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Using CropSyst Model to Predict Barley Yield under Climate Change Conditions in Egypt: II. Simulation of the Effect Rescheduling Irrigation on Barley Yield

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ABSTRACT

The effect of rescheduling irrigation on barley yield grown under heat stress as a result of future climate change was simulated using the CropSyst model. The model was calibrated and validated using data resulted from 2-year field experiments in 2007/08 and 2008/09 growing seasons using six barley cultivars. Two climate change scenarios (A2 and B2) from the CSIRO climate change model were incorporated with the CropSyst model to study the effect on barley yield and water requirements in the year 2039. The results showed that barley yield will be reduced by 17 and 18% when averaged over the six cultivars under the A2 and B2 climate change scenarios, respectively. Furthermore, water requirements for barley will be reduced by 4 and 5% for the above-mentioned climate change scenarios. Moreover, under the A2 scenario, applying irrigation every 23 days would improve barley yield by an average of 2% with no additional increase in the applied irrigation water and applying irrigation every 21 days would increase the amount of applied irrigation by an average of 10%, with an average of 3% improvement in barley yield. In the B2 scenario, in contrast, irrigation every 23 days would attain a 2% yield improvement with 2% saving in the applied irrigation water and applying irrigation every 21 days would improve barley yield by 9% with the application of an additional 8% irrigation water. The most tolerant variety was 'Giza 2000', which was least affected by heat stress, produced the lowest yield reduction, responded well to changing irrigation schedules and attained the highest yield improvement. Therefore, 'Giza 2000' could be a very good candidate for breeding programs to produce more heat stress-tolerant cultivars.

Keywords: A2 and B2 climate change scenarios, barley cultivars, CSIRO, irrigation intervals

INTRODUCTION

The Earth has warmed by 0.7°C on average since 1900 (Jones and Moberg 2003). Most of the warming since 1950 is due to human activities that have increased greenhouse gases (IPCC 2001). There has been an increase in heat waves, fewer frosts, warming of the lower atmosphere and upper ocean, retreat of glaciers and sea-ice, an average rise in global sea-level of approximately 17 cm and increased heavy rainfall in many regions (IPCC 2001; Alexander *et al.* 2006). Many species of plants and animals have changed their location or behavior in ways that provide further evidence of global warming (Hughes *et al*. 2003).

To estimate future climate change, scientists have developed greenhouse gas and aerosol emission scenarios for the 21st century. These are not predictions of what will actually happen. They allow analysis of "what if?" questions based on various assumptions about human behavior, economic growth and technological change (Church and White 2006). Computer models of the climate system are the best tools available for simulating climate variability and change. These models include representations of the atmosphere, oceans, biosphere and Polar Regions (Vinnikov *et al.* 2006). Confidence in the reliability of these models for climate projections has also improved (IPCC 2001), based on tests of the ability to simulate the present average climate, including the annual cycle of seasonal changes, year-to-year variability, extreme events, such as storms and heat waves, climates from thousands of years ago, and observed climate trends in the recent past. The Intergovernmental Panel of Climate Change (IPCC) attributes most of the global warming observed over the last 50 years to greenhouse gases released by human activities. To estimate future climate change, the IPCC prepared 40 greenhouse gas and sulfate aerosol emission scenarios for the 21st century that combine a variety of assumptions about demographic, economic and technological driving forces likely to influence such emissions in the future.

Crop simulation models can be used to assess the likely impact of climate change on grain yield and yield variability. These crop models must accurately predict several key characteristics over a wide range of climatic conditions, such as timing of flowering and physiological maturity, through correct descriptions of phenological responses to temperature and day length. Furthermore, accumulation of yield needs to be predicted by accurately predicting the development and loss of leaf area and, therefore, a crop's ability to intercept radiation, accumulate biomass, and partition it to harvestable parts such as grain. Crop water use also needs to be accurately predicted by correctly predicting evapotranspiration and the extraction of soil water by plant roots (Richter and Semenov 2005). CropSyst is one of these models that could be used along with a set of daily weather data spanning a reasonable number of years to assess the impact of climate change on agriculture (Tubiello *et al.* 2000; Torriani *et al.* 2007a). The application of such models allows the simulation of many possible climate change scenarios from only a few experiments for calibration.

The effect of climate change on barley yield has been studied before in Egypt using GCMs and MAGIC/SENGEN climate change scenarios (Eid *et al.* 1995). The results showed that the national production of barley grain yield will be reduced by 20% and its water needs will be decreased by 1% by the year 2050. However, climate change urgently needs to be assessed at the level of the farm, so that poor and vulnerable farmers dependent on agriculture

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Table 1 Seasonal weather parameters for both growing season at El-Kalubia governorate.

Month	**2007/08 growing season**			**2008/09 growing season**		
	TempM (ºC)	**RH (%)**	**SR* (cal/cm^2/day)**	**TempM (ºC)**	**RH (%)**	**SR* (cal/cm^2/day)**
December	18.7	67	268	17.1	66	268
January	18.0	69	280	17.0	62	280
February	16.2	70	453	17.8	53	453
March	16.2	62	441	18.2	47	441
April	20.8	59	519	21.4	44	519
Average	18.0	56	392	18.3	54	392

TempM= mean temperature; RH= relative humidity; SR= solar radiation.
* estimated from normals (average of 50 years).

can be appropriately targeted in research and development activities to alleviate poverty (Jones and Throntonb 2003). Assessing the possible impact of climate change on production risks is therefore necessary to help decision makers and stakeholders to identify and implement suitable measures of adaptation (Torriani *et al.* 2007a).

Adaptation to climate change has received very little attention compared with mitigation; this may be partly because adaptation seems more complicated than mitigation, emission sources are relatively few, but the array of adaptation is vast, yet to ignore adaptation is both unrealistic and perilous (Parry *et al.* 1998). Adaptation refers to efforts to reduce a system's vulnerabilities to climate. According to the IPCC (1996), adaptation is concerned with the responses to both the negative and positive effects of climate change. It refers to any adjustments, whether passive, reactive, or anticipatory, that can respond to anticipated or actual consequences associated with climate change. Thus it implicitly recognizes that future climate change will occur and must be accommodated in policy. A wide range of responses can be implemented exogenously by management or policy decisions at the regional or national level. Agricultural adaptation to climate change at the farm level depends on the technological potential (different varieties of crops, irrigation technologies); basic soil, water, and biological response; and the capability of farmers to detect climate change and undertake any necessary actions. The effect of using adaptation strategies, such as changing sowing date and/or changing irrigation schedule was simulated for wheat (Khalil *et al.* 2009) and maize (Ouda *et al.* 2009) and proved to reduce yield vulnerability to climate change.

The objectives of this research were: (i) to develop two climate change scenarios using the CSIRO model; (ii) to incorporate the two climate change scenarios into the CropSyst model to predict the effect on barley yield; (iii) to predict the effect of two irrigation schedules on reducing barley's yield losses under climate change conditions.

MATERIALS AND METHODS

Field experiments

Two field experiments were conducted in 2007/08 and 2008/09 growing seasons at Shalakan, El-Kalubia governorate, South Delta, Egypt to collect data on barley yield and consumptive use. The aim of these experiments was to identify parameters to be used as indicators of yield stability of barley cultivars under sufficient irrigation and simulation of irrigation water saving, which could be useful under the stressful condition of climate change. Four hulled barley cultivars were used i.e. 'Giza 123', 'Giza 125', 'Giza 126', and 'Giza 2000', in addition to two hull-less barley cultivars i.e. 'Giza 129' and 'Giza 130'. A complete randomize block design with four replicates was used. The preceding crop was maize in both seasons and the soil type was clay loam with the following characteristics: 7.5% sand, 59.1% silt, 33.4% clay, pH = 7.55, Ec = 0.26 dsm^{-1}, Ca^{++} = 1.1, Mg^{++} = 0.5, Na^{+} = 1.3, K^{+} = 0.8, HCO$_3$ = 0.4, Cl^{-} = 2.6, SO$_4^{--}$ = 0.58 (meq/lit). Barley seeds were sown on the 3rd and 5th of December 2007 and 2008, respectively. Potassium fertilizer was added at a rate of 58 kg/ha (K_2SO_4). Nitrogen fertilizer as 108 kg/ha was divided into two equal doses, the first was added 25-30 days after planting and the second was added 30-35 days after the first dose. First irrigation was applied at sowing day, the second irrigation was applied one month after the first irrigation then plants were irrigated every 21 days. The total number of irrigation was five. Soil moisture was sampled before irrigation to calculate the needed amount of applied irrigation water to reach field capacity. Consumptive use was calculated using the following equation (Israelsen and Hansen 1962):

$$CU = (\Theta_2 - \Theta_1) * Bd * ERZ \qquad [1]$$

where: CU = the amount of consumptive use (mm), Θ_2 = soil moisture percentage after irrigation, Θ_1 = soil moisture percentage before the following irrigation, Bd = bulk density (g/cm^3) and ERZ = effective root zone. Maximum, minimum and mean temperatures in both growing seasons are included in **Table 1**.

CropSyst model

Data needed to calibrate CropSyst (Stockle *et al.* 1994) was collected. These data were phonological data i.e. days to emergence, anthesis, beginning of grain filling and physiological maturity, which were recorded in the field. Furthermore, maximum leaf area index was measured at anthesis. At harvest, grain and biological yield were measured and harvest index (HI) was calculated. HI is the proportion of biological yield represented by economic yield (Gardner *et al.* 19985). Detailed description of the calibration and validation of the CropSyst model, in addition to the goodness of fit between the measured and predicted data are included in part I of this paper (Ouda *et al.* 2010).

Climate change scenarios

Several global climate change models are available to produce climate change scenarios. One of them is CSIRO-MK2 model, which was developed by the Commonwealth Science and Industrial Research Organization (CSIRO) in Australia. Most of the future climate scenarios are produced by coupled Atmosphere-Ocean General Circulation Model (AOGCM), using different future trace gas emissions scenarios. CSIRO-MK2 is a globally coupled ocean-atmosphere-sea-ice model (CSIRO coupled). Atmospheric and oceanic components use a spectral R21 horizontal grid (each grid box measuring about 625 × 350 km) with 9 vertical levels in the atmosphere and 21 levels in the ocean. The ocean model has a heat transport scheme, which significantly reduces problems associated with excessive mixing in the Southern Ocean. This data was downloaded from Intergovernmental Panel on Climate Change (IPCC) Data Distribution Center (DDC). These data files are generally in 'grib' format; therefore they are read using 'pingo' software or by using any other software to convert into ACCII format. The downloaded GCM data is divided into two files based on base (1961-1990) and warm (1991-2099) scenarios. A FORTRAN program reads the parameter files of all the grids and makes interpolation for the studied area.

Scenarios A2 and B2 were used the most and have received the most scientific peer review. Because their output data are widely available, these two were adopted for use in study the impacts of climate change on barely in Egypt. The A2 climate change scenario storyline depicts a world of regional self-reliance and preservation of local culture. Furthermore, fertility patterns across regions converge slowly, leading to a steadily increasing population and per capita economic growth and technological change is slower and more fragmented than for the other storylines. The B2 storyline places emphasis on local solutions to economic, social and environmental sustainability. The population increases more slowly than that in A2. The economic development is intermediate and less rapid, and technological change is more diverse (Hennessy 2006). By incorporating these scenarios into computer models of the climate system, the IPCC (2001) estimated a global-average warming of 0.5-1.2°C by 2030, 0.7-2.5°C by 2050 and 1.4-5.8°C by 2100.

A2 and B2 climate change scenarios were incorporated in the CropSyst model to predict barley yield in 2039. The reason for choosing that year to predict potential barley yield was to perceive how barley productivity on the farm level will be affected after 30 years. Furthermore, the Egyptian agricultural strategic policy is concerned about the effect of climate change on crop production after 30 years. Percent reduction in barley yield as a result of these two scenarios was calculated. The effect of climate change on each of the two growing season will be discussed separately as if each season could be a representation of the growing season of the year 2039.

Effect of irrigation rescheduling

Two irrigation schedules were tested. These schedules were irrigation every 23 days and irrigation every 21 days, which increase the number of irrigation from five to six irrigations. To avoid the occurrence of water stress, the CropSyst model was set to apply enough water to refill the root zone. The model was also set to calculate the applied amount of irrigation for each cultivar under each schedule. Percent difference between the predicted yield values under the effect of climate change and the predicted values after the application of the two irrigation schedules was calculated.

RESULTS AND DISCUSSION

Effect of climate change scenarios on barley yield and the applied irrigation amount

The six barley cultivars responded differently under the stressful conditions imposed by the two climate change scenarios (**Table 2**). The effect of A2 climate change scenario was less pronounced on barley yield than the B2 scenario. In the 1st growing season, the highest yield reduction was found for 'Giza 123', i.e. 19.03 and 19.30% for A2 and B2 scenarios, respectively. 'Giza 125' was ranked second in yield reduction after 'Giza 123', where the reduction was 15.63 and 15.97% under A2 and B2 scenarios, respectively. The lowest yield reduction was found for 'Giza 2000', where it was 11.41 and 13.81% under A2 and B2 scenarios, respectively.

In the 2nd growing season, in general, barley yield reduction was higher, compared with the reduction in the 1st growing season. This could be attributed to relatively more stressful weather conditions that prevailed in the 2nd growing season, compared with the 1st growing season (**Table 1**). A similar response of 'Giza 123', 'Giza 125' and 'Giza 2000' was found in the 2nd growing season under both climate change scenarios, where lowest reduction was found for 'Giza 2000' and highest reduction was found for 'Giza 123', followed by 'Giza 125'. The obtained results implied that barley yield could be reduced by up to 24% under climate change conditions, depending on the cultivar and the expected scenario. These yield losses, although high, could be considered low compared with the expected yield losses for wheat or maize under the expected climate change conditions. Wheat yield is expected to be reduced by up to 46% (Khalil *et al.* 2009) whereas maize yield is expected to be reduced by up to 60% (Ouda *et al.* 2009) depending on the cultivar and the climate change scenario. These large yield losses will have important implications for worldwide food security (Rosenzweig and Hillel 1998). Thus, regional assessments of the effects of climate change on crop production are needed at various decision levels, and they are necessary to quantify the economic impacts at farm and regional scales. Small holder farmers are perhaps the segment of the population whose livelihoods are most susceptible to the impacts of climate variability (Porter and Semenov 2005). Changes in yield behavior in relation to shifts in climate can become critical for the economy of farmers. An increasing probability of low returns as a consequence of the more frequent occurrence of adverse conditions could prove dramatic for farmers operating at the limit of economic stress (Torriani *et al.* 2007b). The possible increase in climate variability has been recognized in recent years as one of the most critical issues (Mearns *et al.* 1997). Shifts in yield and yield stability largely depend on assumptions about future emissions, the climate projections, and the downscaling procedure used to generate the climatic data at the regional scale typically required as input to crop models. Olesen *et al.* (2007) noted that for a site-based analysis the method used for downscaling is more crucial than the choice of a specific climate scenario. They also pointed out that use of climate model outputs directly as input to the crop simulation model is appropriate to assess the impact of climate change on crop production.

With respect to the applied amount of irrigation, the results in **Table 2** show that a certain percent of the applied irrigation amount could be saved, depending on barley cultivars under both climate change scenarios. This result could be attributed to high stress of climate change conditions which reduced plant vegetative and reproductive growth. Furthermore, root growth is also reduced as a result of low vegetative growth. The applied irrigation amount for each of the six cultivars is limited by the root depth which reduced the amount of applied irrigation water as a result of limited root growth. This incident was also found for wheat grown under climate change conditions, where applied irrigation water was less than the amount under current conditions (Khalil *et al.* 2009). A similar result was reported by Eid *et al.* (1995), where they concluded that water needs for barley will be reduced by 1% under the projected climate change conditions.

The highest percentage of saved irrigation water was obtained for 'Giza 123' under both climate change scenarios

Table 2 Effect of two climate change scenarios on barley yield and the applied irrigation amount.

Cultivar	**Climate change scenario**	**1st growing season**		**2nd growing season**	
		PR% in yield	**PS% in irrigation**	**PR% in yield**	**PS% in irrigation**
Giza 123	A2	19.03	4.01	22.73	3.71
	B2	19.30	5.68	23.99	5.88
Giza 125	A2	15.63	3.88	20.90	3.62
	B2	15.97	5.64	21.90	5.78
Giza 126	A2	12.50	3.89	19.81	3.44
	B2	14.10	5.49	19.85	5.76
Giza 2000	A2	11.41	3.13	18.01	3.01
	B2	13.81	4.50	17.45	5.02
Giza 129	A2	14.11	3.80	18.87	2.81
	B2	14.52	5.20	19.62	5.64
Giza 130	A2	12.77	3.80	18.87	2.21
	B2	14.23	4.78	19.62	5.44

A2 and B2 = two climate change scenarios; PR% in yield = percent reduction in yield as a result of climate change scenarios**;** PS% in irrigation = percent saving in irrigation amount.

Table 3 Effect of changing irrigation schedule under A2 climate change scenario on barley yield and the applied irrigation amounts.

Cultivar	Irrigation schedule	1st growing season		2nd growing season	
		PI % in yield	**PC% in irrigation**	**PI % in yield**	**PC% in irrigation**
Giza 123	IS1	1.36	+0.37	2.53	+0.81
	IS2	3.24	+10.38	3.82	+10.52
Giza 125	IS1	2.43	+0.31	0.53	-0.77
	IS2	3.13	+10.00	1.32	+9.53
Giza 126	IS1	1.60	-0.02	1.85	-0.52
	IS2	1.92	+10.35	3.09	+10.42
Giza 2000	IS1	3.50	+0.32	2.55	+0.52
	IS2	6.10	+9.92	4.60	+10.02
Giza 129	IS1	1.61	-1.74	1.89	-1.69
	IS2	3.27	+8.48	4.53	+8.51
Giza 130	IS1	2.19	+0.32	1.68	+0.34
	IS2	2.55	+9.92	4.03	+9.99

IS1= irrigation every 23 days; IS2= irrigation every 21 days; PI% in yield= percent improvement in barley yield as a result of changing irrigation schedule; PC% in irrigation= percent change in irrigation amount.

Table 4 Effect of changing irrigation schedule under B2 climate change scenario on barley yield and the applied irrigation amounts.

Cultivar	Irrigation Schedule	1st growing season		2nd growing season	
		PI % in yield	**PC% in irrigation**	**PI % in yield**	**PC% in irrigation**
Giza 123	IS1	1.61	-2.96	1.77	-2.68
	IS2	8.85	+7.50	9.09	+7.97
Giza 125	IS1	1.39	+2.83	1.85	-3.04
	IS2	8.68	+7.45	8.99	+7.32
Giza 126	IS1	1.62	-2.84	1.86	-2.62
	IS2	8.33	+7.58	9.29	+7.96
Giza 2000	IS1	2.50	-2.99	1.94	-3.99
	IS2	9.61	+7.47	9.86	+6.38
Giza 129	IS1	1.61	-2.74	1.89	-2.69
	IS2	9.27	+7.48	9.43	+7.71
Giza 130	IS1	1.82	-2.73	1.68	-2.70
	IS2	9.49	+7.48	9.06	+7.73

IS1= irrigation every 23 days; IS2= irrigation every 21 days; PI% in yield= percent improvement in barley yield as a result of changing irrigation schedule; PC% in irrigation= percent change in irrigation amount.

and under both growing seasons, which also negatively affected yield and increased its losses. This could be an implication of the diminished growth of its roots. The highest percent of water saving was found under the B2 scenario for the six cultivars, which was associated with higher yield reduction, compared with the A2 scenario. Under this scenario, up to 6% of the applied irrigation water will be saved, depending on the cultivar (**Table 2**).

Effect of changing irrigation schedule under A2 climate change scenario

Barley yield was positively affected by changing irrigation schedule under the A2 scenario (**Table 3**). Under irrigation every 23 days (IS1), barley yield was improved by a lower percentage compared to irrigation every 21 days (IS2) for all cultivars and under both growing seasons. The highest improvement in barley yield occurred for 'Giza 2000' under both irrigation schedules and both growing seasons.

With respect to the percent change in the applied irrigation amount as a consequence of applying irrigation every 23 days, < 1% increase in the applied irrigation water improved barley yield by up to 3.50 and 2.55% for the six cultivars in the 1st and 2nd growing season, respectively. Changing irrigation schedule to applying irrigation every 21 days not only improved barley yield, but also increased the amount of applied irrigation water by up to 10.35 and 10.52% for the six cultivars for the 1st and 2nd growing season, respectively. This result implied that increasing the irrigation interval by 2 days from 21 days to 23 days increased the amount of applied irrigation by up to 10%, depending on the cultivar with relatively low yield improvement, which is very disappointing (**Table 3**).

The highest improvement in yield was obtained for 'Giza 2000', i.e. 3.50 and 6.10% for IS1 and IS2, respectively in the 1st growing season. 'Giza 2000' also attained the highest yield improvement in the second growing season. Its yield was improved by 2.55 and 4.60% under IS1 and IS2, respectively. The amount of applied irrigation increased by 0.52 and 10.02% under irrigation every 23 and 21 days, respectively for 'Giza 2000'.

Effect of changing irrigation schedule under B2 climate change scenario

When irrigation was applied every 23 days under the B2 scenario, low yield improvements were obtained, which was similar to the ones that occurred under the A2 scenario for both growing seasons, saving applied irrigation water by < 3% in all cultivars (**Table 4**). However, under irrigation every 21 days, relatively high yield improvement occurred under both growing seasons with < 8% increase in the applied irrigation water.

Thus, in comparison with the A2 scenario, less irrigation water was applied when the irrigation interval was every 21 days and higher yield improvement occurred (**Table 4**). The applied irrigation amounts under B2 were less than under A2 because B2 is more stressful than A2, which resulted in a reduction in barley root growth. However, higher improvement in the yield of all cultivars was observed and could be attributed to the appropriateness of the timing of application, which reduced yield losses and improved yield.

Irrigation scheduling could play a vital role in saving irrigation water in Egypt under current conditions, where the Egyptian government is promoting that concept to farmers. The over-irrigation by Egyptian farmers results in high water losses and low water use efficiency, which creates drainage and salinity problems. Thus, the expected limited availability of irrigation water under climate change conditions requires fundamental changes in irrigation management to save irrigation water.

The highest yield improvement occurred for 'Giza 2000' under both irrigation schedules and under both growing seasons. Barley yield was improved by 2.50 and 9.61% under irrigation every 23 and 21 days, respectively in the 1st growing season. Furthermore, in the 2nd growing season, the yield was improved by 1.94 and 9.86% under irrigation every 23 and 21 days, respectively.

In a previous comparative study between the above mentioned six cultivars conducted in 2002/03 and 2003/04 growing seasons in Egypt (El-Kholy *et al.* 2005), 'Giza 2000' was found to have longer spikes, higher number of spikes/plant, higher number of spikes/m^2 and higher grain number/plant. These four yield attributes might positively contribute to an increase in the tolerance of 'Giza 2000' to heat stress and reduce yield losses under the two studied climate change scenarios (**Table 2**). Furthermore, these four yield attributes might also play a role in increasing the improvement percentage in yield using both irrigation schedules under the two climate change scenarios compared with the other cultivars (**Tables 3, 4**). Similar results were obtained by Ouda *et al.* (2007) when 'Giza 2000' was evaluated under water stress conditions.

CONCLUSION

Rapid changes of climate may seriously inhibit the ability of some crops to survive or to achieve the desired yields in their current region. Our results showed that barley yield will be reduced 17 and 18% on average over the six cultivars for A2 and B2 climate change scenarios, respectively. Furthermore, water requirement for barley will be reduced by 4 and 5% for these climate change scenarios.

The positive effects of adaptation strategies on agriculture under climate change have been confirmed in many studies. The best way to adapt to some uncertain future climate is to improve adaptation to present day climate variability and to reduce vulnerability to extreme events. Changing irrigation schedule is an important adaptation option that could reduce the vulnerability of a growing crop to climate change conditions. The significance of it is related to having a cheap option; adding no cost to farmers' budgets, in addition to being easy to implement. Simulation models can provide an alternative, less time-consuming and inexpensive means of determining the effect of changing irrigation schedule on crops under climate change conditions. Our results proved that changing the irrigation schedule was effective in reducing barley yield vulnerability to climate change.

Under the A2 scenario, applying irrigation every 23 days improved barley yield by an average of 2% with no additional increase in the applied irrigation water compared with the amount applied under current climate condition. Furthermore, applying irrigation every 21 days increased the amount of irrigation applied by an average of 10%, with an average of 3% improvement in barley yield under the same scenario.

The benefit of changing irrigation schedule was more pronounced under the B2 scenario, where under irrigation every 23 days 2% yield improvement was achieved with 2% saving in the applied irrigation water. However, applying irrigation every 21 days improved barley yield by 9% with the application of an additional 8% irrigation water.

Depending on what the policy maker wants to achieve a conclusion can be draw. If the policy maker wants to conserve irrigation water, regardless of the amount of yield, applying irrigation every 23 days could be used. On the other hand, if the policy maker is more concerned about improving yield production and not concerned about the amount of applied irrigation water, which is less likely to happen, irrigation every 21 days could be used.

The most tolerant barley cultivar between the studied six cultivars was 'Giza 2000'. It was less affected by heat stress and produced the lowest reduction in yield. Furthermore, it responded well to changing irrigation schedules and attained the highest yield improvement. Therefore, 'Giza 2000' could be a very good candidate to be used in breeding programs to produce more tolerant cultivars for heat stress.

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