Impact of Global Warming on Irrigated Rice Production in the Southern Coasts of Caspian Sea

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Abstract: Agriculture and crop production is one of the factors which depend on the weather conditions and it provides the human requirements in many aspects. The objective of this study is to assess the impact of future global warming on irrigated rice using the Ceres-Rice model in the Southern Coast of Caspian Sea under three climate change scenarios of Sra1b, Sra2 and Srb1. Required data for include the meteorological, soil and crop management data. The meteorological data include the daily data of minimum temperature, maximum temperature, solar radiation and precipitation during 1981-2010 and Global Climate Models (HADCM3, ECHAM5, IPCM4, GFCM2, NCCCSM and INCM3) during 1971-2000. Soil and product management data provided from field experiment was conducted from 2008 to 2009 at the Rice Research Institute in Rasht. Results of evaluating of global climate models show that ECHAM5 model has the highest correlation with the lowest error to simulate the future climate. The prediction of temperature shows that minimum and maximum temperature will be ascending during the rice-growing season. Results of simulated irrigated rice yield and biomass base on scenarios of Sra1b, Sra2 and Srb1 show that rice crop yield and biomass will decrease with mean temperature rise.

1. Introduction

Future climate change due to anthropogenic pollution of the atmosphere is the most important threat for water resources, soil, agriculture, human health and food security. Food security is one of the main goals of the government's agenda. The role of agriculture due to its contribution to promote the economic growth and development and food security for a growing population, production, exchange, employment and development activities related to crop production is important from the perspective of economic development. On the other hand, agriculture and crop production is one of the factors which depend on the weather conditions and it provides the human requirements in many aspects. Future climate change can have considerable effects on growth, performance and water consumption for crops (Bazzaz and Sombroek, 1996). In general, organisms such as plants have adapted to their environment over a long period of time, and had matched their growth with this condition. In this regard, any rapid change in weather conditions will cause significant changes in the patterns of growth and development of plants and depending on the changes; the plants will have spatial and temporal displacement and ultimately may even exclude them from the agricultural system in a particular area (Horie et al., 2000).

The increasing atmospheric CO_2 and other greenhouse gases due to anthropogenic are well documented and theoretical reasons for higher concentrations of these gases to cause global warming in recent years. The fourth assessment report (AR4) of the IPCC indicates that the atmospheric CO_2 is accumulating in the atmosphere faster than past and global temperatures have increased in the past 100 years by an average of 0.74°C (IPCC, 2007). Evidences show the maximum and minimum temperatures are likely to increase at different rates, often with a faster increase in minimum temperature than maximum temperature (Easterling et al., 1997). Rainfall in the high latitudes of the northern hemisphere has increased, while rainfall in eastern Asia, Australia, the Sahel and the Pacific region has declined, with rainfall variability increasing almost everywhere in the world (Dore, 2005). The changing of atmospheric concentration of CO_2, increasing temperatures, increasing of rainfall variability and severe and frequent droughts have serious direct and indirect consequences on crop production and food security (Reddy and Hodges, 2000).

Many researchers have been conducted to determine the effects of climate change and other environmental factors on growth and yield of crops over the past two decades. Sarker et al. (2012) studied the relationship between the yield of three major rice

crops (Aus, Aman and Boro) and three main climate variables for Bangladesh. They used time series data for the period of 1972–2009 at an aggregate level to assess the relationship between climate variables and rice yield using both the ordinary least squares and regression methods. The results showed that maximum temperature is statistically significant for all rice yields with positive effects on Aus and Aman rice and adverse effects on Boro rice. Minimum temperature has a statistically significant negative effect on Aman rice and a significantly positive effect on Boro rice. Finally, rainfall has a statistically significant effect on Aus and Aman rice. Mainuddin et al. (2013) studied impact of climate change on rice in the lower Mekong Basin base on ECHAM4 global climate model and A2 and B2 scenarios. The results show that yield of rain fed rice may increase in the upper part of the basin in Laos and Thailand and may decrease in the lower part of the basin in Cambodia and Vietnam. Gohari et al. (2013) evaluated climate change impacts on crop production and water productivity of four major crops (wheat, barley, rice, and corn) in Iran's Zayandeh-Rud River Basin. They show crop production and water productivity of all crops is expected to decrease due to lower precipitation and higher water requirements under higher temperature. Soora et al. (2013) assessed the regional vulnerability of rice to climate change in India using A1b, A2, B1 and B2 emission scenarios and global climate model (MIROC3.2.HI). The study projected a progressive reduction in irrigated rice yields due to climate change towards the end of the century, if no adaptation is followed; while for rain fed rice, negative impacts likely to reduce with time due to projected increase in rainfall in many areas. Poudel and Kotani (2013) studied climatic impacts on crop yield and its variability in Nepal. The results show that an increase in the variance of both temperature and rainfall has adverse effects on crop productions in general. On the other hand, a change in the mean levels of the temperature and rainfall induces heterogeneous impacts, which can be considered beneficial, harmful or negligible, depending on the altitudes and the kinds of crops.

The results, depending on the type of plant photosynthetic pathway and geographic area, are varied and having an overall statement about the response of different species to climate change needs to conduct a case study.

Rice is a main food for half of the world's population, including most of the world's 1 billion poor, and any significant negative effect on rice production caused by climate change would be devastating for efforts to achieve global food security and address poverty. In Iran, rice is the second important staple food crop after wheat and the main

rice cultivation center is across of plains in southern coasts of Caspian Sea. This region provides 70% of total rice production areas in Iran (Iran Ministry of Agriculture, 1993).

The objective of this study is to assess the impact of future global warming on irrigated rice crop in the Caspian Sea coastal area under three climate change scenarios of SRA1B, SRA2 and SRB1. Different instruments must be used to predict or simulate the effects of climate change on crops so that the best policy making and planning can be conduct and ultimately provide the food security and the maximum economic welfare of manufacturers.

2. Materials and Methods

The study area is located in the southern coasts of Caspian Sea. The Rasht station is selected as the rice cultivation center in the southern coasts of Caspian Sea with long-time weather data, to simulate the effects of future warming on irrigated rice in this study. Annual total of precipitation is 1337.5 mm and maximum rainfall occurs in autumn. The mean maximum air temperatures ranged between 11 to 30 °C and the mean minimum air temperatures is varied between 6 to 26 °C. Required data for this research includes the meteorological, soil and crop management data. Meteorological data include the collection of daily data of minimum temperature, maximum temperature, solar radiation and precipitation during 1981-2010 and Global Climate Models (HADCM3, ECHAM5, IPCM4, GFCM2, NCCCSM and INCM3) for the period of 1971-2000. Soil and crop management data have provided from field experiment. Soil data include the classification of the soil, the water-holding characteristics of different soil layers plus their bulk density, organic C, PH, drainage coefficient and root growth factor. Crop-management factors include planting date, planting depth, row spacing and direction, plant population, fertilization, irrigation, inoculation, residue applications, tillage, and harvest date.

The future climate change scenarios that are usually generated using global circulation models cannot provide the details on very small spatial scales due to scientific limitations and incomplete observational data (IPCC, 2007). For decreasing of gap between the scale of GCMs and required resolution for practical applications, downscaling provides climate change information at a suitable local scale from the GCM data (Hewitson and Crane, 1996). We used Lars-Weather Generator model for simulating time-series of daily weather and downscaling climate models at a single site in this study. It was calibrated and validated using statistical tests between generated and observed data. Although the Lars-Wg model contains 15 global climate models,

the six models (HADCM3, ECHAM5, IPCM4, GFCM2, NCCCSM and INCM3) have three scenarios of SRA1B, SRA2 and SRB1. In evaluating the accuracy of the atmosphere general circulation models in production of future weather data, we validated six global climate models using the absolute root mean square error (RMSE) and mean absolute error (MAE) between the simulated and observed data. Future weather data generated for 2011-2032 and 2046-2065 base on climate change scenarios.

Field experiment was conducted from 2008 to 2009 at the Iranian Rice Research Institute in Rasht (37◦12 N, 49◦38 E) during the rice-growing season. The rice crop varieties Hashemi and Alikazemi have been selected for calibrating of crop model that widely cultivated in the north of Iran. The experiment was done in a split-plot design with three irrigation regimes as the main plot, four N levels and three replications. The plot size for the subplots was 15 m^2. The irrigation regimes were continuous submergence with irrigation at 5-day intervals and 8-day interval. The four N rates applied were 0, 30, 60, and 90 kg N ha^{-1}. The subplots (15 m^2) consisted of four N levels: N1: no N application; N2: total N rate of 45 kg ha^{-1}; N3: total N rate of 60 kg ha^{-1}; and N4: total N rate of 75 kg ha^{-1}.

Seedlings were grown in wet beds for approximately 25–30 days and was done transplanting at three plants per hill with a spacing of 20 × 20 cm. Seeding was done in the nursery in early April. Thirty-day-old seedlings were transplanted in early May. Treatments were harvested in mid August. Weeds, insects, and diseases were controlled in all plots to avoid yield loss.

Soil physical and chemical properties such as texture, bulk density, hydraulic conductivity, drained upper limit, drained lower limit, field capacity, PH, cation-exchange capacity (or CEC that is the total capacity of a soil to hold exchangeable cations), organic carbon, total N, phosphorus (P), potassium (K) were determined up to a depth of 80 cm, at an interval of 10 cm, following standard procedures (Table 1).

Table 1. Physical and chemical per soil layers of the experiment field

Soil properties	Depth(CM)					
	0-10	10-20	20-30	30-40	40-60	60-80
Clay (%)	47	44	47	47	49	61
Sand (%)	14	17	9	11	9	5
Loam (%)	39	39	44	42	42	34
Bulk density (g cm)	1.10	1.20	1.32	1.31	1.33	1.29
Water content at saturation	0.65	0.62	0.62	0.60	0.60	0.60
Water content at FC	0.40	0.40	0.41	0.42	0.42	0.39
Water content at PWP	0.27	0.30	0.30	0.30	0.32	0.29
K_{sat}(cm day^{-1})	57.5	30.8	0.4	11.4	10.4	21.4
PH	7.1	7.23	7.26	7.08	7.5	7.5
CEC (meq/100g−1)	33	32	31	31	30	30
Organic carbon (%)	0.16	0.14	0.074	0.074	0.09	0.09
P (ppm)	10.1	7.3	5.2	3.2	2.1	1.7

Crop simulation models are an efficient tool for studying the present and future effects of climate changes on crop. Because of the limitations and weak of statistical models, the simulation of the effects of climate change on agriculture usually employs a climate model coupled with a crop growth model (Yao et al., 2011). The crop model that used for simulating rice response to future warming is Ceres-Rice model. The Crop Estimation Resource and Environment Synthesis (CERES)-Rice model was one of the DSSAT models developed by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project which can simulate growth, development and yield of rice varieties by numerical integration of constituent processes under different agroclimatic conditions and management strategies (Mathauda et al., 2000). Ceres-Rice has been evaluated for many tropical and sub-tropical locations in Asia and in temperate climates (Timsina and Humphreys, 2006). Databases contain weather, soil, experiment conditions and measurements, and genotype information for applying the models to different situations. According to Jones et al. (2003) this software helps users prepare these databases and compare simulated results with observations to give them confidence in the models if modifications are needed to improve accuracy. In addition, programs contained in DSSAT allow users to simulate options for crop management over a number of years to assess the risks associated with each option.

The Ceres-Rice model has been evaluated separately for the calibration data set of 2008 and for

the validation data set of 2009 in this study. Calibration is defined as a set of operations that adjust some model parameters, under specified conditions, to local conditions and it creates genetic coefficients for new cultivars. The calibration of the Ceres-Rice model was based on data from end-of-season samplings of grain yield, crop biomass, and N contents in biomass and in grain in 2008 field experiment. Growth and development of crop varieties in maturity are distinguished using the genetic coefficients in Ceres-Rice model. The genetic coefficients of the cultivar of Hashemi and Alikazemi that affect the occurrence of phonological stages in the Ceres-Rice models were derived using the Genotype Coefficient Calculator program (GENCALC) which is part of the Decision Support System for Agrotechnology Transfer (DSSAT). This program estimates the coefficients for a genotype by iteratively running the crop model with an approximate value of the coefficients concerned. It alters the cultivar coefficients automatically until the simulated and measured values match (Hunt et al., 1993). Table 2 shows results of calibrating the Ceres-Rice model in 2008 field experiment for cultivars of Hashemi and Alikazemi.

Table 2. Genetic coefficients of the rice cv. Hashemi and Alikazemi as derived by GENCALC of DSSAT model

Genetic parameters	Hashemi	Alikazemi
P1	310	320
P2R	20	20
P5	350	360
P2O	13.5	13.5
G1	55	55
G2	0.025	0.028
G3	1	1
G4	1	1

P1 is respectively thermal time in the basic vegetative phase of the plant, P2O is critical photoperiod of development occurs at a maximum rate, P2R is photoperiod sensitivity in panicle initiation, P5 is grain filling duration, G1 is potential spikelet number coefficient, G2 Single grain weight under ideal growing conditions, G3 tillering coefficient under ideal conditions, G4 is temperature tolerance coefficient.

We compared the simulated and measured data for validating of model to increase confidence in the ability of model. The combination of graphical and statistical methods was used to compare the simulated and observed results (final biomass and yield). So, we evaluated model performances using the absolute root mean square error (RMSE), root mean square error normalized (RMSEn) and mean absolute error (MAE). RMSE and RMSEn are well statistical methods to test the goodness of fit of simulation models (Bouman and Van Laar, 2006). Willmott and Matsuura (2005) suggested that MAE is the most natural measure of average error magnitude and is an unambiguous measure of average error magnitude. Willmott et al. (1985) suggested some statistical methods for evaluating of model and offered that RMSE is the ''best'' measure as it summarizes the mean difference in the units of observed and simulated values:

$RMSEa = [1/n \, \Sigma \, (Yi - Xi)^2]^{0.5}$
$RMSEn = 100. [RMSEa / \Sigma X_{obs}]$
$MAE = \Sigma \, | (Yi - Xi)| / n$

Where Yi is the simulated value, Xi is the measured value, and n is the number of measurements. It was calculated the slope of linear relation between simulated and observed values (α), intercept (β), and coefficient of determination (R^2) of the linear regression between simulated (Xsim) and measured (Xobs) values for the same variables. We also calculated the T-test of means assuming unequal variance (P (t*)) between simulated and measured values. Scatter plots between simulated and measured data were used to show the overall goodness-of-model fit.

We studied the Sensitivity of rice yield and Biomass to temperature rise and simulated the yield and biomass of rice base on the prediction of GCM under climate change scenarios of Sra1b, Sra2 and Srb1 during 2011-2032 and 2046-2065.

3. Results

The Lars-WG model was validated using statistical tests such as the Kolmogorov-Smirnov (K–S) test, T- test and F-test with P-value. The K–S test was done for testing equality of the seasonal distributions of wet and dry series (WDSeries), distributions of daily rainfall (RainD), and distributions of daily minimum (TminD) and maximum temperature (TmaxD). The T-test is performed on testing equality of monthly mean rainfall (RMM), monthly mean of daily maximum temperature (TmaxM), and monthly mean of daily minimum temperature (TminM) and The F-test is performed on testing equality of monthly variances of precipitation (RMV) calculated from observed data and downscaled data. If the P-value of a data set is below a certain pre-determined amount (0.05), the "null hypothesis" of their experiment rejects. The null hypothesis is that the simulated data is same observed data. Table 3 shows the p-value of statistical test for validating of the Lars-WG model in Rasht stations. Figure 1 shows generated and observed monthly mean and standard deviation of temperature and precipitation in Rasht station.

Table 3. The P-value of statistical test for validating of the Lars-WG model in Rasht station

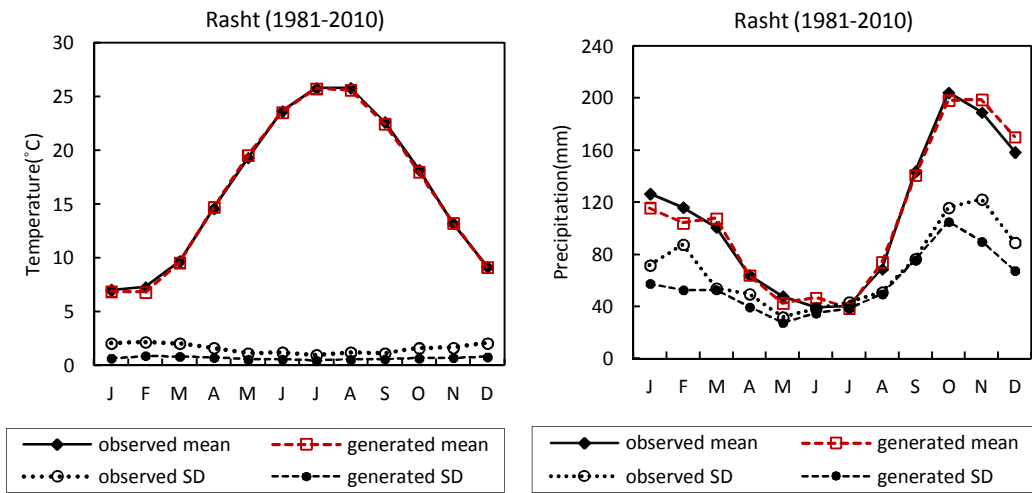| Statistical Test	WDSeries	RainD	RMM	RMV	TminD	TminM	TmaxD	TmaxM
	K-S	K-S	T test	F test	K-S	T test	K-S	T test
winter	0.79	1	0.5	0.35	0.99	0.55	0.99	0.34
spring	1	0.89	0.59	0.34	1	0.33	1	0.63
autumn	1	1	0.79	0.74	0.99	0.45	0.99	0.55
summer	1	0.99	0.67	0.2	0.99	0.62	1	0.74

Figure 1. Generated and observed monthly mean and standard deviation of temperature and precipitation in the Rasht station.

The global climate models validated using measures of accuracy indicators during baseline period (1981-2000). The measures of accuracy indicators show that ECHAM5 climate model (European Community Hamburg atmospheric model coupled to a large scale geostrophic ocean model that was generated by Max-Planck Institute for Meteorology in Germany) has the highest correlation with the lowest error to simulate the temperature and precipitation (Table 4). Therefore, according to the uncertainty principle, due to the low performance of other models in simulating the temperature and precipitation for reducing the errors in simulating, they won't be used in simulation of future climate.

Table 4. Validation of global climate models using measures of accuracy indicators

Global Climate Models	RMSE		MAE	
	Temperature (°C)	Precipitation (mm)	Temperature (°C)	Precipitation (mm)
GFCM2	8/5	3/34	8/35	2/81
HADCM3	6/06	3/61	5/34	2/99
INCM3	5/98	3/5	5/73	2/96
IPCM4	4/4	3/44	3/9	2/91
ECHAM5	2/69	3/19	2/36	2/69
NCCCSM	4/28	2/96	4/09	2/53

The results of statistical methods used to evaluate the model performance are shown in Tables 5. The RMSE was 306.3 kg ha^{-1}, the normalized RMSE was 1.34 % and the MAE was 270 for rice crop yield. The biomass was slightly over predicted with an RMSE of 480.7 kg ha^{-1}, the normalized RMSE was 0.89% and the MAE was 354.2 for total biomass. Paired t-test showed no significant differences between the measured and simulated yield and total biomass values at P = 0.05 confidence level.

Table 5. Results for Ceres-Rice simulations of final yield and biomass for the calibration conditions

year	Crop Parameters	X obs	X sim	α	β	R^2	P(t)	RMSEa	RMSEn	MAE
2009	Biomass (kg ha⁻¹)	6704	6747.7	0.82	1238	0.94	0.5	480.7	0.89	354.2
	Yield (kg ha⁻¹)	2843	3114	0.89	570.7	0.87	0.2	306.3	1.34	270

Xobs, Mean of measured values; Xsim, Mean of simulated values; P(t*), Significance of paired T-test at 95%; α, Slope of linear relation between simulated and measured values; β, Intercept of linear relation between simulated and measured values; R^2, coefficient of determination; RMSEa, Absolute root mean square error; RMSEn, Normalized root mean square error (%); MAE, mean absolute error.

Figure 2 shows the comparison of simulated with measured yield and final biomass for all data of the validation sets. The linear regression between simulated and measured values had a slope α close to 1, an intercept β that was small (compared with the range in the recorded values), and r relatively close to 1, indicating a close correlation between the simulations and the measurements.
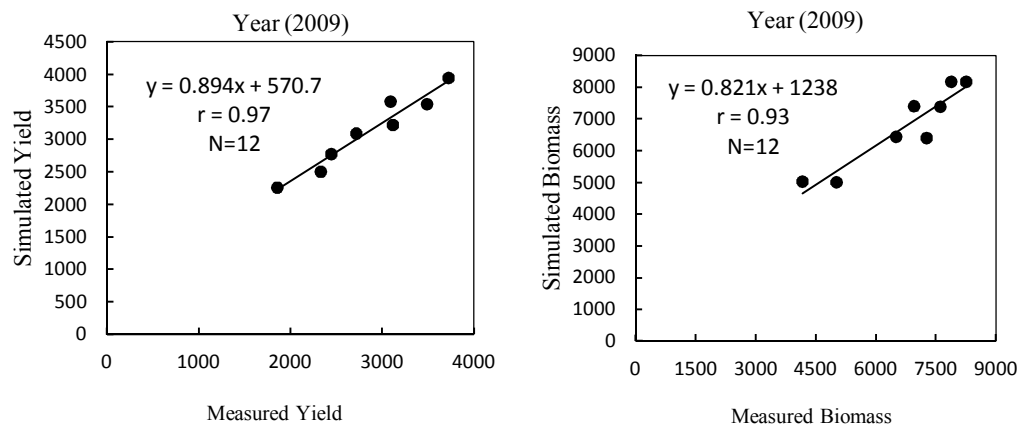

Figure 2. Evaluating of simulated versus observed yield and Biomass. α, Slope of linear relation between simulated and measured values that is close to 1; β, Intercept of linear relation between simulated and measured values that is small; r, Correlation Coefficient is close to 1; N, number of value.

It can be concluded that the Lars-WG model has good performance in the Rasht station in generating daily minimum and maximum air temperature and daily precipitation. So, it was used to predict daily minimum and maximum temperature and daily precipitation for the Rasht station during 2011–2032 and 2046-2065 under three scenarios of Sra1b, Sra2 and Srb1. Results show that minimum and maximum temperature will increase in future during the rice-growing season. Also, the minimum air temperature will increase more than maximum air temperature. The prediction results under three scenarios of Sra1b, Sra2 and Srb1 in comparison with present level showed that the maximum temperature increase will be 0.5 – 1.9°C during 2011-2032 and 1.7 – 2.1°C during 2046-2065. The minimum temperature increase will be 0.4 – 2°C during 2011-2032 and 1.7 – 2.1°C during 2046-2065. Total precipitation will decrease comparison to the normal level in the Rasht station. Also, study of total precipitation showed that precipitation will decrease between 10 to 28% during 2011-2032 and between 29 to 17% during 2046-2065

in the rice-growing season (April- august) in comparison to the normal level in the Rasht station (Table 6).

The results from ECHAM5 show mean temperature increase will be 0.4 –1.9 °C during the rice-growing season. Higher temperature shortens the crop growth period; consequently reduce the available to the plant for photosynthetic accumulation (Ritchie, 1993). High temperature conditions after heading result in smaller kernels at maturity leading to reduction in grain yield (Yoshida and Hara, 1977). In this study, the Sensitivity of rice yield and Biomass to changes in atmospheric temperature is studied and presented in Figure 3. The figure shows a decrease in Hashemi and Alikazemi rice yield and biomass for a 1 to 3°C rise in mean daily temperature from present day level. At 2°C temperature rise the yield decreases 6% and 2.8% respectively in Hashemi and Alikazemi rice from the base temperature level. The biomass decreases 3% and 2.4% respectively in Hashemi and Alikazemi rice crop from the base temperature level.

Table 6. Results of ECHAM5 model's predictions under three scenarios of Sra1b, Sra2 and Srb1 in the Rasht station during the rice-growing season

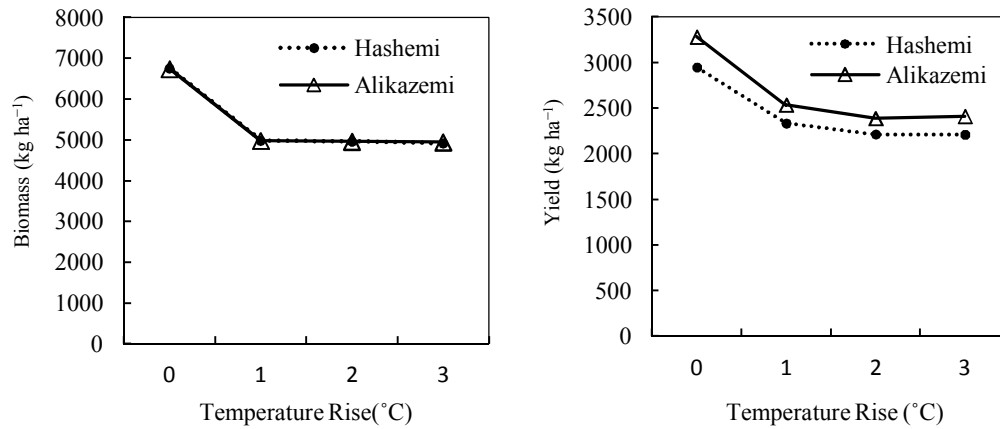| Climate variables	Observed period (1981-2010)	2011-2032			2046-2065		
		Sra1b	Srb1	Sra2	Sra1b	Srb1	Sra2
Minimum Temperature (˚C)	17/39	19/47	17/8	18/24	19/49	19/11	19/38
Maximum Temperature (˚C)	28/2	30/1	28/7	28/9	30/26	29/96	30/14
Total Precipitation (mm)	52/8	38	45/9	47/2	37/84	44/1	43/2

Figure 3. Sensitivity of rice yield and biomass to mean temperature changes between 0 to 3˚C as simulated by the Ceres-Rice model

Figure 6 and 7 show the simulated yield and Biomass of the irrigated rice crop base on scenarios of Sra1b, Sra2 and Srb1. The Hashemi and Alikazemi rice yield decreases for 2011-2032 and 2046-2065 with temperature rise. The decrease of irrigated rice yield is 1/3% and 1/1% respectively in Hashemi and Alikazemi rice during 2011-2032 and 3/6% and 3/2%

respectively in Hashemi and Alikazemi rice during 2046-2065. Also, the decrease of irrigated rice biomass is 1/4% in Hashemi and 1/1% in Alikazemi rice during 2011-2032 and 4/2% and 4/7% respectively in Hashemi and Alikazemi rice during 2046-2065.
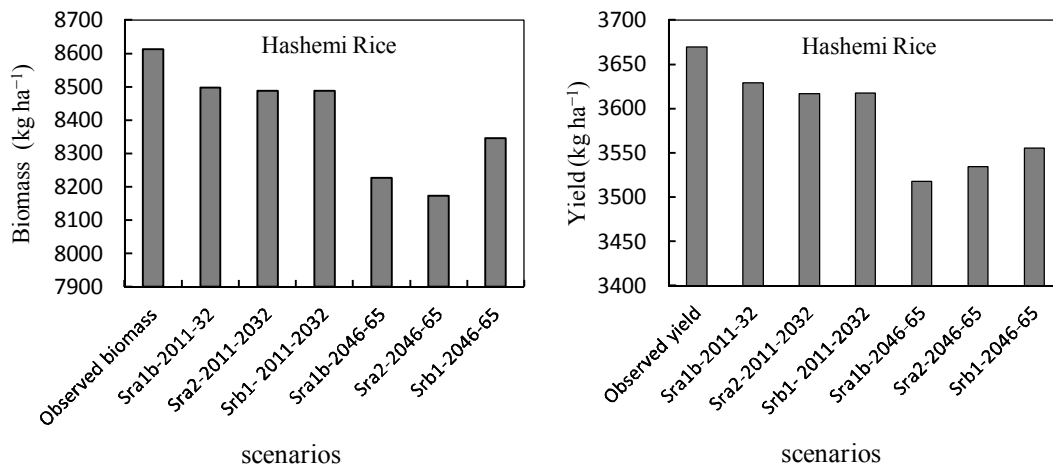

Figure 6. Simulation of Hashemi rice yield and Biomass under three scenarios of Sra1b, Sra2 and Srb1in the Rasht station for 2011-2032 and 2046-2065 as compared with observed data.
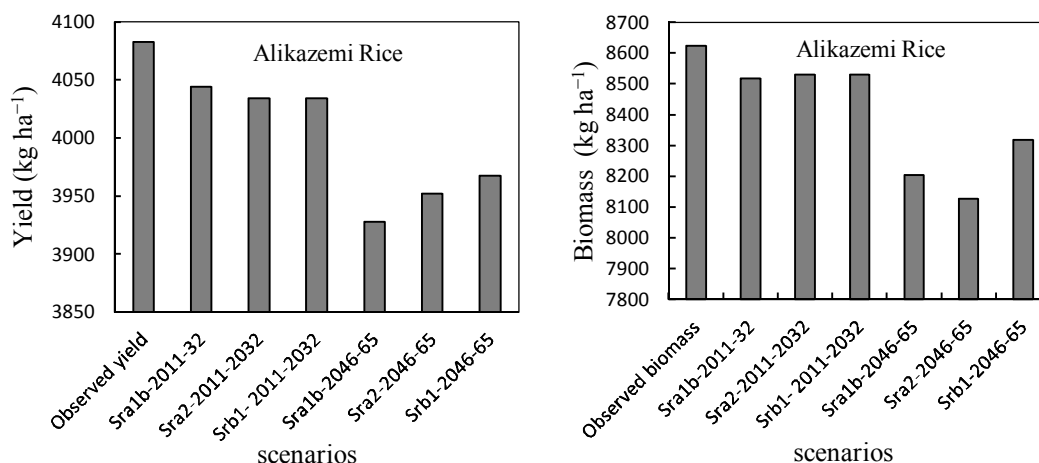
Figure 7. Simulation of Alikazemi rice yield and Biomass under three scenarios of Sra1b, Sra2 and Srb1in the Rasht station for 2011-2032 and 2046-2065 as compared with observed data.

4. Discussion

The impacts of global warming on irrigated rice yield and Biomass will depend on the actual patterns of change in rice growing areas. The results of prediction of ECHAM5 climate model under scenarios of Sra1b, Sra2 and Srb1 show that trend of temperature will be ascending in the southern coast of Caspian Sea and the minimum temperature will increase more than maximum temperature. Total precipitation will decrease comparison to the normal level. It may increase evapotranspiraton level and relative humidity due to increasing of temperature. The findings of this study confirm that climate variables have had significant effects on rice crop. The sensitivity of irrigated rice crop yield and biomass to air temperature changes showed that for two degree temperature rise there is about 6 and 2/8% decline in rice yield and about 3 and 2/4% decline in rice biomass respectively in Hashemi and Alikazemi. The yield and Biomass of the irrigated rice crop under scenarios of Sra1b, Sra2 and Srb1 show that Hashemi and Alikazemi rice yield and biomass will decrease for 2011-2032 and 2046-2065 with temperature rise. These impacts can be averted through the efforts of agricultural research and policies aiming to improve rice varieties and accompanying management strategies.

Present study shows similar results to other researches. Zhiqing et al. (1994) reported that an increase in temperature alone would decrease rice yield but that enhanced photosynthesis caused by increased CO_2 can compensate for this effect. Saseendran et al. (2000) reported an increase in the trend of simulated rice yield for a 1 to 3°C drop in temperature. Aggarwall and mall (2000) show that increase of 1°C temperature without any increase in CO_2 resulted in a 3- 7% decrease in grain yield in eastern and western region India. Peng et al. (2004) concluded that grain yield declined by 10% for each 1°C increase in growing-season minimum temperature in the dry season.

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