



Simulation of global warming effect on irrigated rice Phenology in the major rice production region of Iran, Rasht

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General Note



Article is recommended to print as color version in recycled paper. *Save Trees, Save Climate*

ABSTRACT

The effects of global warming on crop production and food security are of concern and have been extensively evaluated by various simulation models. The effect of future climate on rice phenology was investigated under climate change scenarios in Rasht station

in this study. Data for this research includes the meteorological, soil and crop management data. Meteorological data include the daily data of minimum temperature, maximum temperature, solar radiation and precipitation during 1981-2010 and monthly temperature and precipitation of general circulation models during 1971-2000. Soil and product management data were provided from field experiment in the Iranian Rice Research Institute in Rasht, from 2008 to 2009. We used stochastic weather generators (Lars-WG) for downscaling of climate model. The prediction of climate did using of ECHAM5 model under of SRA1B, SRA2 and SRB1 scenarios. This model was validated using RMSE and MAE. Ceres-Rice model was used for simulating of rice phenology in two irrigation regimes (continuous submergence and irrigation at 5-day intervals). Results show that minimum and maximum temperature will increase in the Rasht during the rice-growing season. Simulation of rice phenology showed the beginning of Panicle Initiation, anthesis and physiological maturity day will happen earlier with increasing of temperature in continuous submergence and will not happen earlier with increase in interval of irrigation. Also, the beginning of phenological stages will delay with increasing of temperature above 1°C even in continuous submergence.

Key Words: Global warming, ECHAM5 Model, Rice Phenology, Simulation, Ceres-Rice Model.

1. INTRODUCTION

The global mean surface temperature change for the period 2016 – 2035 will likely be in the range 0.3°C to 0.7°C (IPCC, 2014). Though the 0/6°C increase in the global average temperature is small in the beginning of the twentieth century, the evidence shows that climate change has already affected various physical and biological systems (Barrie Pittock, 2005).

Climate change due to anthropogenic changes in natural ecosystems has been so great that effect of climate change on all human activities received particular sensitivity in the scientific study. Agriculture and crop production depend on the weather and it provides the human needs. Climate change can have important effects on growth, performance and water consumption of crops (Bazzaz and Sombroek, 1996; Tushar Pandey et al. 2015; Kasahun Kitila Hunde, 2015). 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. any rapid change in weather will cause significant changes in the growth and development of plants and the plants will have displace and finally may even exclude them from the agricultural system in a particular area (Horie et al., 2000).

Rice is one of the world most important cereal food crops in Asia (Jagadish and Pal, 2009). More than 90 percent of the world's rice grow and consume in Asia, where 60 percent of the earth's people live (Horie et al., 2000). Since the world population is increasing at 1.17 % annually, an annual increase in rice production by 0.6–0.9% require until 2050 (Carriger and Vallee, 2007). The south coasts of Caspian Sea with a 78 percent of the rice cultivation lands are among the most important rice growing areas in Iran (Iran Ministry of Agriculture, 1993).

Major environmental factors that limit rice cultivation are air temperature and water supply (Horie et al., 2000). Rice, like other crops, has an optimum temperature for growth and development. Increase or decrease in optimum temperature will result in an altered physiological activity or may lead into a different developmental pathway (Downton and Slatyer, 1972). Phenology and growth period of rice are among the major factors determining agro ecological congruency of different rice types in rice cultivations (Yin, 2005). A correct estimation of phenological stages of crop plants for optimization of crop management practices on the farm and better compatibility of crops calendar with particular agro ecological systems, is important (Khanal, 2005).

Many researchers conducted to determine the effects of global warming and other environmental factors on growth and phenology of crops over the past two decades. The results of studies, depend on the plant photosynthetic pathway and geographic area vary and having an overall statement about the response of different species to climate change needs to conduct a case study.

Mahmood (1997) studied variations of air temperature on the Boro rice growth stages using general circulation model predictions. Results show that an increase in air temperature will provide longer and more stable thermal conditions for Boro rice maturing stage. A 5% increase and a 4% decrease in seasonal total evapotranspiration will occur under each 1° cooler and warmer air temperature conditions, respectively. Tao et al (2006) synthesized crop and climate data from representative stations across China during 1981–2000 to find out whether there were significant trends in changes of climate in different regions, and whether these changes have had significant impact in the development and production of the staple crops (rice, wheat, and maize). Results show that significant warming trends observe at most of the stations and the changes in temperature have shifted crop phenology and affected crop yields during the two decades. Cheng et al (2009) studied a combination of high night temperature and elevated CO₂ during the on rice growth and yield. The results show that whole plant and stem dry weight increase by both elevated CO₂ and high night temperature, while the ear dry weight increase significantly by elevated CO₂ and decreased by high night temperature. Zhang and Tao (2012) modeled the response of rice phenology to climate change and variability in different climatic zones using five rice models (CERES-Rice, ORYZA2000, RCM, Beta Model and SIMRIW). Results showed that simulated changes in rice phenology were consistent when temperatures were below the optimum; however varied largely when temperatures were above the optimum. The simulated rice growing season under future climate scenarios shortened about 0.45–5.78 days; but in northeastern China, increased temperature variability may prolong the growing season of 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 upperparts of the basin in Laos and Thailand and may decrease in the lower part of the basin in Cambodia and Vietnam. Devkota et al (2013) studied the effects of projected increases in temperature and atmospheric CO₂ concentration on the phenological development and grain yield of rice using the “ORYZA2000” model and three field experiments with three widely cultivated rice varieties under various seeding dates in the 2008–09 growing seasons in the Khorezm region of Uzbekistan. Temperatures and CO₂ concentrations projected by the Intergovernmental Panel on Climate Change for the B1 and A1F1 scenarios for the period 2040–69 to explore rice growth and yield. Under both climate change scenarios, the seeding dates could delay by 10 days. Increased temperature and CO₂ concentration resulted in higher rice grain yields.

This study assesses the impact of global warming on rice phenology in the major rice production region in Iran (Gilan) under scenarios of IPCC fourth assessment report. Different instruments must use to simulate the effects of climate change on crops so 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

2.1. Study area

The Rasht station selected as the most productive rice in Iran with a 57-year-old meteorological data, to simulate the effects of future warming on phenology of rice in this study. Annual total of precipitation is 1337.5 mm and the mean maximum temperature ranged between 11 to 30 °C and the mean minimum temperature vary between 6 to 26 °C.

2.2. Model input data

Used data for this research includes the meteorological, soil and crop management data. Meteorological data includes the daily data of minimum temperature, maximum temperature, solar radiation and precipitation during 1981–2010 and outputs of global climate models (HADCM3, ECHAM5, IPCM4, GFCM2, NCCCSM and INCM3) for the period of 1971–2000 and predicted data during 2011–2032. Soil data includes the classification of the soil, the water-holding characteristics of different soil layers plus their bulk density, organic carbon, PH, drainage coefficient and root growth factor. Crop-management data include planting date, planting depth, row spacing and direction, plant population, fertilization, irrigation, inoculation, residue applications, tillage, and harvest date. The Soil

and crop management data was provided from field experiment. Hashemi variety selected for calibrating of crop model that widely cultivated in the north coast of Iran.

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) determined up to a depth of 40 cm, at an interval of 10 cm, following standard procedures (Table 1).

Table 1 Physical and chemical each soil layers of the experiment field

Depth	0-10	10-20	20-30	30-40
Clay (%)	47	44	47	47
Sand (%)	14	17	9	11
Loam (%)	39	39	44	42
Bulk density (g cm)	1.10	1.20	1.32	1.31
Water content at saturation (cm ³ /cm ³)	0.65	0.62	0.62	0.60
Water content at FC (0.01 MPa)	0.40	0.40	0.41	0.42
Water content at PWP (1.5 MPa)	0.27	0.30	0.30	0.30
K _{sat} (cm day ⁻¹)	57.5	30.8	0.4	11.4
PH	7.1	7.23	7.26	7.08
CEC (meq/100g-1)	33	32	31	31
Organic carbon (%)	1/72	1/54	1/25	0/76
P (ppm)	10.1	7.3	5.2	3.2
K (ppm)	195	176	185	161

Phosphorus (P) and potassium (K) applied at transplanting in all plots at the rate of 25 kg phosphorus (P) ha⁻¹ and 75 kg potassium (K) ha⁻¹. The dates of emergence, panicle initiation, flowering, and physiological maturity recorded for each management.

2.3. Field Experiment

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 experiment did 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 m². The irrigation regimes were continuous submergence with irrigation at 5-day intervals and 8-day interval. The four N rates applied were 0, 45, 60, and 75 kg N ha⁻¹. The subplots (15 m²) 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 were done transplanting each 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.

2.4. Generating of Future Weather data

We used the coupled ocean-atmosphere models for prediction of future temperature. Since the oceanic-atmosphere models provide different climatic outputs, it is necessary to validate the climate models. We validated six global climate models using the

root mean square error (RMSE) and mean absolute error (MAE) between the simulated and observed data for evaluating the accuracy of the climate models in production of future weather data. RMSE is 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.

The statistical downscaling technique was used to convert the global climate models outputs into local-scale, to overcome the low resolution problem in global climate models. The statistical downscaling technique of the global climate models include: weather pattern based methods, random and regression methods. Random weather generating methods have greater score for downscaling. This method produces long-term series and reduces the uncertainties of climate fluctuation (Semenov et al., 1998). In this method, both the changes in mean and fluctuations are reflected (Prudhomme et al., 2002). In this study, the LARS-Weather Generator model was used to downscale. Thus, the Lars-WG validated using some statistical tests such as Kolmogorov-Smirnov (K-S) and T- test with P-value. The K-S test was done for testing equality of distributions of daily minimum (TminD) and maximum temperature (TmaxD). The T-test performed for testing equality of monthly mean of daily maximum temperature (TmaxM) and monthly mean of daily minimum temperature (TminM). Daily temperature data was generated under of SRA1B, SRB1 and SRA2 scenarios for the period 2011- 2032.

2.5. Crop model

Crop simulation models are an efficient tool for studying the present and future effects of climate changes on crop. The crop model for simulating rice response to future warming is CERES-Rice model. The Crop Estimation Resource and Environment Synthesis (CERES-Rice) model is one of the DSSAT models developed by the International Benchmark Sites Network for Agro technology Transfer (IBSNAT) project which can simulate growth, development and yield of rice varieties by numerical integration of constituent processes under different agro climatic conditions and management strategies (Mathauda et al., 2000). CERES-Rice model evaluated for many tropical and subtropical 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 model to different situations.

2.6. Crop Model Calibration and Validation

The Ceres-Rice model evaluated separately for the calibration data set of 2008 and for the validation data set of 2009 in this study. The calibration of the CERES-Rice model based on data from end-of-season samplings of panicle initiation day, anthesis day and physiological maturity day in 2008 field experiment. Growth and development of crop varieties in maturity distinguished using the genetic coefficients in the CERES-Rice model. The genetic coefficients of Hashemi variety that affect the occurrence of phenological stages in the CERES-Rice models 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 Hashemi rice.

Table 2 Genetic coefficients of the rice cv. Hashemi gained by GENCALC of DSSAT model

Genetic features	Hashemi
P1	310
P2R	20

P5	350
P2O	13.5
G1	55
G2	0.025
G3	1
G4	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.

The model performance of the CERES-Rice was validated to increase confidence in the ability of model. So, we evaluated model performances using linear regression and coefficient of determination (R^2). The panicle initiation day, anthesis day and physiological maturity day simulated in the Rasht station under SRA1B, SRB1 and SRA2 scenarios for the period 2011- 2032. The impact of temperature on rice phenology stage studied using correlation coefficient (R) in the future.

3. RESULTS

The statistical method for validating of global climate models during baseline period (1971-2000) presented in table 3. Results showed 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) had the lowest error to simulate the air temperature. Therefore, according to the uncertainty, because of the low performance of other models in simulating the air temperature, they did not use in simulation of future climate in the Rasht station.

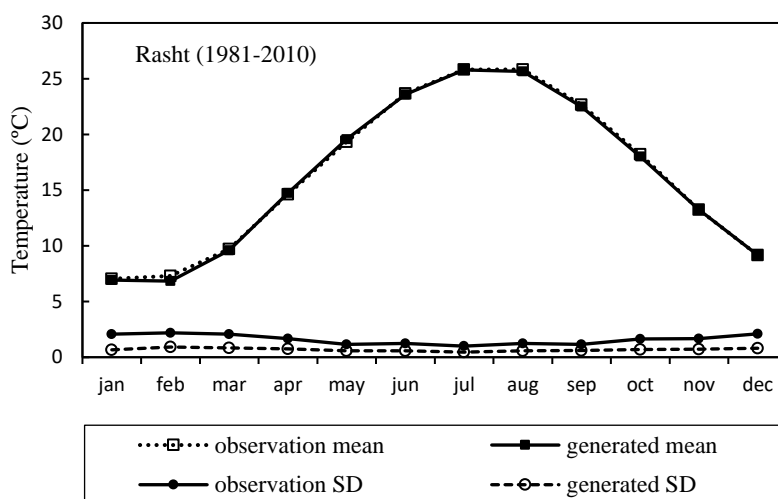
Table 3 Validation of global climate models using measures of accuracy indicators

Global Climate Models	Temperature (°C)	
Statistical Tests	RMSE	MAE
GFCM2	8/5	8/35
HADCM3	6/06	5/34
INCM3	5/98	5/73
IPCM4	4/4	3/9
ECHAM5	2/69	2/36
NCCCSM	4/28	4/09

The P-values of statistical tests for validating of the Lars-WG model in observation period (1981-2010) presented in table 4. If the P-value is below a certain predetermined amount (0.05), the "null hypothesis" of their experiment rejects. The null hypothesis is the simulated data is same observed data. The values of generated and observed monthly mean and standard deviation of air temperature in the Rasht station presented in figure 1. The monthly means of air temperature are the same and the monthly standard deviations of air temperature have negligible different.

Table 4 The P-value of statistical tests for validating of the Lars-WG model in the Rasht station

Parameter	TminD	TminM	TmaxD	TmaxM
Statistical Tests	K-S	T test	K-S	T test
Winter	0.99	0.55	0.99	0.34
Spring	1	0.33	1	0.63
Autumn	0.99	0.45	0.99	0.55
Summer	0.99	0.62	1	0.74

**Figure 1** Generated and observed monthly mean temperature in the Rasht station

It concluded the Lars-WG model has good performance in the Rasht station in generating daily air temperature. Table 5 and 6 presented the obtained results of ECHAM5 under three scenarios. From the results obtained, the minimum and maximum temperature will increase in the future during the rice-growing season (April-August). Also, the minimum air temperature will increase more than maximum air temperature. The ECHAM5 model under SRA1B, SRA2 and SRB1 scenarios predicted the minimum temperature mean will increase 0.65–2/1°C and the maximum temperature mean will increase 0.6–2°C in the rice-growing season in comparison to the normal level.

Table 5 Mean of minimum temperature under three scenarios in the Rasht station during the rice-growing season

Month	Observed period (1981-2010)	SRA1B	SRA2	SRB1
April	10/1	12/4	11/2	11/1
May	15	17/1	15/6	15/8
June	19/25	21	19/7	19/8
July	21/3	23/6	22/1	22/5
August	21/3	23/3	21/6	22

Mean	17/39	19/48	18/04	18/24
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Table 6 Mean of maximum temperature under three scenarios in the Rasht station during the rice-growing season

Month	Observed period (1981-2010)	SRA1B	SRA2	SRB1
April	19/1	21/5	20/1	20/1
May	23/7	25/8	24/5	24/7
June	28/1	29/7	28/5	28/7
July	30/4	32/3	30/9	31/2
August	30/3	32/5	30/9	31/3
Mean	26/3	28/3	26/9	27/2

Figure 2 shows the comparison of simulated with measured values of panicle initiation day, anthesis day and physiological maturity day for all data in different irrigation regimes using linear relation and coefficient of determination (R^2). Results show that slope of linear (a) is close to 1 and intercept of linear relation (b) is small. Also, the coefficient of determination is close to 1.

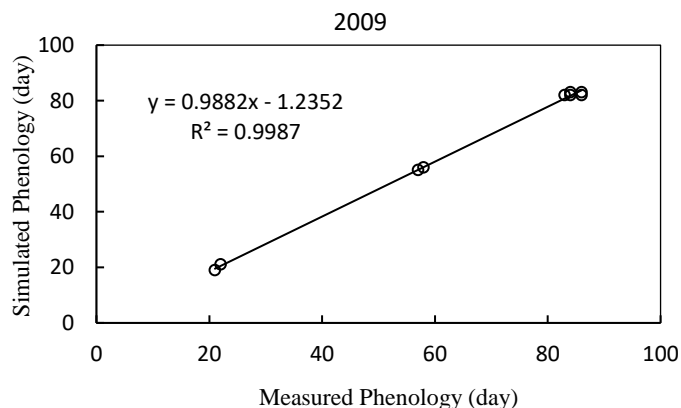


Figure 2 Evaluating of simulated versus observed phenological stages. Slope of linear relation (a) between simulated and measured values that is close to 1; intercept of linear relation (b) between simulated and measured values that is small; R^2 , coefficient of determination is close to 1.

Table 7 presents the correlation coefficient between temperature increase and the panicle initiation day, anthesis day and physiological maturity day in the future. Negative values of correlation coefficient (R) show the panicle initiation day, anthesis and physiological maturity day will reduce with temperature increase in the future. The correlation coefficient in different irrigation regime shows that with increase in temperature, the beginning of rice phenological stages in the continuous submergence irrigation happens earlier than that in irrigation at intervals of 5 days. In other words, with increase in interval of irrigation, the beginning of phenological development will happen later accordingly and the correlation coefficient had a value close to zero in irrigation at intervals of 5 days.

Table 7 Correlation coefficient between temperature and panicle initiation, anthesis and physiological maturity day

Irrigation regime	Scenarios	Panicle Initiation day	Anthesis day	Physiological maturity day
		R	R	R
Continuous submergence	SRA1B	-0/45	-0/46	-0/3
	SRA2	-0/48	-0/55	-0/36
	SRB1	-0/07	-0/43	-0/07
5-day interval	SRA1B	-0/41	-0/42	-0/12
	SRA2	-0/42	-0/44	-0/18
	SRB1	-0/16	-0/29	0/04

The study of rice phenological stages in the future shows the panicle initiation day, anthesis and physiological maturity day will decrease about 0/3 to 0/5, 0/3 to 1 and 0/5 to 1/2 days respectively in the continuous submergence irrigation and will decrease about 0/9 to 1/3, 0/8 to 1/5 and 0/5 to 1/2 days at interval of 5 days irrigation regime in comparison present level. In contrast, the beginning of rice phenology will delay with temperature rise above 1°C even in continuous submergence (Table 8).

Table 8 Beginning of rice phenological stages during 2011-2032 in the different irrigation regime

Irrigation regime	Scenarios	Panicle Initiation day	Anthesis day	Physiological maturity day
Continuous submergence	Observation period	26	58	85
	SRA1B	25/7	57/7	85
	SRA2	25/6	57/6	85
	SRB1	25/5	57/04	84/3
5-day interval	Observation period	27	59	86
	SRA1B	26	58/14	85/46
	SRA2	26/1	58/13	85/44
	SRB1	25/7	57/5	84/8

4. DISCUSSION

According to the ECHAM5 climate model, the average of temperature under three scenarios of SRA1B, SRA2 and SRB1 in comparison with present level will be 0.6–2/1°C during 2011–2032 in the rice-growing season. The beginning of rice phenology stages will happen earlier with temperature rise but the increase of irrigation interval will delay the beginning of rice phenology. When temperature is more than one degree, the rice phenology will delay even in continuous submergence irrigation. A study carried out by Aggarwal and Mall (2002) on the impact of climate change on rice yield in India revealed that increase in temperature will decrease the flowering period and that temperature change before flowering doesn't affect the phenological processes at all.

The study carried out by Zhang and Tao (2012) modeled the rice phenological response to climate change using 5 agricultural models in China, showed the rice growing season will decrease by 0/4 to 5/7 days under future climate change scenarios.

REFERENCES

- Aggarwal, P.K., Mall, R.K. (2002) Climate Change and Rice Yields in Diverse Agro-environments of India. II. Effect of Uncertainties in Scenarios and Crop Models on Impact Assessment. *Climatic Change* 52:331–343. doi: 10.1023/A:1013714506779
- Barrie Pittock, A. (2005) *Climatic Changes: Turning Up the Heat*. CSIRO publishing.
- Bazzaz, F. and Sombroek, W. (1996) *Global Climate Change and Agricultural Production*. Food and Agriculture Organization of the United Nations and John Wiley and Sons.
- Bouman, B.A.M., Van laar, H.H. (2006) Description and Evaluation of The Rice Growth Model ORYZA2000 Under Nitrogen-Limited Conditions. *Agricultural Systems* 87(3):249–273. doi: 10.1016/j.agsy.2004.09.011
- Carriger, S., Vallee, D. (2007) More Crop per Drop. *Rice Today*, 6(2):10–13.
- Cheng, W., Sakai, H., Yagi, K. and Hasegawa, T. (2009) Interactions of Elevated [CO₂] and Night Temperature on Rice Growth and Yield. *Agricultural and Forest Meteorology* 149(1):51–58.
- Devkota, K.P., Manschadi, A.M., Devkota, M., Lamers, J.P.A., Ruzibaev, E., Egamberdiev, O., Amiri, E. and Vlek, P.L.G. (2013) Simulating the Impact of Climate Change on Rice Phenology and Grain Yield in Irrigated Drylands of Central Asia. *J. Appl. Meteor. Climatol.*, 52: 2033–2050. doi: <http://dx.doi.org/10.1175/JAMC-D-12-0182.1>
- Downton, J. and Slatyer, R.O. (1972) Temperature Dependence of Photosynthesis in Cotton. *Plant Physiol.* 50:518–522. doi: 10.1104/pp.50.4.518
- Horie, T., Baker JT, Nakagawa H, Matsui, T. and Kim, H.Y. (2000) Crop Ecosystem Responses to Climate Change: Rice. In: Reddy KR, Hodges HF (eds.) *Climate Change and Global Crop Productivity*. CABI publishing, Wallingford, Oxon, pp 81–106.
- Hunt, L.A., Pararajasingham, S., Jones, J.W., Hoogenboom, G., Imamura, D.T. and Ogoshi, R.M. (1993) Gencalc: Software to Facilitate the Use of Crop Models for Analyzing Field Experiments. *Agronomy Journal*, 85: 1090–1094.
- IPCC (2014) *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of The Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.) Geneva, Switzerland, 151 pp.
- Intergovernmental Panel on Climate Change (IPCC), 2014
- Iran Ministry of Agriculture (1993) *The Feasibility Study on The Irrigation and Drainage Development Project in The Haraz River Basin*. Tokyo. Japan International Cooperation Agency.
- Jagadish, S.V.K. and Pal, M. (2009) Response of Rice (*Oryza sativa* L.) to Increasing Temperature and Atmospheric CO₂. In: Singh SN (ed) *Climate Change and Crops*, Environmental Science and Engineering. Springer, pp 63–79.
- Kasahun Kitila Hunde. (2015). The role of Agroforestry system as strategy to adapt and mitigate climate change: A review with examples from Tropical and Temperate regions. *Climate Change*, 1(1), 20–25
- Khanal, R.R. (2005) *Phyllochron and Leaf Development in Field Grown Rice Genotypes Under Varying Thermal Environments of a High Altitude Cropping System*. MSc. Thesis. Univ. of Zu Bonn. Germany.
- Mainuddin, M., Kirby, M. and Hoanh, C.T. (2013) Impact of climate change on rain fed rice and options for adaptation in the lower Mekong Basin. *Nat Hazards* 66(2): 905–938.
- Mahmood, R. (1998) *Air Temperature Variations and Rice Productivity in Bangladesh: a Comparative Study of the Performance of the YIELD and the CERES-Rice Models*. Ecological Modelling 106. 201–212.
- Mathauda, S.S., Mavi, H.S., Bhangoo, B.S. and Dhaliwal, B.K. (2000) Impact of Projected Climate Change on Rice Production in Punjab, India. *Tropical Ecology* 41(1): 95–98.
- Prudhomme, C., Reynard, N. and Crooks, S. (2002) Downscaling of Global Climate Models for Flood Frequency Analysis: Where Are We Now?. *Hydrological Processes* 16: 1137–1150. doi: 10.1002/Hyp.1054.
- Sarker, A.R., Alam, K. and Gow, J. (2012) Exploring the Relationship Between Climate Change and Rice Yield in Bangladesh: An Analysis of Time Series Data. *Agricultural Systems* 112:11–16.
- Semenov, M., Brooks, R., Barrow, E. and Richardson, C. (1998) Comparison of The WGEN and LARS-WG Stochastic Weather Generators for Diverse Climates. *Clim Res* 10(2):95–107.
- Tao, F., Yokozawa, M., Xu, Y., Hayashi, Y. and Zhang, Z. (2006) Climate Changes and Trends in Phenology and Yields of Field Crops in China, 1981–2000. *Agricultural and Forest Meteorology* 138: 82–92. doi:10.1016/j.agrformet.2006.03.014
- Timsina, J. and Humphreys, E. (2006) Performance of CERES-Rice and CERES-Wheat Models in Rice-Wheat Systems: A Review. *Agricultural Systems* 90: 5–31. doi: 10.1016/j.agsy.2005.11.007

25. Tushar Pandey, Parth Joshi, Srijita Dutta. (2015). Institutional Innovation in Climate Smart Agriculture. *Climate Change*, 1(2), 143
26. Wilks, D.S. (2006) *Statistical Methods in The Atmospheric Sciences*, 2nd end, Elsevier, Amsterdam.
27. Willmott, C.J., Ackleson, S.G., Davis, R.E., Feddema, J.J., Klink, K.M., Legates, D.R.J., Oconnell, J. and Rowe, C.M. (1985) Statistics For the Evaluation and Comparison of Models. *J Geophys Res.* 9(C5) 8995–9005.
28. Willmott, C.J. and Matsuura, K. (2005) Advantages of The Mean Absolute Error (MAE) Over The Root Mean Square Error (RMSE) in Assessing Average Model Performance, *Climate Research* 30:79–82.
29. Yin, X., Struik, P.C., Tang, J., Qi, C. and Liu, T. (2005) Model Analysis of Flowering Phenology in Recombinant Inbred Lines of Barley. *J Exp Bot* 56(413): 959–965.
30. Zhang, S. and Tao, F. (2012) Modeling the Response of Rice Phenology to Climate Change and Variability in Different Climatic Zones: Comparisons of Five Models, *European Journal of Agronomy* 45, 165-176.