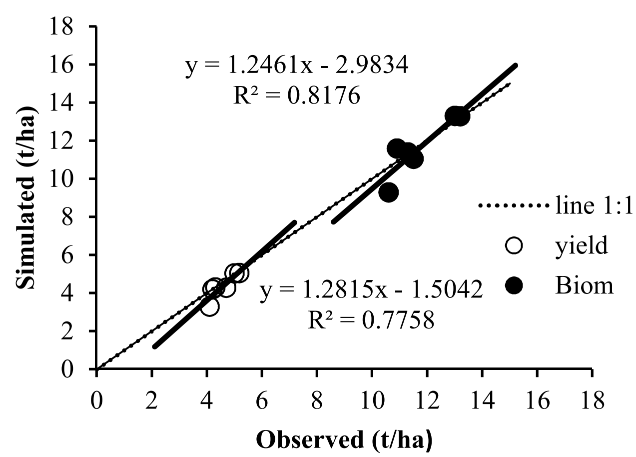

Figure 6. Simulated versus measured grain yield and biomass for the three seasons (2012-2013, 2013-2014 and 2014-2015).

For water content, the high RMSE values ranging between 18.9 and 27.2 mm confirmed that the model overestimated the soil water content as mentioned by Farahani *et al*. (2009) and Zeleke *et al*. (2011). These values are comparable to those reported by Andarzian *et al*. (2011) where RMSE and r^2 were 18 mm and 0.86, respectively, under full irrigation.

Moreover, the model tends to overestimate the soil salinity with a RMSE values ranging between 1.6 to 2.4 dS m^{-1}. This finding was confirmed by El Mokh *et al*. (2017). Thus, more works needed to test the model simulations under saline conditions in order to improve the salt balance compound when necessary. Otherwise, the model could be a useful tool to simulate barley yield under different initial soil conditions, seasons and sowing dates.

Therefore, the different sowing date scenarios developed using calibrated model are summarized in a simplified calendar as a guideline for barley cultivated under three different conditions. The table 3 showed that the yield decrease slightly with the delay of the sowing dates and the potential yield was obtained in the end of November beginning of December. Therefore, barley growing cycle may accumulate the required temperatures for each stage that permit to produce optimum yield for this sowing period. This funding was confirmed by Begum *et al*. (1999) who reported that the 30 November sowing produced the length of spike (6.65 cm) followed by that in 20 November and 10 December (6.33 cm) which was explained by the environmental conditions that may not suitable for spike development. Kavak (2004) indicated that from November 10 to November 25 the grain yield was similar but in later dates from December 10 to February 8 the grain yield was significantly reduced which was due to reduction in yield attributes. Moustafa *et al*. (2021) confirmed also that the late sowing in December showed significant barley yield reduction and attributed this reduction to not receiving the growing degree-day (GDD) requirements at early growth stages, which reinforced plants to hasten maturity. Ahmed *et al*. (2020) reported the effect of late sowing (20th December) on wheat yield reduction and recommended November 20 as the optimal wheat sowing date. Therefore, barley should be sown in the optimal period (highlighted in table 3) to avoid yield reduction.

Table 3. Sowing guideline for maximum and acceptable barley grain yield and final biomass under two irrigation strategies for sandy soils in the region of Medenine (Tunisia).

Sowing			**November**	**December**					**January**
5 days period			**1**	**2**	**3**	**4**	**5**	**6**	**7**

Sowing			**November**			**December**			**January**
5 days period			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
2012-2013	**FI**	Biomass (t ha^{-1})	13.4	13.4	13.5	13.4	13.1	12.9	12.6	12.3
		Yield (t ha^{-1})	5.1	5.1	5.1	5.0	4.9	4.8	4.7	4.5
	DI-TM	Biomass (t ha^{-1})	11.4	11.2	10.9	10.6	10.4	10.2	9.9	9.6
		Yield (t ha^{-1})	4.3	4.2	4.1	3.9	3.8	3.7	3.6	3.5
2013-2014	**FI**	Biomass (t ha^{-1})	13.4	13.2	12.9	12.6	12.5	12.1	11.8	11.6
		Yield (t ha^{-1})	5.1	5.0	4.9	4.8	4.7	4.6	4.4	4.3
	DI-TM	Biomass (t ha^{-1})	11.4	11.5	10.6	10.3	9.9	9.1	9.2	8.9
		Yield (t ha^{-1})	4.29	4.2	4.0	3.8	3.7	3.6	3.4	3.4
2014-2015	**FI**	Biomass (t ha^{-1})	12.9	12.4	12.4	12.2	12.0	11.6	11.2	10.8
		Yield (t ha^{-1})	4.8	4.6	4.5	4.4	4.3	4.2	3.8	3.3
	DI-TM	Biomass (t ha^{-1})	11.2	10.6	10.5	10	9.6	9.3	9.1	8.8
		Yield (t ha^{-1})	3.9	3.7	3.7	3.4	3.3	3.3	3.0	2.7

Conclusions: According to this study, FAO Aquacrop model was used as decision tool to evaluate management practices options for growing barley crop in arid environment and using saline water for irrigation. Results of simulation show that the initial soil conditions affect barley yield especially in dry season. It starts to be affected considerably by initial ECe up to 6 dS m^{-1} and only when it's combined with low initial water content. However, this reduction remain relatively low and barley (cv. Ardhaoui) can be considered as tolerant crop to these stressful conditions. Rainfall events and their well distribution during crop cycle improve considerably yield. Therefore, farmers in the region should use saline water with caution practically in dry season, and when the soil salinity increases it's recommended to start the crop season with a wetted soil. Results show also that barley yield was affected by sowing dates. Therefore, the late sowing (after the December 10) affect the length of early growth stages and might induce the early maturity. Thus, this cultivar of barley should be sown in the optimal period, which is ranging between the end of November and the beginning of December under these conditions.

The low values of RMSE (0.36 to 1.6 t ha^{-1}) and relatively high values of r^2 ranging between 0.77 and 0.81 for simulated barley yield, confirm the suitability of this model for developing simple guideline for farmers. While with the effect of climate change this management practices could not be adapted. To this end, the guideline should be updated and developed for more sites in order to be applicable to large scale and more different climate conditions.

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