RESEARCH ARTICLE

Simulating future wheat yield under climate change, carbon dioxide enrichment and technology improvement in Iran. Case study: Azarbaijan region

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Abstract

Climate change and technology development can affect crop productivity in future conditions. Precise estimation of crops yield change as affected by climate and technology in the future is an effective approach for management strategies. The aim of this study was to estimate the impacts of climate change, technology improvement, CO_2 enrichment, and overall impacts on wheat yield under future conditions. Wheat yield was projected for three future is time periods (2020, 2050 and 2080) compared to baseline year (2011) under two scenarios of IPCC Special Report on Emission Scenarios (SRES) including SRES-A2 as regional economic scenario and SRES-B1 as global environmental scenario in Azarbaijan region (NW of Iran). A linear regression model, describing the relationship between wheat yield and historical year, was developed to investigate technology development effect. The decision support system for agro-technology transfer (DSSAT4.5) was used to evaluate the influence of climate change on wheat yield. The most positive effects were found for wheat yield as affected by technology in all studied regions. Under future climate change, the SRES projected a decrease in yield, especially in West Azarbaijan region. When the effects of elevated CO_2 were considered, all regions resulted to increase in wheat yield. Considering all components effect in comparison with baseline (2011), yield increase would range from 5% to 38% across all times, scenarios and regions. According to our findings, it seems that we may expect a higher yield of wheat in NW Iran in the future if technology development continues as well as past years.

Additional key words: DSSAT; general circulation model; SRES; crop model

Abbreviations used: CERES (Crop Environment Resource Synthesis); CSM (Cropping System Model); DSSAT (Decision Support System for Agro-technology Transfer); GCM (General Circulation Model); GENCALC (Genetic Calculator); HadCM3 (Hadley Centre Coupled Model, version 3); IPCC (Intergovernmental Panel on Climate Change); MAPE (Mean Absolute Percentage Error); ME (Modeling Efficiency); RMD (Root Mean Deviation); RMSE (Root Mean-Squared Error); SRES (Special Report on Emissions Scenarios).

Introduction

Total crops production in Iran is estimated at 74 million tons approximately on 13,500,000 ha. Cereals (wheat, barley, maize and rice) production consists of about 73% of the total crop production (MAJ, 2009). Wheat (*Triticum aestivum* L.) is the main crop grown in Iranian agro-ecosystems and it is cultivated almost all over the country. Total wheat production area is 5.25 million hectares with production of 7.9 million tons per year. Azarbaijan region is one of the main produc-tion areas of Iran with about 694,000 ha of wheat-cultivated area (MAJ, 2009).

Ongoing changes in the global climate are likely to have significant effects on agriculture (Watson *et al*., 1996). Since, there is a direct relationship between climate conditions and agricultural production, so climate change can affect future production of agro-ecosystems through changes in rates of plant growth and transpiration (Mall *et al.,* 2004). Climate change will also affect physiological processes such as photosynthesis and respiration, development rate and crop

efficiency for completing its growing cycle (Chartzou-lakis & Psarras, 2005; Yang & Zhang, 2006). There-fore, agricultural production systems are highly vulner-able to climate change. Intergovernmental Panel on Climate Change (IPCC, 2007) has explained standard greenhouse gas emission scenarios to plan climate change based on various socioeconomic, technological and energy use factors. The IPCC Special Report on Emission Scenarios (SRES) provides a suitable con-cept for the development of alternative scenarios of future crop productivity (Nakicenovic *et al.,* 2000). The SRES-A2 considers a very heterogeneous world condition with high population growth rate, slight economic development and slow technological change (Prudhomme *et al.,* 2010). The SRES-B1 defines a convergent world with a global population that peaks in mid-century and rapid changes in economic struc-tures towards a service and information economy (Wetterhall *et al.,* 2009). The two scenarios explain future worlds that may be regional economic (SRES-A2) and global environmental (SRES-B1) (Ewert *et al.,* 2005). Studies on climate change effect on rainfed and irrigated wheat at global scale have reported re-duction of yield by 10%-40% and 20%-50%, respec-tively (Parry *et al.,* 1999, 2004). Studies carried out at national scale by Eyshi Rezaie & Bannayan (2012) using HadCM3 General Circulation Model under SRES-A2 estimated that wheat yield would decrease by 50% in 2040-2069 period.

High reliance on energy production from fossil fuels caused to increasing CO_2 concentration of atmosphere from about 275-280 ppm to 370 ppm since 1750 (Ether-idge *et al.,* 1996; Keeling & Whorf, 2000) and may reach 600-1000 ppm by the end of 21th century (Cox *et al.,* 2000). The positive effects of CO_2 enrichment on plant physiology such as photosynthetic rates and photorespiration especially for C_3 crops is well verified. Some studies illustrated that the yield of many crops will be increased in response to elevated CO_2 levels if the other factors such as temperature are considered unchanged (Amthor, 2001; Bannayan *et al.,* 2005; de Costa *et al.,* 2006; Bannayan & Hoogenboom, 2008; Yoon *et al.,* 2009).

In addition, technology development can affect crop productivity (Ewert *et al.,* 2005). A higher production of wheat has been seen in Iran during the past 50 years, some of which is due to increase in cultivated area, but most is due to technology improvement (Koocheki *et al.,* 2003). Technology improvement such as new cultivars, irrigation, pesticides, machin-ery, fertilizer, and other factors were mainly respon-sible for yield increase in past decades (Evans, 1997; Amthor, 1998; Reynolds *et al.,* 1999). Therefore, another aspect of future conditions (*e.g.* technology

improvement) needs to be considered to assess the impact of climate change plus CO_2 enrichment on agriculture production. For climate change studies on crop production, leading factors affecting crop yields such as technology development are still in need of careful study. Limited attempts have been made to evaluate the integrated effects of climate change, rais-ing CO_2 levels and technology development (Ewert *et al.,* 2005). Building on these considerations, the main aim of the present study was to investigate the individual and combined effects of climate change (temperature and precipitation), elevated CO_2 concen-tration and technology improvement on the regional production of wheat in Azarbaijan region. For this purpose, we used LARS-WG as weather generator to produce daily data of climate variables and Crop En-vironment Resource Synthesis (CERES)-Wheat model to simulate growth of wheat in future climate change conditions. In addition, analysis of historical yield trend was considered to study the effect of technol-ogy development.

Material and methods

Study area

Azarbaijan region is located in the northwest of Iran and covers a vast area of the country with three prov-inces, including East Azarbaijan, West Azarbayjan and Ardabil. Mean precipitation across Azarbaijan region during the last 50 years was about 310 mm per year and fluctuates from 288 mm at the East Azarbaijan to 341 mm at the West Azarbayjan that was provided by Iran Meteorological Organization (http://www.irimo.ir/farsi/amar/map/index.asp). These provinces are lo-cated at 36°-40° N latitude. Agriculture plays the major role in the regional economy. Azarbaijan region is one of the main production areas of Iran with about 694,000 ha of wheat-cultivated area (MAJ, 2009).

Effects of climate change

Climate change scenarios

The General Circulation Model (GCM), Hadley Centre Coupled Model, version 3 (HadCM3) (Mitchell *et al.*, 1995) under two scenarios (SRES-A2 and SRES-B1) was considered to evaluate climate change effects in this study. SRES-A2 and SRES-B1 are the regional economic and global environmental scenarios, respec-tively. HadCM3 is a coupled atmosphere-ocean GCM, described by Gordon *et al.* (2000).

Climate simulation

Daily climate data including, maximum and minimum temperatures (^{0}C) and precipitation (mm) were obtained for the period of 1983-2011 from East Azarbaijan, West Azarbayjan and Ardabil climatological stations. The weather generator LARS-WG was used to produce daily data of climate variables as one stochastic growing season for each projection period. The daily climate data were simulated using the LARS-WG for four projection times (1983-2011, 2020, 2050 and 2080). LARS-WG is a stochastic weather generator based on the series approach (Semenov & Stratonovitch, 2010). LARS-WG produces synthetic daily time series of maximum and minimum temperatures, precipitation and solar radiation. LARS-WG applies observed daily weather data for a given site to compute a set of parameters for probability distributions of weather variables as well as correlations between them (Semenov & Brooks, 1999).

Model calibration

The Decision Support System for Agro-technology Transfer (DSSAT, version 4.5) is comprised of six models to simulate the growth of many crops (Jones *et al*., 2003). The model has demonstrated high reliability under different climates, soil, and management conditions (Bannayan *et al*., 2003). Palosuo *et al*. (2011) reported that DSSAT model had the best performance on simulation of winter wheat production among eight crop growth simulation models. One of the most popular and highly reliable wheat models is Cropping System Model (CSM)-CERES (Rinaldi, 2004) which has been evaluated in many regions across the world, the results indicating its potential for simulating grain yields under different climatic conditions (Pecetti & Hollington, 1997). The crop model was calibrated based on an experiment that was carried out in the field research of Ardabil University at Ardabil province in 2010 year. The experiment was loaded as factorial strip plot based on a randomized complete block design with three replications (Mohammaddoust Chamanabad *et al*., 2013). Treatments were different nitrogen rates at three levels (0, 75 and 150 kg N/ha) and five wheat cultivars (Caskozhen, Sayson, Gaspard, Azar and MV17). Genetic Calculator (GENCALC) software was used to identify genetic coefficients of wheat cultivars. Plants in 1-m^2 were sampled to measure crop characterizes at harvest time. Measured variables such as, grain yield, biological yield, leaf number and harvest index were provided for the crop model as observed data.

Model validation

Field experiment data under Azarbaijan climate were used for validating the crop model. The experiment was conducted as a randomized complete block design at research station of Tabriz Agriculture College in East Azarbaijan province in 2010 year (Ahmadinezhad *et al*., 2013). Experimental treatments were different levels of organic and chemical fertilizers of nitrogen at seven levels. Alvand cultivar of wheat was cultivated and the effects of treatments were investigated on the growth properties. Grain yield, biological yield, leaf number and harvest index were simulated by the model and compared to the observed data. The simulation model options were set according to weather, soil and treatments that employed in the experiment.

The coincidence between observed and simulated values was measured by root mean-squared error (RMSE) (Eq. [1]), while root mean deviation (RMD) (Eq. [2]) was calculated to evaluate systematic bias of the model. Modeling efficiency (ME) (Eq. [3]) was considered as tool to evaluate model performance with regard to mean of observed data (Nash & Sutcliffe, 1970). Another criterion to test the difference between measured and simulated data was the comparison of linear regression against the 1:1 line. Under best simulation, the simulated and observed data should be the same so its regression equation is y=x (1:1 line). Comparison of fitted regression equation between simulated and observed data (Simulated = a + b × Observed) against the 1:1 line (Simulated = Observed) was tested by t-test. If a=0 and b=1, the null hypothesis is acceptable so this means that the difference between simulated and observed data is not significant.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(P_i - O_i\right)^2}{n}} \times \frac{100}{\overline{O}} \quad [1]$$

$$RMD = \sum_{i=1}^{n}\frac{P_i - O_i}{n} \times \frac{100}{\overline{O}} \quad [2]$$

$$ME = 1 - \frac{\sum_{i=1}^{n}\left(P_i - O_i\right)^2}{\sum_{i=1}^{n}\left(\overline{O} - O_i\right)^2} \quad [3]$$

where *P* and *O* are predicted and observed data, respectively, is the mean of observed data and *n* is the number of observations. The RMSE illustrates the model's prediction error by heavily weighting high error, whilst

the RMD uses same weights for all errors, which tends to smooth out discrepancies between simulated and observed data. The ME indicates the efficiency of the model and it can have positive or negative values (Bannayan & Hoogenboom, 2008; Huang *et al.*, 2009).

Effects of technology improvement

Technology improvement was largely responsible for the achieved yield increases of crops especially wheat, during the past decades in the studied region. Therefore, it is necessary to consider the effects of technology development for estimating the yield change in future conditions. In this study, we supposed all measures and inputs related to crop management as technology development (such as pesticides, fertilizers, irrigation, modern varieties and machinery) which will result in yield rise. Technology development was divided into two main components, one is the raising yield potential ($f_{T,P}$) and the other is the declining of the gap between actual and potential yields ($f_{T,G}$) (Ewert *et al.*, 2005). In order to evaluate the technology improvement effects on yield changes of wheat in the future, historical yield trend of wheat was calculated based on data provided by the Iranian Ministry of Agriculture. Yield trends were calculated by fitting liner regression through the observed data for each province in a 29-years period from 1983 to 2011. We assumed that the historical yield trend was a time series which should not have included seasonal component, so we adjusted data to remove seasonal component effect. Therefore, we used adjusted data to fit yield trend. To obtain the adjusted data, we used the decomposition method to separate the time series into linear trend and seasonal components, as well as error, and provide adjusted data by removing the effect of seasonal component. Minitab vers. 16 software was applied to obtain the adjusted data.

$$Y_e = a + r_y \times t \qquad [4]$$

where Y_e is the estimated wheat yield at a particular year t; r_y is the annual rate of yield change and a is an empirical parameter; a and r_y parameters were estimated by fitted linear regression between adjusted yield and time for each region. The accuracy of the fitted regression was tested by Mean Absolute Percentage Error (MAPE). MAPE expresses accuracy as a percentage (Yaffee & McGee, 2000).

$$MAPE = \frac{\sum \left((Y_a - Y_e) / Y_a \right)}{n} \times 100 \qquad [5]$$

where Y_a equals the actual value, Y_e equals the fitted value and n equals the number of observations. The smaller values of MAPE indicate a better fit of the model. Relative yield change (Y_r) between years was calculated according to Ewert *et al.* (2005) as:

$$Y_r(t) = \frac{Y_e(t)}{Y_e(t-1)} \qquad [6]$$

where Y_e was calculated using the Eq. [4]. The baseline in our study was 2010-2011. Thus, wheat yield change as affected by technology improvement in future time (compared to baseline P_{t0}) was obtained from relative yield change at baseline and a factor that considers the impacts of technology on potential yield and yield gap (Ewert *et al.*, 2005):

$$\frac{P_{t,T}}{P_{t0}} = Y_r(t_0) + \int_{t_0}^{t=t_s} \left(\frac{Y_{r,a} \cdot f_{T,P(t)} \cdot f_{T,G(t)}}{0.5} \right) dt \qquad [7]$$

where $P_{t,T}$ is the future yield of wheat as affected by technology improvement, $Y_r(t_0)$ is relative yield change in baseline year, $Y_{r,a}$ is annual increase of relative yield change with reference to the baseline and is calculated from: $Y_r(t_0)$-1. According to Nassiri & Koocheki (2010), the present wheat yield in Iran is about 50% of potential yield, so, the value 0.5 indicates the current yield as a relative share of potential yield. This value is 0.8 for European countries, as reported by Ewert *et al.* (2005). The values of $f_{T,P}$ and $f_{T,G}$ for different scenarios were obtained from Ewert *et al.* (2005) (Table 1).

Table 1. Values of $f_{T,P}$ and $f_{T,G}$ for calculating the technology improvement effects and projected increasing of CO_2 concentration (ppm) on yield change of wheat under different scenarios of Intergovernmental Panel on Climate Change (IPCC) and time periods (Ewert *et al.,* 2005).

Parameter	Year	Scenario	
		A2	B1
$f_{T,P}$	2020	0.5	0.4
	2050	0.3	0.2
	2080	0.1	0.0
$f_{T,G}$	2020	0.55	0.55
	2050	0.60	0.60
	2080	0.65	0.65
CO_2	2020	424	417
	2050	537	484
	2080	709	518

Effects of CO₂ enrichment

CO₂ effect on wheat yield was calculated based on future CO_2 concentration by IMAGE model (IMAGE-Team, 2001) (Table 1). According to the results of Koocheki & Nassiri (2008), average yield change of wheat is 0.05% per unit increase in CO_2 concentration (in ppm) suggesting that rising CO_2 concentration from current (350 ppm) to *e.g.* 550 and 700 ppm would increase wheat yield by 10.3% and 19.5%, respectively. To evaluate the CO_2 enrichment impact on change of wheat yield, the relative yield change as affected by rising CO_2 levels was calculated using the following equation (Ewert *et al.*, 2005):

$$\frac{P_{t,co}}{P_{t0}} = \frac{f_{co,r}.\Delta C_{t-t_0}}{100} + 1 \qquad [8]$$

where $P_{t,co}$ is the future yield of wheat as affected by CO_2 concentration, $f_{co,r}$ is the relative yield change per unit change in CO_2 concentration ($f_{co,r}$ = 0.05%) and ΔC_{t-t0} is the difference between future and current CO_2 concentration.

Integrated effects

Precise estimation of wheat yield in future needs to integrate the effects of all components (climate change, elevated CO_2 and technology improvement). For this purpose, according to Ewert *et al.* (2005), the integrated effects of all components were calculated by:

$$\frac{P_t}{P_{t0}} = \frac{1+\left(\frac{P_{t,cl}}{P_{t0}}-1\right)+\left(\frac{P_{t,co}}{P_{t0}}-1\right)+\left(\frac{P_{t,T}}{P_{t0}}-1\right)}{1} \qquad [9]$$

where P_t is the future yield as affected by all components and $P_{t,cl}$ is the relative yield change as affected by climate change compared to the baseline year.

Results and discussion

Evaluation of climate and crop model

The precise estimate of weather parameters such as maximum and minimum temperatures and precipitation in the baseline period may show accuracy of down scaling models in climate change researches (Viglizzo *et al.*, 1997). Weather prediction results indicated higher accuracy projection of maximum temperatures than minimum temperatures and precipitation across all regions (Fig. 1). The results of RMSE showed that all the predictions and observations of minimum temperatures were closely matched, so that the RMSE values were less than 20%. The accuracy of precipitation prediction for East Azarbaijan (with more value of RMSE) was lower compared to other regions. The highest and lowest exactitude for predicting of weather parameters were obtained by maximum temperature and precipitation in Ardabil region, respectively (Fig. 1).

Evaluation of crop model showed an adequate accuracy of model to simulate the biological and seed yield, harvest index and leaf number of wheat. All the predictions of biological and seed yield, harvest index and leaf number showed that RMSE values were lower than 10.0%. Simulated biological and seed yield, harvest index and leaf number had little differences with observed values, so that they were ±2.87%, ±5.02%, ±5.52% and ±6.08% of the observed data, respectively. The model results illustrated a high accuracy for simulating the biological and seed yield compared to harvest index and leaf number based on lower values of RMSE and RMD and higher values of ME (Table 2). In general, the model accurately predicted all the traits.

The t-test was carried out to compare the slop and intercept of the 1:1 line against the fitted linear regression between observed and simulated data. The results indicated that there was no statistically significant difference in slope and intercept between the lines for all traits (Table 3, Fig. 2). High correlation was obtained between observed and simulated values of biological and seed yield (R^2 > 0.95), harvest index (R^2 = 0.83) and leaf number of wheat (R^2 = 0.73) (Table 3, Fig. 2).

Table 2. Comparison of simulated and observed values of seed and biological yield, harvest index and leaf number by root mean-squared error (RMSE), root mean deviation (RMD) and modeling efficiency (ME).

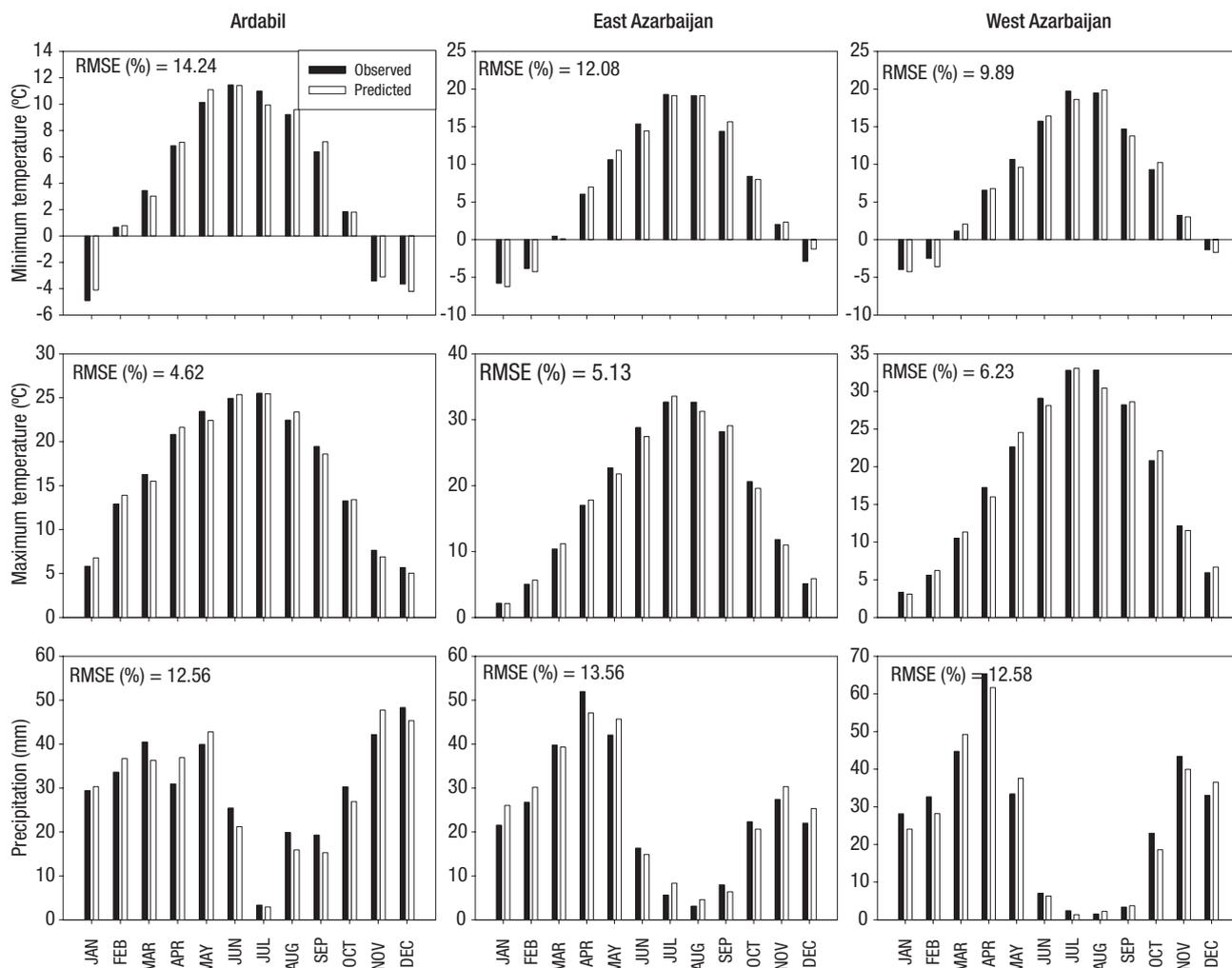| Parameters	RMSE	RMD	ME
Biological yield	2.87	−1.79	0.97
Seed yield	5.02	−0.96	0.95
Harvest index	5.52	3.35	0.51
Leaf number	6.08	−2.03	0.42

Figure 1. Observed and predicted values of climate variables and Root Mean-Squared Error (RMSE) values (as average from 1983 to 2011 year) for different provinces of Azarbaijan region.

Table 3. Results of the t-test for comparing the slop (b) and intercept (a) of the 1:1 line against the fitted linear regression between observed and simulated data (Simulated = a + b × Observed).

	b		a		t-value		H0	R^2
	Value	SE	Value	SE	t_b	t_a	(a=0, b=1)	
Biological yield	0.893	0.051	646.4	302.9	2.08	2.13	Accepted	0.989
Seed yield	1.105	0.088	−252.5	198.5	1.19	1.27	Accepted	0.969
Harvest index	1.180	0.235	−4.378	7.041	0.766	0.622	Accepted	0.834
Leaf number	1.175	0.312	−8.263	13.19	0.563	0.626	Accepted	0.739

SE: standard error; H0: null hypothesis.

Table 4. Regression equation between adjusted wheat yield (Y_e, as dependent variable) and time (t, as independent variable), values of mean absolute percentage error (MAPE) and relative yield change (Y_r) for various provinces of Azarbaijan region.

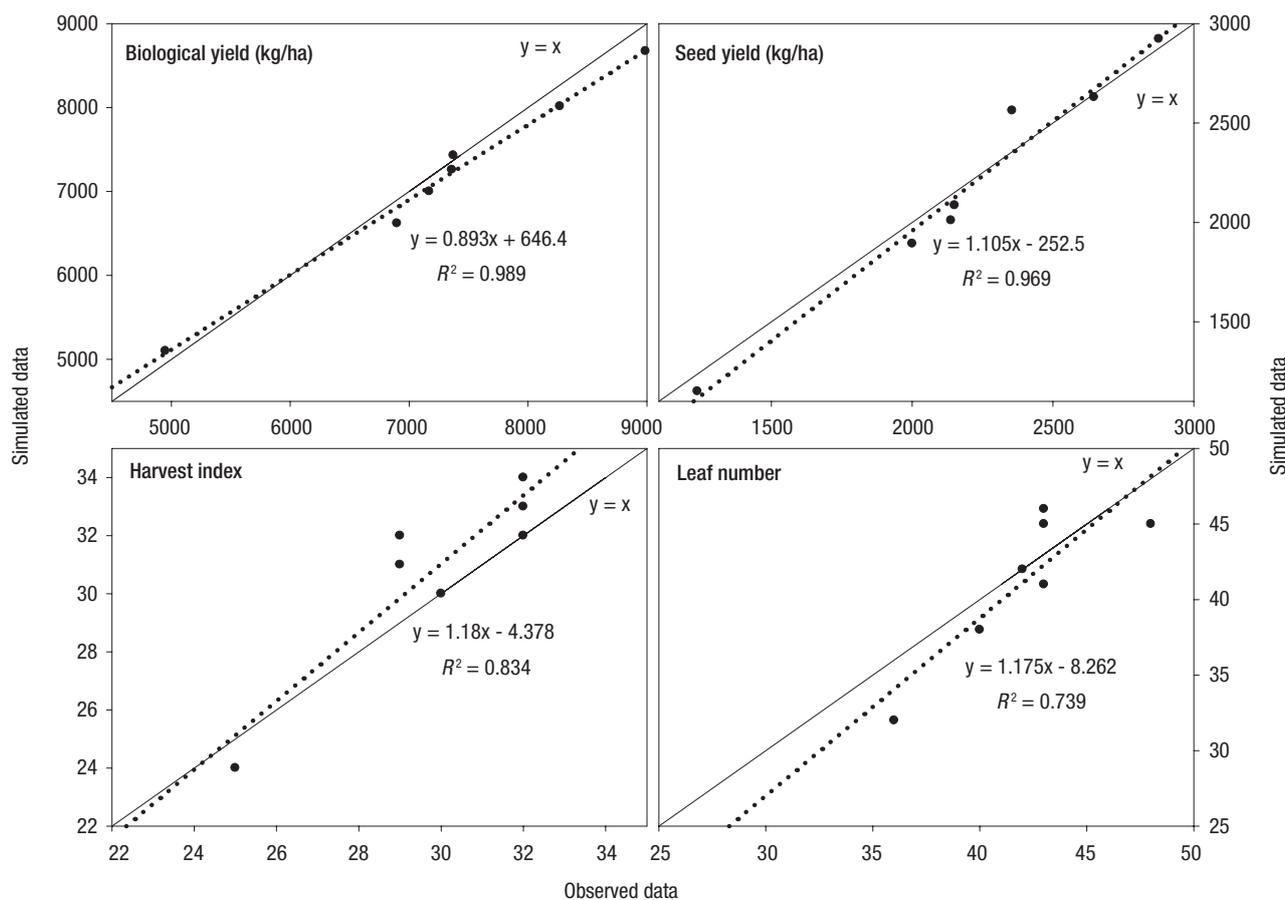| Region	Regression equation	MAPE (%)	Y_r
Ardabil	$Y_e= 1.242 + 0.114\ t$	10.19	1.026
East Azarbaijan	$Y_e= 1.564 + 0.065\ t$	11.59	1.019
West Azarbaijan	$Y_e= 1.294 + 0.084\ t$	13.71	1.023

Figure 2. Observed and simulated values of biological and seed yield, harvest index and leaf number of wheat and comparison of the 1:1 line (solid line) against the fitted linear regression between observed and simulated data (dotted line).

Effect of technology improvement

Figure 3 shows the historical yield trend of wheat (as original data) and adjusted data in various provinces. Wheat yield in different regions increased during time from 1983 to 2011 due to development of technology. Yield increase trend was calculated by the linear regression and its slope indicated annual rate of yield increase. For Ardabil province, the annual rate of increase in wheat yield was higher than other regions based on the higher value of regression slope that was 0.114 (Table 4). The slope of the fitted regression between adjusted yield and time for East and West Azarbaijan were 0.065 and 0.084, respectively; it means that increasing of yield per year were 65 and 84 kg, respectively.

The highest value of relative yield change (Y_r), 1.026, was observed in Ardabil province (Table 4). Because the value of MAPE in Ardabil region (10.19%) was smaller than in other regions, it can be concluded that the regression model fitted wheat yield with more accuracy in Ardabil compared to others.

Table 5 shows that the effect of technology improvement on yield was positive and ranged between 2% (East

and West Azarbaijan, SRES-B1, 2080) and 39% (Ardabil, SRES-A2, 2080) depending on the region, time and scenario compared to the baseline year. Some physiologists reported that there are opportunities for any yield improvements of crops by increasing potential yield and reducing the yield gap (Evans, 1997; Austin, 1999; Reynolds *et al.*, 1999; Lobell *et al.*, 2009; Battenfield *et al.*, 2013). Improving light capture and light and nitrogen use efficiency can increase potential yield (Loomis & Amthor, 1999; Borlaug, 2000). Biotechnology achievements and improved pest management by using tolerant plants to biotic and abiotic stresses and resistant plants against pests and disease may result in reduction of gap yield between actual and potential yield (Borlaug, 2000; Miflin, 2000). These approaches are considered as next positive effect of technology improvement on agriculture production for future conditions. Ewert *et al.* (2005) estimated wheat yield as affected by technology development under different scenarios in future conditions and reported increasing crop yields ranging from 20% to 134%. Yield change under SRES-A2 was higher than SRES-B1 because of higher values of $f_{T,P}$ and $f_{T,G}$ under SRES-A2 (Table 1). The results showed that Ardabil
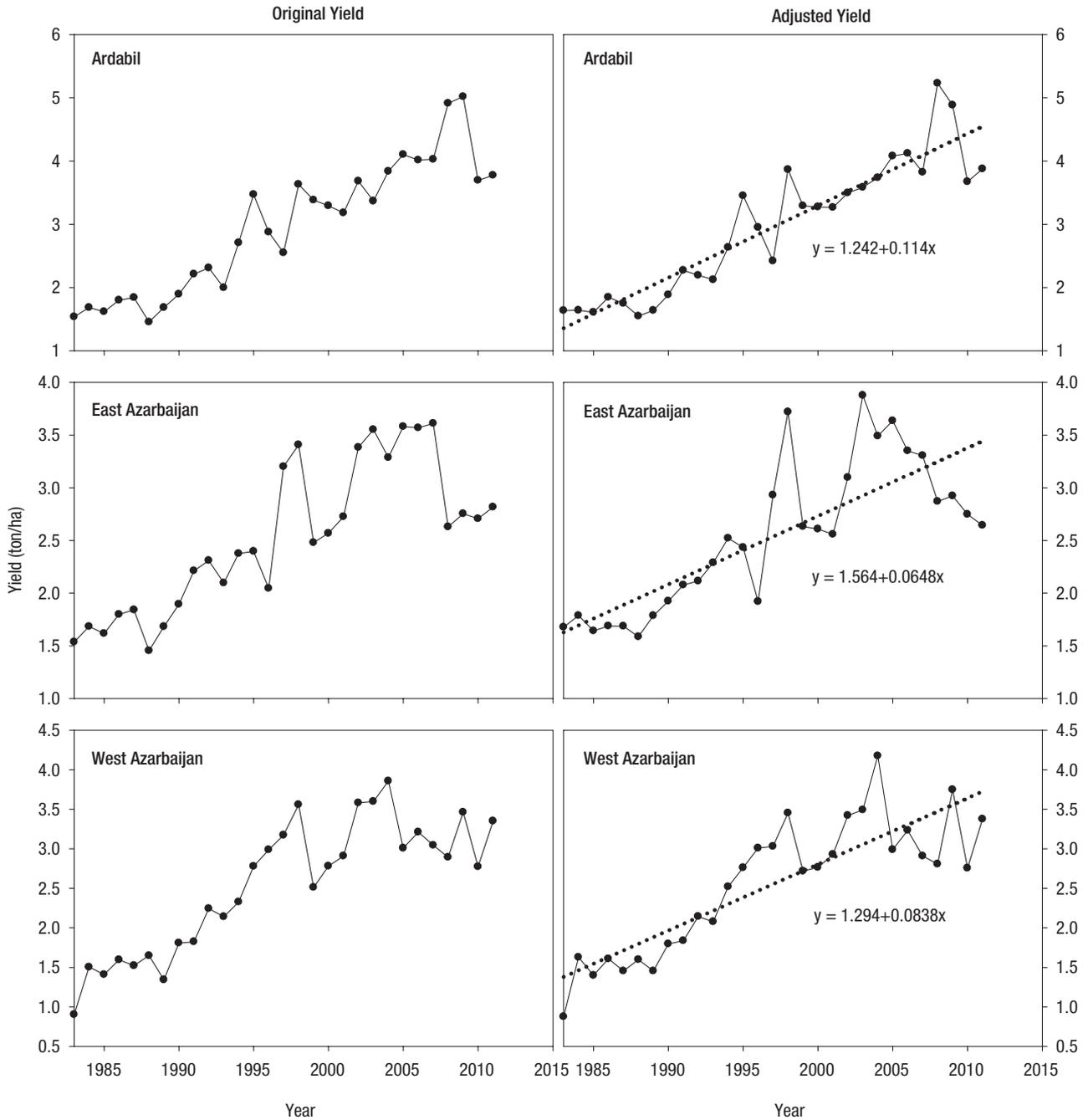
Figure 3. Historical yield trend of wheat (as original data) and adjusted data (along with its linear regression equation) for various provinces of Azarbaijan region.

region was more affected by the technology development compared to the other provinces in both scenarios and all times (Table 5). Technology development showed higher impact on wheat yield than climate change and CO_2 enrichment (Table 5).

Effect of CO_2 enrichment

Increasing CO_2 concentration in future conditions caused to improve wheat yield in both scenarios and

all times (Table 5). The effect of CO_2 concentration on wheat yield was similar for all regions. This might be due to this fact that changing CO_2 concentration is global, not regional. Increasing yield under SRES-A2 was more than SRES-B1 in all times, because increase in CO_2 concentration under SRES-B1 was less than that for SRES-A2 in future. The highest yield change as affected by CO_2 was under SRES-A2 in 2080 (18%) and the lowest rate was obtained under SRES-B1 in 2020 year (3%) in comparison with the baseline (Table 5). Elevated CO_2 concentration stimulates the

Table 5. The effects of technology improvement, CO_2 enrichment and climate change on yield change of wheat under different scenarios of Intergovernmental Panel on Climate Change (IPCC) and time periods (compared to the baseline, 2011) for different provinces of Azarbaijan region.

Components effect	Scenario	Year	Region		
			Ardabil	East Azarbaijan	West Azarbaijan
Technology improvement	SRES-A2	2020	1.15	1.11	1.14
		2050	1.39	1.29	1.35
		2080	1.26	1.19	1.23
	SRES-B1	2020	1.13	1.10	1.11
		2050	1.27	1.20	1.24
		2080	1.03	1.02	1.02
CO_2 enrichment	SRES-A2	2020	1.04	1.04	1.04
		2050	1.09	1.09	1.09
		2080	1.18	1.18	1.18
	SRES-B1	2020	1.03	1.03	1.03
		2050	1.07	1.07	1.07
		2080	1.08	1.08	1.08
Climate change	SRES-A2	2020	0.94	0.94	0.90
		2050	0.89	0.88	0.85
		2080	0.91	0.88	0.82
	SRES-B1	2020	0.98	0.92	0.94
		2050	1.05	0.99	0.96
		2080	1.09	1.02	0.97

rate of photosynthesis and cause higher biomass and economic yield of crops (de Costa *et al.*, 2006; Bannayan & Hoogenboom, 2008; Bannayan *et al.*, 2009). Amthor (2001) mentioned that elevated CO_2 concentration could affect many crops production especially C_3 plants by increasing photosynthesis rate and reducing photorespiration. In addition, higher CO_2 concentration reduces stomata conductance of leaves that caused to improving water use efficiency (Lawlor & Mitchell, 1991). Thus, positive impacts of CO_2 enrichment on crops yield may be due to increase in photosynthesis system and water use efficiency (which is very important under semiarid conditions) or both of them (Amthor, 2001). However, Tubiello & Ewert (2002) think that there are some factors which negate or limit the fertilization influence of CO_2, including the effect of soil quality, and the presence of additional inputs such as nitrogen or tropospheric ozone.

Effect of climate change

In most cases, simulation of wheat yield under climate change showed that climate change had adverse effects on yield (Table 5). Values less than one indicate that wheat yield decreased in comparison with the baseline year and values greater than one mean that climate change led to increase in yield. Climate change affected yield that ranged from -18% to +9% depending on the region, time and scenario (Table 5). Climate change could affect crops productivity not only by increasing temperature but also by altering the rainfall amounts and pattern. SRES-A2 had more adverse effects on yield than SRES-B1, so that SRES-A2 decreased wheat yield under all regions and times. This is mainly because SRES-B1 is based on achieving global solutions, clean and environmental friendly technologies and interest in food quality and environmental issues but SRES-A2 is based on less concern for rapid economic development and environmental issues (Nakicenovic *et al.*, 2000). Therefore, severity of climate change in SRES-B1 is less than SRES-A2. Positive effects of climate change were observed under SRES-B1 in Ardabil and East Azarbaijan (Table 5). Under SRES-B1, climate change not only had no adverse effect but also increased the yield of wheat in 2050 and 2080 years for Ardabil and 2080 year for East Azarbaijan. West Azarbaijan province was more affected by climate change than others were. The highest reduction of yield, 18%, was obtained for West

Azarbaijan region under SRES-A2 in 2080 year and the highest increase in yield, 9%, was gained for Ardabil region under SRES-A2 compared to the baseline year (Table 5).

Integrated effects

Figure 4 shows that considering the integrated effects of all components including climate change, CO_2 concentration and technology on wheat yield could be an effective approach for future management of agro-ecosystems. In all regions, integrated effects of factors led to produce higher yields in comparison with the baseline year under both scenarios and all future times. Projection for Ardabil province showed higher change of yield than two other provinces. Estimation of yield change as affected by integrated effects showed a positive effect of integrated components and increased wheat yield that ranged from 5% to 38% across all provinces, scenarios and times.

The highest yield of wheat was simulated for Ardabil region under SRES-B1 in 2050 year and the lowest value was achieved for East Azarbaijan under SRES-B1 in 2020 year as increase of 5% compared to the baseline (Fig. 4). It seems that higher adverse effect of climate change on yield (8% reduction) and less increase (10%) in yield as affected by technology improvement were the main reasons of yield drop in East Azarbaijan (Table 5). In general, integrated components had more effect on wheat yield in 2050 year compared to 2020 and 2080 years. Eyshi Rezaie & Bannayan (2012) performed an evaluation of future climate effects on wheat yield in the northeast of Iran. They reported sharp reduction in yield under future conditions but they did not consider the effects of technology and increasing of CO_2 concentration. The simulation results of Ewert *et al*. (2005) illustrated that wheat yield will be increased as affected by integrated factors of climate change, CO_2 and technology in future. They estimated that technology improvement and elevated CO_2 could increase wheat yield in future conditions but climate change might decrease wheat yield. Their results were coincident with our findings and indicated that wheat yield will be in the future more affected by technology development in European conditions than in Iran.

In summary, our simulation results indicate that climate change, technology improvement and increasing CO_2 concentration could change wheat yield in future conditions. However, focus on integration of these components, especially on technology development, has not yet sufficiently considered. According to our results, it could be concluded that wheat yield was less affected by climate change in Ardabil, and yield change was more affected in West Azarbaijan than in other regions. After integrating all evaluated components, Ardabil region showed the highest yield change and, among other components, had the maximum yield change through technology improvement. In general, SRES-A2 showed higher change of wheat yield across all components, regions and times than SRES-B1, because SRES-A2 is known as an economic scenario less concern for rapid economic development. Effects of increasing CO_2 concentration and technology improvement on yield were positive, but in most cases the impact of climate change was negative causing a re-
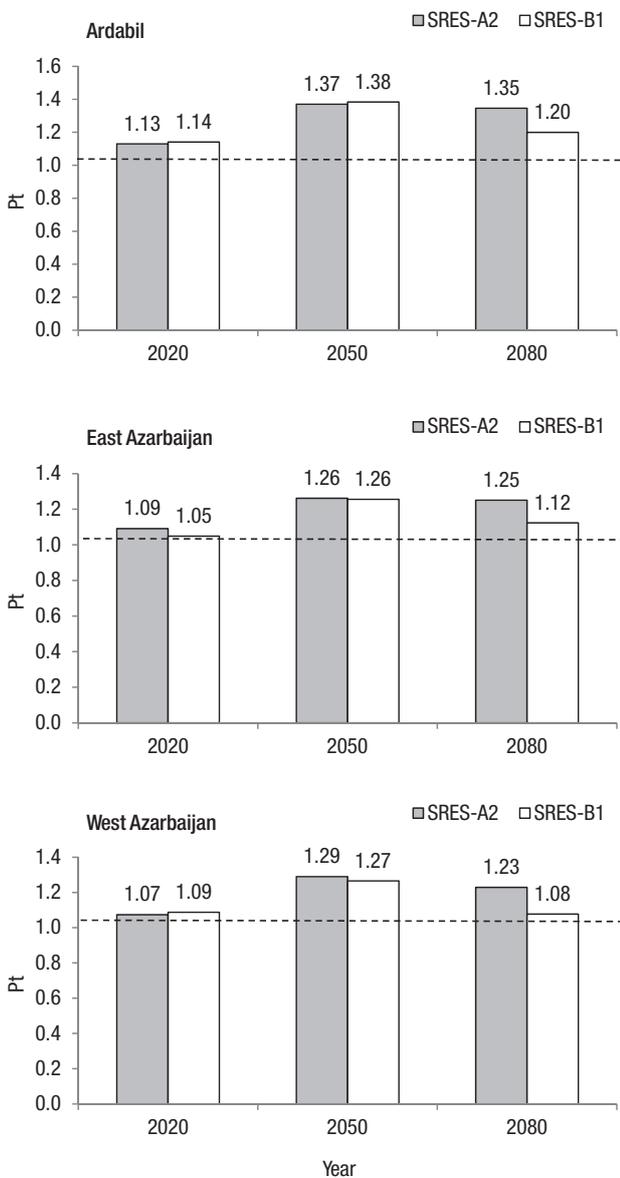

Figure 4. Integrated effects of all components (Pt, unitless) on yield change of wheat under two scenarios of Intergovernmental Panel on Climate Change (IPCC) and time periods (compared to the baseline, 2011 [dashed line]) for different provinces of Azarbaijan region.

duced wheat yield. However, the integrated effect of the three components on wheat yield was beneficial. In essence, our results illustrated increasing wheat production in future conditions as affected by simultaneous impacts of climate change, CO_2 and technology. Although it should be emphasized that projection of yield change was optimistic and did not consider the adverse impacts of biotic and abiotic stresses, pests and pollutants such as ozone in future conditions.

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