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IMPACT OF TEMPERATURE CHANGE AND ELEVATED CARBON DIOXIDE ON WINTER WHEAT (*TRITICUM AESTIVUM* L.) GROWN UNDER SEMI-ARID CONDITIONS

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Abstract

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A study was conducted to determine effects of changed daily maximum, minimum, and elevated CO_2 levels on winter wheat yield and yield components. Treatments included 0 ± 2, 4, and 6^0C in daily maximum and minimum temperatures, and 380, 420, 460, and 500 ppm elevated CO_2 levels. CERES-Wheat model was utilized for simulations and results were used for graphical and statistical analysis. Simulations showed that change in both temperature affected yield and all simulated physiological parameters. Results indicated that when both temperatures increased by 6^0C, yield decreased 30%, while 6^0C decrease in temperatures increased yield by 37% (about 5000 kg ha^{-1}). The same effect was observed on the other simulated parameters such as biomass, 1000 seed weight….etc. However effects of both temperature changes were not equally divided. Daily maximum temperatures were affecting simulated parameters more than minimum temperatures. On the other hand, elevated CO_2 levels also positively affected yield, grain number, leaf area, and biomass. While, elevated CO_2 levels reduced harvest index and evapotranspiration but did not had any effect on flowering date, maturity, and 1 000 seed weight. Every 40 ppm increase in CO_2 level increased yields about 150 kg ha^{-1} in all elevated CO_2 treatments.

Key words: CERES-Wheat; changed maximum and minimum temperatures; elevated $CO_{2;}$ wheat yield and evapotranspiration

Introduction

Intergovernmental Panel on Climate Change claimed that globally 0.23°C per decade increase will occur in average annual temperatures and indicated that in next century, if the rate of emission of greenhouse gases (CO, CH, CFCs, N, O) to atmosphere continues, global mean temperatures will increase by 1.4 to 5.8^0C (IPCC, 2001). Even though, in the period of 1951-1990 mean temperatures increased about 0.5^0C (Jones et al., 1991), Karl et al. (1991) claimed that minimum temperatures increased 3 times

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higher than maximum temperatures. Conroy et al. (1994) stated that elevated temperatures effect is not yet well known, while CO_2 alone will be beneficial to most crops. Trough 19581997 years CO_2 concentrations has been rising and totaled a 16% increase.

Temperature plays a crucial role on wheat growth (Grace, 1988) and physiological parameters (Bauer et al., 1984) such as cold hardening and winterkill (Gusta and Fowler, 1976), vernalization (Trione and Metzer, 1970), leaf appearance (Baker et al., 1980), carbohydrate fixation and respiration (Goudriaan et al., 1985), rate of grain-filling (Wardlaw, 1994), evapotranspiration and water stress (Ritchie, 1972). However, there are limited predictions about how elevated temperatures may effect crop growth and yield. Those are; reduce vernalization, increase evapotranspiration, and decrease length of growing season (Meams et al., 1992; Monteith, 1981; Butterfield and Morison, 1992).

CERES-Wheat crop model, part of DSSAT Version 3.5 package, was developed to mimic the effects of cultivar, weather, soil parameters on crop growth and production, thus allowing to forecast the effect of different management strategies. CERES models have widely been used to asses the impact of climatic change on agricultural crops development and production (Otter-Nacke et al., 1986; Moulin and Beckie, 1993; Gennadiy and Larisa, 1994; Otavio et al., 1994; Rao and Sinha, 1994; Rosenzweig and Iglesias, 1998; Mahmood, 1998; Ghaffari et al., 2002; Luo et al., 1998; Dhakhwa et al., 1997; Mati, 2000). CERES-Wheat model is intended to simulate wheat grain response in a given year and location and is widely studied and results were found to be promising (Otter-Nacke et al., 1986), while the model was also used to asses the effect of climate changes with different scenarios (Rosenzweig and Tubiello, 1996). Model input files include soil, weather, cultivar genetic files and some management factors such as plant population, row spacing, irrigation, fertilization, and CO_2 level. Mainly soil file includes; number of layers and depth in soil profile, texture, permeability, bulk density, saturated hydraulic conductivity for each soil layer, soil water holding capacity, wilting point, and organic mater. While, weather file includes daily maximum and minimum temperatures (^{0}C), precipitation (mm), and solar radiation (MJ m^{-2} day^{-1}).

Zhiqing et al. (1994) stated that with temperature increase, crop yield of rain fed rice would decrease but with elevated CO_2 level photosynthesis would increase and may compensate the negative effect of temperature while Tubiello et al. (1995) claimed the same thing for wheat. Ghaffari et al. (2002) conducted a study to determine the effect of 6 different temperature increase rates expected to happen in England in years 2025-2050 using CERES-Wheat model and concluded that temperature increases alone reduced yield. Then, they tried to find the best way of increasing yield and found that with increased fertilization and early planting along with elevated CO_2 levels could prevent crop yield losses and may even increase. Lal et al. (1998) conducted a study using CERES-Wheat model under northwest of India conditions and claimed that, in general, wheat production would decrease with enhanced temperatures even with the positive effect of elevated CO_2 levels.

A study conducted in midwest of the USA evaluated different climatic scenarios for four different crops and concluded that temperature increase due to global warming would shortened maturity time, decrease water use efficiency and lower yield (Brown and Rosenberg, 1997). Lobell et al. (2005) claimed that wheat yield in northwest states of Mexico increased about 25% over past two decades and that increase was attributed mostly to decrease in night time temperatures.

Researchers indicated that increase in CO_2 levels would increase photosynthetic rates resulting in increased biomass and yield production of not only agricultural crops but also naturally grown plants as well (Kimball, 1983; Lawlor and Mitchell, 1991; Norby et al., 1999; Poorter and Navas, 2003). Studies conducted to determine the effect of elevated CO_2 levels on rice (Baker et al., 1996; Ziska et al., 1997; Moya et al., 1998; Kim et al., 2003) soybean (Booker et al., 2005; Hamilton et al., 2005) cotton (Reddy et al., 2004) concluded that yield of those crops were increased with elevated CO_2 levels.

Harran Plain is part of Southeastern Anatolian Project (GAP), an integrated irrigation and regional development project covers about 7.5 million ha of land in which 3.1 million ha is cultivated. When the project is completed, in total 1.7 million ha agricultural land will open to irrigation. Part of GAP project, Harran Plain was the first to open irrigations in 1995 and currently 140 000 ha of agricultural land is irrigated and expected to help the development of the region with its potential of producing high valued crops as well as traditional crops. However, there is need to determine the effect of global or regional climate change including temperature fluctuations and elevated CO_2 on agronomic crops grown in this semi-arid region such as Harran Plain.

Therefore objectives of this study was; to determine the impact of changed daily minimum and maximum temperatures, and elevated CO_2 level on winter wheat growth and yield under semi-arid climatic conditions of Harran Plain, Sanliurfa, Turkey, so as to make interpretation of possible applications of the results to semi-arid conditions of the study area and similar semi-arid regions in the world.

Materials and Methods

CERES-Wheat model

Decision Support System for Agrotechnology Transfer (DSSAT, 3.5) software is set to manage and manipulate weather, soil, and crop data and to run different crop models such as soybean, maize, wheat, barley in various ways and analyze outputs. Crop growth, and resulting yield and yield components were simulated under no water stress using the CERES-Wheat model, with different rates of current daily minimum and maximum temperatures and CO_2 levels on wheat growth and yield parameters. Some of the weather and soil characteristics were presented in Table 1. Simulated parameters included flowering date, physiological maturity, grain yield (kg ha^{-1}; dry), 1000 seed weight (g), grain number (grain m^{-2}), maximum leaf area index (m^2 m^{-2}), biomass (kg ha^{-1}) at harvest maturity, and harvest index (kg kg^{-1}).

Simulation region was assumed to be faculty of agricultural engineering research field (37^{0}08^I N, 38^{0}46^I E, with altitude of 465 m) located at Research Station of the University of Harran, Sanliurfa, Turkey. Experiment was conducted on a clay loam soil type classified as of the Ikizce soil series (Vertic Calciorthid Aridisol) that had a field capacity of around 32%, permanent wilting point about 22%, available water about 155 mm /120 cm and infiltration rate was 13 mm h^{-1}(Table 2). The reason this location was selected for this study was because recent studies showed that climate in this region, either because of global warming or since it was recently opened to irrigation, is changing (Tonkaz et al., 2003). Sanliurfa has average temperature, relative humidity, and wind speed values of 18.1 ^{0}C, 52%, and 1.7 m s^{-1}, respectively, and surrounded with Fatik and Tektek mountains from

Table 1
Some of the characteristics of weather related parameters for study area

Parameters	November	December	January	February	March	April	May	June
Min. air temp. (^{0}C)	5.7	2.9	1.4	1.8	4.5	9.2	12.8	17.9
Max. air temp. (^{0}C)	22.1	14	11.3	14.7	20.1	25.4	32	36.9
Av. temp. (^{0}C)	13.3	8	6.3	7.5	11.4	16.5	22.2	27.7
Precipitation (mm)	47.3	76	66.1	79.4	61.7	42.6	29.2	4.1
Relative hum. (%)	61.9	71.5	70.4	66.6	61.6	57.9	46.5	35.2
Wind speed (m s^{-1})	1.2	1.2	1.3	1.5	1.6	1.8	1.9	2.4
Solar radiation (MJ m^{-2} day^{-1})	9.1	6.6	7.5	10.9	15.1	19	22.8	25.8

west and east, respectively, while Urfa mountain on the north and Syrian border on the south side.

Winter-US cultivar was used in simulations under the conditions that; there was no fertilizer deficiency and water stress (automated irrigation, 100% efficiency), 1st of October was planting date, and 250 seed m^{-2} sowing rate was used with 100% germination rate. Weeds, insects and crop diseases had no negative effect on yield. CERES-Wheat model was set to use Priestly-Taylor evapotranspiration model to calculate crop water requirement

Weather data used in this study were generated using Autoregressive Moving-Average method (ARMA (p, q) (Salas et al., 1980), with which daily average minimum and maximum data for each set of temperatures (0 and ±2, 4 , and 6 ^{0}C, 0 represents long term average values of temperature and hereafter called as current) were simulated. Daily average solar radiation and precipitation values were average of 1975-2005 years.

Treatments used in this study in order to determine the effect of different air temperatures and CO_2 levels on winter wheat were as follows:

1. Daily minimum temperatures; current (average of 31 years, 1975-2005) 0 and ± 2, ±4, and ±6^{0}C (total of 7)

2. Daily maximum temperatures; current (average of 31 years, 1975-2005) 0 and ±2, ±4, and ±6^{0}C (total of 7) and,

3. Current CO_2 level (380 ppm) and possible elevated CO_2 levels of 420, 460, and 500 ppm (total of 4).

With treatment combinations (total of 196 (7*7*4) runs), it was hoped that the effect of minimum and maximum temperatures along with CO_2 levels would be determined.

Simulated results were analyzed with regression analysis in order to determine the effect of each treatment and the combination of treatments. Additionally simulated data were evaluated graphically.

Results and Discussion

ARMA(3,1) and ARMA(3,2) models were well fitted to daily maximum and minimum temperatures series of the station, respectively. In order to generate synthetic data, residuals of the model fitted to certain probability distributions. Considering KS values, logistic and BetaGeneral distributions were found adequate for maximum and minimum temperatures series, respectively. Synthetic temperature series were generated using the adequate models recombining periodic and probabilistic components of the series.

At 380 ppm CO_2 level, the lowest yield occurred at +6^{0}C, +6^{0}C treatment (max. and min. temperatures, respectively) as 5209 kg ha^{-1}, while highest yield occurred as 10843 kg ha^{-1}, at -6^{0}C,-6^{0}C treatment with an average yield of 8018 kg ha^{-1}. At current temperatures (0^{0}C) and CO_2 level (380 ppm) simulated yield was 8287 kg ha^{-1}. Similarly, at 420 CO_2 level, highest and lowest wheat yields were 11 101 and 5 312 kg ha^{-1}, respectively (Table 3 and Figure 1). Average and current yield at 420 ppm CO_2 level were 8183 and 8455 kg ha^{-1}, respectively. Likewise,

Table 2

Some of the selected soil properties used in the study FC, Field capacity; PWP, Permanent wilting point; BD, Bulk density, OM, Organic water

Depth, cm	FC, cm^3 cm^{-3}	PWP, %	BD, g cm^{-3}	pH	Soil particle distribution, % Sand	Silt	Clay	Texture class
18	0.39	0.23	1.35	7.3	7.3	34.7	58	Clay
39	0.39	0.23	1.35	7.3	7.1	32.6	60.3	Clay
49	0.39	0.23	1.36	7.4	7.7	29.2	63.1	Clay
88	0.39	0.23	1.36	7.4	34.3	19.3	46.4	Clay
120	0.39	0.23	1.35	7.4	34.3	19.3	46.4	Clay

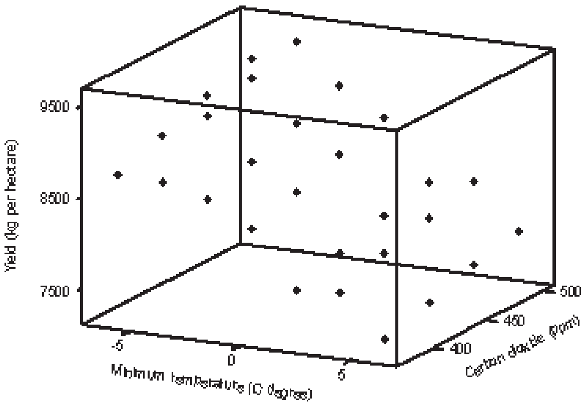

Fig. 1. Yield response to minimum temperature and CO_2 at constant value of current maximum temperature

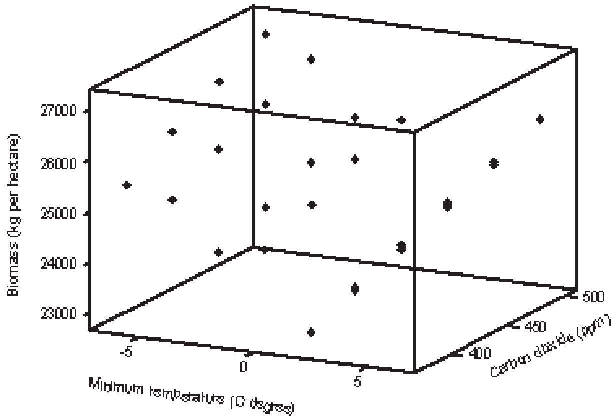

Fig. 2. Yield response to maximum and minimum temperature at constant value of CO_2 at current value of 380 ppm

highest and lowest wheat yields were simulated as 11343 and 5 413 kg ha^{-1} with current and average yields of 8611 and 8 336 kg ha^{-1} at 460 CO_2 level, respectively (Table 3). In agreement with the other three levels, at 500 CO_2 level maximum, minimum, current and average wheat yields turned out to be 11 579, 5 498, 8 754, and 8 478 kg ha^{-1}, respectively. Also, when CO_2 level was fixed, effect of both studied temperatures were similar and there was about 37% increase and 32% decrease in wheat yields compared to current situation (Table 3 and Figures 1 and 2). It was noticed that 4.5 ^{0}C increases in both temperatures would result in severe impact on wheat yield production. Statistical analyses of all CO_2 levels data indicated that both maximum and minimum temperatures significantly effected wheat yield at P<0.01 level. Overall results of this study showed that, when temperatures increased, maturity time decreased parallel to seasonal crop water use resulting in lower yields by 5634, 5789, 5930, and 6 081 kg ha^{-1} for 380, 420, 460, and 500 ppm CO_2 levels, respectively (Table 3). Simulation results showed that yield increased, for every 40 ppm increase in CO_2 levels, about 150 kg ha^{-1}, however, yield increase was limited compared to temperature effect . The highest increase in CO_2 could not compensate yield reduction

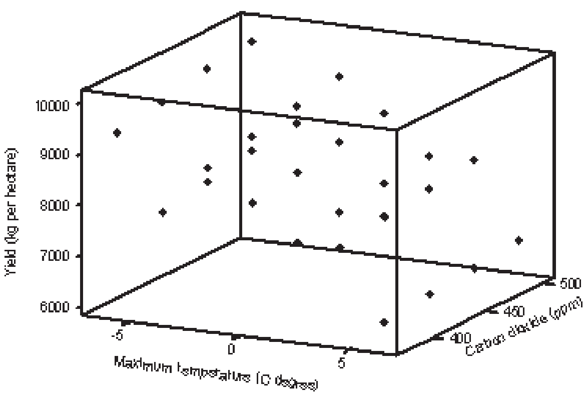

Fig. 3. Yield response to maximum and CO_2 at constant value of current minimum temperature

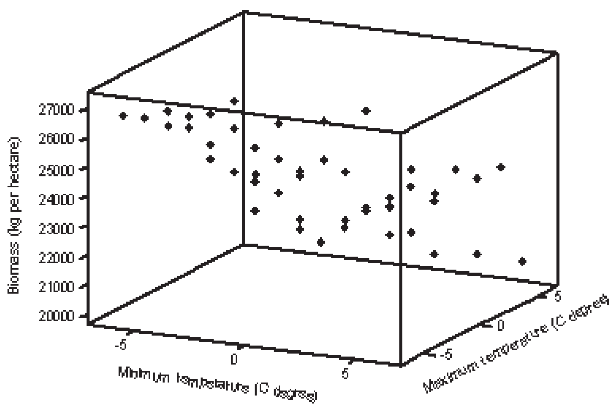

Fig. 4. Biomass response to maximum and minimum temperature at constant value of CO_2 at current value of 380 ppm

Table 3
CERES-Wheat model simulation results

Parameters	CO_2 levels (ppm)			
Yield, kg ha^{-1}	380	420	460	500
Lowest	5209	5312	5413	5498
Highest	10843	11101	11343	11579
Current	8287	8455	8611	8754
Average	8018	8183	8336	8478
% increase	**37.14**	**37.17**	**37.14**	**37.19**
% decrease	**30.84**	**31.29**	**31.73**	**32.27**
Flowering date (DAP)				
Lowest	156	156	156	156
Highest	203	203	203	203
Current	181	181	181	181
Average	177	177	177	177
% increase	**13.82**	**13.81**	**13.81**	**13.81**
% decrease	**12.16**	**12.15**	**12.15**	**12.15**
Maturity (DAP)				
Lowest	198	198	198	198
Highest	244	244	244	244
Current	219	219	219	219
Average	218	218	218	218
% increase	**9.59**	**9.59**	**9.59**	**9.59**
% decrease	**11.42**	**11.42**	**11.42**	**11.42**
1000 grain weight, g				
Lowest	20	20	20	20
Highest	24.5	24.5	24.5	24.5
Current	21.2	21.2	21.2	21.2
Average	22.1	22.1	22.1	22.1
% increase	**5.66**	**5.66**	**5.66**	**5.66**
% decrease	**15.57**	**15.57**	**15.57**	**15.57**
Grain number, grain m^{-2}				
Lowest	25438	25944	26435	26854
Highest	45227	45981	46985	47962
Current	39005	39796	40529	41205
Average	36223	36967	37628	38269
% increase	**34.78**	**34.81**	**34.76**	**34.83**
% decrease	**15.95**	**15.55**	**15.93**	**16.40**

(continued)

Continued Table 3

Leaf area, m^2 m^{-2}				
Lowest	5.63	5.75	5.85	5.95
Highest	7.18	7.38	7.53	7.66
Current	6.65	6.75	6.85	6.93
Average	6.3	6.38	6.45	6.53
% increase	**15.34**	**14.81**	**14.59**	**14.14**
% decrease	**7.97**	**9.33**	**9.93**	**10.53**
Biomass, kg ha^{-1}				
Lowest	20385	20846	21237	21587
Highest	26956	27632	28141	28633
Current	24532	24958	25354	25718
Average	23941	24420	24873	25297
% increase	**16.9**	**16.48**	**16.24**	**16.06**
% decrease	**9.88**	**10.71**	**10.99**	**11.33**
Harvest index				
Lowest	0.254	0.253	0.253	0.252
Highest	0.407	0.407	0.407	0.407
Current	0.338	0.339	0.34	0.34
Average	0.334	0.334	0.334	0.334
% increase	**24.85**	**25.37**	**25.59**	**25.88**
% decrease	**20.41**	**20.06**	**19.71**	**19.71**
Evapotranspiration, mm				
Lowest	431	431	429	429
Highest	572	560	556	554
Current	495	491	488	486
Average	484	481	478	476
% increase	**12.93**	**12.22**	**12.09**	**11.73**
% decrease	**15.56**	**14.05**	**13.93**	**13.99**

Current values represent long term maximum and minimum temperatures with no change and 380 ppm elevated CO_2 level and DAP, day after planting.

due to increased temperatures even with the smallest temperature increase (2^0C in this study) in maximum and minimum temperatures (Table 3 and Figures 1, 2, and 3). Results of this study are in agreement with Karim et al. (1996) and Ghaffari et al. (2002).

Wheat physiological parameters were also significantly (P<0.01) affected by all treatments similar to yield results. Simulated biomass values indicated that reduction in maximum and minimum temperatures increased biomass results (P<0.01) about 16% while increase in both temperatures reduced (P<0.01) about 10% at each of the CO_2 level (Table 3 and Figures 4, 5, and 6). Flowering and maturity dates were similarly reduced with changed maximum and minimum temperatures regardless of CO_2 levels and were ranged from 156 to 203 and 198 244 days, respectively (Table 3). On the other hand, despite of CO_2 levels, 1 000 grain weights were influenced by change

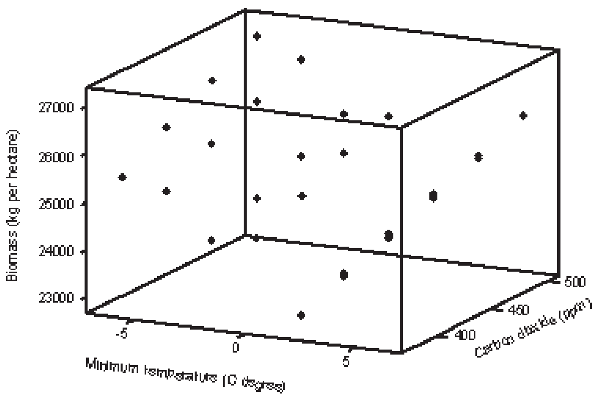

Fig. 5. Biomass response to minimum temperature and CO_2 at constant value of current maximum temperature

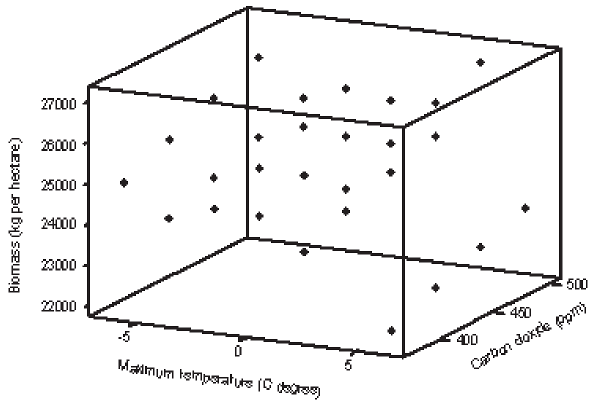

Fig. 6. Biomass response to maximum and CO_2 at constant value of current minimum temperature

in temperatures, resulting in minimum of 20 and maximum of 24.5 g. Grain number, leaf area, and harvest index simulation results, likewise, showed significant difference ($P<0.01$) by all three treatments. However, temperatures had more impact than elevated CO_2 levels (Table 3).

Simulated seasonal wheat crop avapotranspiration values (ETc) were also affected by maximum and minimum temperatures as 12-13% increase and 14-16% decrease. In all temperatures and CO_2 combination treatments lowest and highest ETc values were 431 and 572 mm per season both occurring at $+6^0$C, -4^0C and -6^0C, 0^0C treatments, respectively. Those differences happened partly because of influenced crop growing period affected by all maximum, minimum and CO_2 treatment combinations. Crop water use also influenced by maximum and minimum temperatures (Table 3).

When maximum, minimum, and CO_2 levels were separately analyzed, results clearly indicated that the most effective treatment on simulated parameters was maximum temperature changes, even though all three treatments were statistically significantly effected physiological parameters.

Conclusions

This study was conducted to determine the impact of daily maximum, minimum temperatures, not only due to climate change but also interannual oscillation of meteorological parameters, and elevated CO_2 levels effect using CERES-Wheat model on winter wheat yield and yield components under semi-arid conditions of Sanliurfa, Turkey. Results showed that both daily maximum and minimum temperatures affected wheat crop yield and all simulated physiological parameters. Simulations indicated that when both daily maximum and minimum temperatures increased by 6^0C, yield decreased 30%, while those temperatures decreased at 6^0C, wheat yield increased about 37%. However impact of both temperatures was not equally balanced. Analyses of the data showed that daily maximum temperatures were affecting more simulated parameters than minimum temperatures. Simulated biomass values increased about 16% with lowered temperatures and 10% reduction with increased temperatures. On the other hand, elevated CO_2 levels also positively affected wheat yield, grain number, leaf area, and biomass. While, elevated CO_2 levels reduced harvest index and crop water use (evapotranspiration) but did not had any effect on flowering date, maturity, and 1000 grain weight. Every 40 ppm increase in CO_2 level increased wheat yields about 150 kg ha^{-1} in all maximum and minimum temperature treatments. These results could be used for similar regions of the world with semi-arid climatic conditions in order to forecast future scenarios of predicting wheat yield and yield components. Additionally, since 12%

increase was observed in evapotranspiration, results could be use for management of water sources for future planning. Previous studies claimed that global warming results in higher temperatures in current semi-arid regions, such as this study area. Additionally, it is reported that opening large areas to irrigation brings unexpected change in meteorological characteristics. These changes pushes wheat belt from current locations to northern areas of the world. Thus findings of this study may help to have better understanding of effect of meteorological changes on wheat in semi-arid regions.

Results also point out that in current semi-arid regions there may be need for new breeding studies concentrating on heat tolerant varieties of wheat or even change in land use or cultivating different crops, which will adapt to new climatic conditions, might be considered to avoid or at least reduce the negative impact of climate change on agricultural crops.

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