COMPARISON OF SIMULATION MODELS FOR DETERMINATION OF FUTURE WHEAT YIELDS IN THRACE, TURKEY

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Abstract

Wheat is one of the most important crops used as a global food source. For this reason, it is extremely important how wheat will be affected in the future by ongoing and possible changes in climate both quantitatively and qualitatively. That's why, numerous studies have been conducted for the estimation of future agrometeorological conditions. Among these conditions, especially higher temperatures and lack of water for plant consumption due to decreased precipitation come to forefront for semi-arid regions like the Thrace part of Turkey. Hence, high reliability is needed within studies on future climate projections which can be taken as meteorological inputs of the dynamic crop growth models into consideration. Such models can mimic the behaviour of rather complex crop system. In order to avoid misleading results, they should be priorly calibrated using actual field data.

This study represents one of the first aforementioned steps taken at a location in the Thrace region of Turkey by means of investigation of the possible future variations of wheat. Agricultural management information together with meteorological data were collected directly from an agrometeorological station. Then, calibration procedure was applied to two crop growth models, namely DSSAT and WOFOST by considering one recent growing season (2010-2011) of the selected winter wheat field in Kırklareli city of the Thrace. Later, calibration is repeated also for the representation of long term (1975-2010) mean wheat growth of the field. Finally, the outputs of a regional climate model (RegCm4) were adapted into the crop models for the estimation of the future periods between the years 2013 and 2040. As a result, both models indicated slight decreases (2 to 6 %) in average wheat grain yield, whereas no such agreement could be found between the models.

Key words: *climate change, winter wheat, crop-climate model, model calibration*

1. INTRODUCTION

Winter wheat (Triticum aestivum L.) is a widely grown crop as the major nutrient source in Turkey. In common with all other crops, also the growth of winter wheat occurs under the effect of the atmospheric conditions which are mostly uncontrollable. That's why the current and expected aspects of increasing greenhouse gases and variations in some dominant meteorological variables like temperature, precipitation, solar radiation, etc., are needed. Taking the related steps is especially important to reveal the possible aspects of food quantity and quality by means of climatic change. Concordantly, recent agricultural meteorological studies are focused on modeling approaches for the analysis of the effects of environmental factors on crop growth and yield. As a complex and dynamic system, the crop growth can be represented by relatively simple mathematical models (Penning de Vries et al., 1989). These crop growth simulation models require various management and meteorological input data for the calculation of major growth and yield parameters. Thus, scheduling and amount of significant management activities (tillage, irrigation etc.,) can be better planned so that needful measures can be taken also for the future (Whisler et. al., 1986). Gangopadhyaya and Sarker (1965) made an attempt for the representation of wheat yield in a descriptive way by considering precipitation data. As another early step, Haun (1974) presented wheat growth and yield as functions of temperature and moisture. Following studies on crop modeling were in coincidence with developments in computer technology (Dumanski and Stewart, 1983). Effect of increasing CO_2

concentrations on wheat yield was modeled by Diepen et. al., (1987). Baier (1978) interpreted the complex interaction between the meteorological parameters and crop dynamics like transpiration and photosynthesis. Chipanshi et. al. (1997) used the explanatory CERES-Wheat model for modeling the wheat yield in Canada. Possible shortening in wheat's growing season due to increasing temperatures was quantified by Mearns et. al. (1997) in Canada. Hsiao et. al. (2009) investigated the impacts of variations in soil moisture on crop yield by AquaCrop Model. Palosuo et al. (2011) performed a comparative modeling study on winter wheat for different climatic regimes in Europe. Iglesias et. al. (2012) also used different crop models to display possible related effects of climate change in Europe. Similarly, Eitzinger et al. (2013) applied a comparative sensitivity analysis on wheat to show the probable effects of extreme atmospheric variations on yield. Complexity of the analysis and evaluation process for wheat under varying climate conditions was revealed by Asseng et. al., (2013).

In Turkey; however, preliminary results on crop growth modeling studies come first from 1990's. In this context, Şaylan et. al. (1995) investigated the facilities of crop models for drought analysis. Later, Çaldağ and Şaylan (2005) applied a consequtive growing season analysis of 2 years for winter growth and yield in Northwest Turkey using the CERES-Wheat Model. Finally, a recent study was conducted by Çaldağ et. al. (2017), in which comparative analysis was done between two crop models by means of validation and sensitivity analysis.

2. MATERIAL AND METHODS

2.1. Data Collection

The study was carried out on a winter wheat field in the research area of Kırklareli Atatürk Soil, Water and Agricultural Meteorology Research Institute (41°41'53''N, 27°12'37''S). Required field data were collected directly using an automatised agrometeorology station established in that field (Fig. 1). In addition to the sensors for meeting the model input requirements, installations on the measurement of net radiation, soil heat flux etc. were also included in the whole system for further agrometeorological analysis.

Figure 1. Agrometeorology station established in the winter wheat field.

Daily averages needed for the model input database were derived from the 30 minutes interval data with relatively higher temporal resolution. Extra effort was given to the usage of a LAI (Leaf Area Index) instrument on a weekly basis for monitoring the crop dynamics and supply the model calibration needs. All the aforementioned daily data are integrated with regular and up-to-date measurements of environmental and management factors (soil texture, soil water content, organic matter, fertilization, agricultural spraying, etc.).

2.2. WOFOST and DSSAT Models

As a joint product of the Center for World Food Studies and the Wageningen University, the WOFOST (WOrld FOod STudies) was developed to represent the major parameters of crop growth in a dynamic way (De Wit, n. d.). Currently, the model is widely in use to analyze possible effects of field experiments and expected effects of climate change on crop growth. Similarly, the DSSAT (Decision Support System for Agrotechnology Transfer) is a common software structure for the purpose of crop modeling, which includes also the CERES-Wheat Model within the frame of CERES (Crop Environment Resource Synthesis) model group (Tsuji et. al., 1994).

Major common meteorological data needed for both of the models are daily maximum-minimum temperatures, global solar radiation and precipitation. Moreover, other input requirements on soil and crop features at the beginning of the growing period together with agricultural management activities were also supplied to the models prior to the calibration step. Comparison of daily actual evapotranspiration and soil water content were also done with corresponding model outputs.

3. RESULTS AND DISCUSSION

3.1. Observations and Field Studies

Samples taken from different layers in the soil showed that sand represents ca. 50% of the general soil texture, whereas each of the clay- and silt contents varies between 20 and 30% (Şaylan et. al., 2012). A domestic genotype (Gelibolu) was cultivated in the field, for which the growing season was between 25.10.2010 (sowing) and 8.7.2011 (harvest). Full set of the phenological stages of the crop is given in Table 3.1.

Table 3.1. Winter wheat phenology during the 2010-2011 growing season.

Phenological stages of "Gelibolu"	**Date**
Sowing	25.10.2010
Germination	5.11.2010
Second Leaf	10.11.2010
Third Leaf	15.11.2010
Tillering	7.12.2010
Stem Formation	29.03.2011
Earing	10.05.2011
Flowering	19.05.2011
Grain Filling Period	01.06.2011
Maturity	13.06.2011
Harvest	08.07.2011

Sowing depth and germination capacity values were 6 cm and 73.05 %, respectively. Maximum crop length occurred as 91 cm during the harvest stage, while maximum LAI value was measured as 4.2 within the flowering period. High non-linear relationship (R^2=0.91) was calculated between LAI and total above ground biomass with regard to regular and biweekly measurement data. List and some statistics of the data collected from the winter wheat station during the 2010-2011 growing season can be found in Table 3.2.

Table 3.2. Agrometeorological station data during 2010-2011 season in Kırklareli.

DATA	MEAN	MAX.	MIN.	STD. DEV.
Mean Air Temp. at 2 m (°C)	9.98	23.64	-3.76	7.14
Maximum Air Temp. at 2 m (°C)	15.47	33.02	-2.44	8.5
Minimum Air Temp. at 2 m (°C)	5.0	16.6	-7.67	6.1
Mean Relative Humidity at 2 m (%)	77	98.2	45.7	11.5
Maximum Relative Humidity at 2 m (%)	94.06	100	70.6	5.75
Minimum Relative Humidity at 2 m (%)	53.7	87.5	17.2	17.7
Mean Air Temp. at 3 m (°C)	10.05	23.53	-3.73	7.1
Mean Relative Humidity at 3 m (%)	76.9	98.9	45.0	12.17
Global Solar Radiation (MJ/m^2day)	13.6	31.7	1.2	9.0
Surface Temperature (°C)	9.38	24.97	-3.1	7.2
Soil Water Content at 0-30cm (%)	21.3	30.8	11.8	4.8
Soil Water Content at 30-60cm (%)	24.0	33.7	14.5	4.7
Soil Water Content at 60-90cm (%)	30.6	39.2	24.4	3.2
Wind Speed at 2 m (m/s)	2.19	11.06	0.2	1.85
Wind Speed at 10 m (m/s)	3.36	13.47	0	2.1
Soil Temperature at 2 cm (°C)	11.1	25.7	0.17	6.6
Soil Temperature at 5 cm (°C)	11.1	25.2	0.5	6.5
Total Precipitation (mm)	339.6			

3.2. Model Results

3.2.1 Model Validation and Sensitivity Analysis

Actual field data on wheat biomass and grain yield were 2429.5 kg/da and 519.4 kg/da, respectively. Both models have underestimated the total biomass by showing an approach about 70 %. However, the grain yield could be almost perfectly represented by WOFOST and CERES-Wheat as 502.7 and 504 kg/da after the calibration process, during which the major role had been played by the selection criteria of the optimum wheat genetic coefficients. A remarkably higher determination coefficient is obtained by WOFOST (R^2=0.87) than CERES-Wheat (R^2=0.48) between the actual-and simulated LAI data.

Results of the model sensitivities to expected changes in climatic variables (according to Table 3.3) using CERES-Wheat indicate that the variations of the biomass and grain yields would be highest in case of extremely low cumulative precipitation values (decrement) and CO_2 fertilization (increment) both for biomass and grain yield (Table 3.4). Such an agreement cannot be seen with WOFOST.

Table 3.3. Meteorological parameters with their related scenarios.

Symbol	**Definition**
T	Air Temperature
T+1	1 °C increase in air temperature (followed then by: T+2, T+3, T+4 and T+5)
P	Precipitation
P-%10	10 % decrease in precipitation (followed then by: P-20%, P-30% and P-40%)
R_g	Global Solar Radiation
R_g+%10	10 % increase in global solar radiation (followed then by: R_g+20% and R_g+30%)
CO_2	Atmospheric Carbondioxyde Concentration
CO_2X2	Doubled Atmospheric Carbondioxyde Concentration (followed then by: CO_2X3)

Table 3.4. Peak biomass and grain yield changes of single atmospheric parameter variations.

Kırklareli Winter Wheat (2010-2011)	**MODEL**			
	CERES-Wheat		**WOFOST**	
	Biomass	**Grain Yield**	**Biomass**	**Grain Yield**
Scenario; Max. Decrement	P-40%; -43.3%	P-40%; -21.8%	T+3; -11.1	R_g+30%; -70.1
Scenario; Max. Increment	CO_2X3; 59.9%	CO_2X3; 36%	R_g+10%; -2%	T+4; 43.9%

Table 3.4 shows the future aspect of model estimations in which only one meteorological parameter is changing. It is obvious that the CERES-Wheat indicates consistent negative sensitivities to precipitation decreases and positive responses to CO_2 increments. Opposite to CERES-Wheat, WOFOST showed higher responses of grain yield than biomass. To obtain a more meaningful aspect, coupled (combined) variations of two parameters are also considered and evaluated (Table 3.5).

Table 3.5. Extreme results of model predictions for combined atmospheric parameter variations.

Kırklareli Winter Wheat (2010-2011)	**MODEL**			
	CERES-Wheat		**WOFOST**	
	Biomass	**Grain Yield**	**Biomass**	**Grain Yield**
(Scenario); Max. Decrement	(R_g+30%; P-40%); -58.5%	(P-20%; T+5); -51.3%	(P-40%; T+3); -17.4	(R_g+30%; P-40%); -84.7
(Scenario); Max. Increment	(T+1; CO_2X3); 60.2%	(CO_2X3; R_g+30%); 62.8	(R_g+30%; T+4)	(R_g+10%; T+4); 47.4%

Consideration of multi-parametric variation has increased also the extremities of the results as expected. Coherent with Table 3.4., combined maximum decrement and increment scenarios include precipitation and CO_2, respectively. WOFOST is also consistent in itself by indicating precipitation for both maximum biomass and grain yield decrements and containing solar radiation for maximum increments. Similar to the single scenario results, significantly higher grain yield variations than biomass changes are shown by WOFOST whereas the increments/decrements are comparable by CERES-Wheat.

3.2.2. Application of IPCC-A1B Climate Change Scenario to the Crop Models

In addition to the evaluation of the effects of single and combined variations in meteorological inputs, future scenarios of IPCC have also been taken into consideration to enable a more rational analysis. To achieve this, CERES-Wheat and WOFOST Models were supplied with corresponding projections of the RegCm4 regional climate model on the research field according to the IPCC's A1B scenario. Prior to this, control runs of the regional climate model were applied for optimum representation of the actual conditions. Then, crop model calibrations were repeated for the representation of the long term (1975-2010) mean yield of wheat in Kırklareli. Yield responses of wheat after application of the same sensitivity scenarios (Table 3.3.) are summarised in Table 3.6 and Table 3.7, respectively.

Table 3.6. Long term mean yield responses of wheat.

Kırklareli Winter Wheat (1975-2010)	**MODEL**			
	CERES-Wheat		**WOFOST**	
	Scenario		**Scenario**	
	T+5	CO_2X3	R_g+30%	T+4
Grain Yield Variation	-35.9%	27.6%	-50.8	68.7

Table 3.7. Long term mean yield responses of wheat (combined scenarios).

Kırklareli Winter Wheat (1975-2010)	**MODEL**			
	CERES-Wheat		**WOFOST**	
	Combined Scenario		**Combined Scenario**	
	P-40%; R_g+30%	R_g+30%; CO_2X3	P-40%; R_g+30%	R_g+10%; T+4
Grain Yield Variation	-40.7%	45.8%	-89	69.2

WOFOST and CERES-Wheat are opposite by means of the possible effects of extreme temperatures on average winter wheat biomass in Kırklareli (Table 3.6). Although CERES-Wheat indicates that same extreme increment ratio in solar radiation could show the minimum grain yield, it could represent however also the maximum yield, related to its accompanying parameter. The models commonly put forward the precipitation and solar radiation variations in minimum and maximum yield producing combinations.

Finally, the mean 2011-2040 growing season was filtered out and compared with the current mean season (1975-2010). Crop model calibrations were also repeated for the representation of the long term mean yield of wheat in Kırklareli. Yield responses of wheat are summarised in Table 3.8., accordingly.

Table 3.8. Yield response of winter wheat for extreme growing seasons.

Kırklareli Winter Wheat (1975-2010 vs. 2011-2040)	**RegCm4 Scenario (IPCC-AB1)**					
	CERES-Wheat			**WOFOST**		
Season	Mean	Hottest	Driest	Mean	Hottest	Driest
Grain Yield Variation	-6%	0%	-19%	-2%	+13%	+9%

3.3. Discussion

A comparative evaluation of two explanatory crop models is done under consideration of a series of approaches. Within this frame, model calibrations are done using actual field data of the 2010-2011 growing season together with essential agrometeorological data archive of a selected research field in Kırklareli City.

Analyses of the study began with simple one-parametric validation and extended over execution of regional climate model projections on the selected winter wheat field. WOFOST indicates that the decrease in wheat yield could exceed 70% by trebled solar radiation conditions during the growing season. The significant fall in grain yield could come up to 85% for the combined R_g+30%; P-40% scenario. Related results of the CERES-Wheat points out the positive effect of CO_2 enrichment on biomass and yield. This sensitivity to positive responses to CO_2 increases maintain also for the mean 1975-2010 wheat growing season. WOFOST indicates positive grain yield responses to increased temperatures in this period which is a point of conflict with regard to the CERES-Wheat's results. Finally, daily meteorological inputs of both models are supplied with the RegCm4 regional climate model projections for the years between 2011 and 2040. Similarly, few common points can be found between the results of the two models according to the mean, hottest, and driest growing seasons of the closest 30- year period. It is obvious that the crop model forecasts are integrated data from numerous soil, plant, atmospheric and management factors and each input can have different quantitative effects in each model. Also the selection criteria and application of the regional climate model and scenario type can produce significantly different results for the future.

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