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RESEARCH ARTICLE

Climate change impacts and adaptations for fine, coarse, and hybrid rice using CERES-Rice

Irfan Rasool Nasir[1] · Fahd Rasul[1] · Ashfaq Ahmad[1] · Hafiz Naeem Asghar[2] · Gerrit Hoogenboom[3]

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Abstract

Climate change has become a threatening issue for major field crops of Pakistan, especially rice. A 2 years' (2014 and 2015) field trial was conducted on fine, coarse, and hybrid rice at Research Area, Department of Agronomy, University of Agriculture, Faisalabad following the split-plot design. Data of growth, yield, and yield components were collected to calibrate and evaluate the CERES-Rice model under Decision Support System for Agro-technology Transfer (DSSAT). Two cultivars of each type of fine, coarse, and hybrid rice were transplanted with interval of fortnight from May to September during 2014 and 2015. The model was calibrated with non-stressed sowing data during the year 2014 and evaluated with the data of 2015. Climate change scenarios were generated for mid-century (2040–2069) under representative concentration pathway (RCP8.5) using different general circulation models (GCMs) (baseline, cool dry, hot dry, cool wet, hot wet, and middle) were using different General Circulation Models (GCMs). CERES-Rice calibration and evaluation results were quite good to simulate impacts of climate change and to formulate adaptations during 2040–2069 (mid-century). Simulations of all GCMs showed an average increase of 3 °C in average temperature as compared to baseline (1980–2010). Likewise, there would be an average increase of 107.6 mm in rainfall than baseline. The future rise in temperature will reduced the paddy yield by 10.33% in fine, 18–54% in coarse and 24–64% in hybrid rice for mid-century under RCP8.5. To nullified deleterious effects of climate change, some agronomic and genetics adaptation strategies were evaluated with CERES-rice during mid-century. Paddy yield of fine rice was increased by 15% in cool dry and 5% in hot dry GCM. Paddy yield of coarse rice was improved by 15% and 9% under cool dry and hot dry climatic conditions, respectively, with adaptations. For hybrid rice, paddy yield was enhanced by 15% and 0.3% with cool wet and hot dry climatic conditions, respectively. Hot dry climatic conditions were the most threatening for rice crop in rice producing areas of Punjab, Pakistan.

Keywords Climate change · Crop modeling · CERES-Rice · DSSAT · GCMs

Introduction

Rice is the vital staple food for more than half of the world's inhabitants (Sasaki and Ashikari 2018; Hasan 2019) and ranked as top cereal crop (Hawkesford and Griffiths 2019). Rice is ranked as 2nd major food crop of Pakistan after wheat, and it contributes 6% in daily intake of calories. Pakistani rice has contribution of more than 1.3% in worldwide production (FAOSTAT 2018). All types of rice: Basmati varieties; Coarse varieties, and IRRI varieties are cultivated in Pakistan but Basmati varieties dominate (Fig 1). The aromatic basmati rice/fine rice of Pakistan has big export potential in world markets (Akhter et al. 2019)

Various agro-climatic conditions are prerequisite for sustainable or improved rice production, but changing climatic conditions have been adversely affecting it for last decade (Kontgis et al. 2019). Poor management practices such as less plant population, inappropriate technique of nutrient application, and unsuitable sowing time further exacerbate the problems and are responsible for low yield as compared to

Responsible editor: Gangrong Shi

✉ Fahd Rasul
drfahrasul@gmail.com

1 Department of Agronomy, University of Agriculture, Faisalabad, Pakistan

2 Institute of Soil and Environment Sciences, University of Agriculture, Faisalabad, Pakistan

3 Agricultural and Biological Engineering, University of Florida, Gainesville, Florida, USA

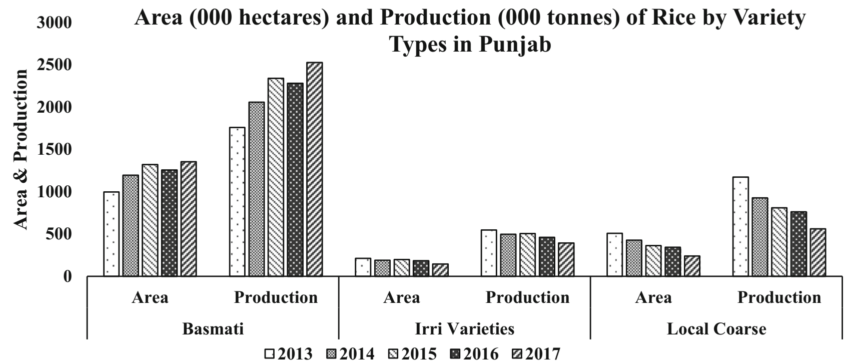

Fig. 1 Area and production of rice by types of varieties in Punjab, Pakistan. Source: Crop Reporting Service, Punjab

potential yield (Ajala et al. 2019). Type of cultivar and transplanting date also affects rice yield by influencing its growth and development (Taylaran et al. 2018; Kaya-Altop et al. 2019). The reason for change in growth stages could be varying temperature requirements of different genotypes (Ferrari et al. 2018). Selection of best basmati rice cultivars can be helpful to achieve potential yield and transplanting time also plays major role for successful production (Saha et al. 2019; Wang et al. 2019)

Varieties vary among each other due to different genetic characteristics, and these characteristics are affected by various climatic variables. Field potential of genotype is not only due to its genetic makeup but the weather conditions that prevail during the cropping season (Patel et al. 2019). Based on difference in genetic makeup of different rice cultivars, their response to future climate would also be different. Rare scientific information is available where performance of different rice types (Fine, hybrid, and coarse) is compared in changing climate scenarios. Climate change has apprehended the cereals during their life cycle by heat stress at critical stages. Rice crop is most vulnerable (6%) to changing climate especially rise in temperature (Gupta and Mishra 2019). Liu et al. (2017) stated that 0.35 °C and 1.13 °C maximum and minimum temperature, respectively, have increased during the last 25 years from 1979 to 2003. Further, rise in climatic variables is expected that ultimately affect rice production. Most of the rice producing areas fall in optimum temperature region required by the crop (Boonwichai et al. 2019). Any alteration in temperature other than normal/optimum temperature may expose this sensitive crop under high temperature stress especially at critical vegetative and reproductive stages that ultimately reduce paddy yield like Pakistan (Fahad et al. 2019). It has been projected that there will be drastically declined in rice production (41%) at the end of this century (Wang et al. 2018). According to Li et al. (2015), kernel yield of rice will be reduced by 10% during growing season of rice with each 1 °C increase in temperature that will lead drastic level difference between actual yield and potential yield (40–50%) (Jagadish et al. 2015).

Variation in temperature significantly influences crop growth duration as well as pattern of growth and phenological stages of rice. Rise in temperature decreases crop yield in addition to grain quality (Zhang et al. 2016). Rainfall amount and pattern also affect crop production, and changes in rainfall distribution limit rice yield in areas where rice is grown as rainfed crop (Tiamiyu et al. 2015; Baliarsingh et al. 2018) .It has been recorded that South and Southeast Asian farmers are major grower (80%) of rice. Current rice production should increase by 1% annually to meet world's food requirement. It is wise to assess negativity of climate change and adapt accordingly (Khanal et al. 2018).

Crop growth models are useful tools and support decision-making under changing climatic conditions and to develop climate change adaptation plan (Ahmed et al. 2018; Ullah et al. 2019b; Vanli et al. 2019). Scientists have done impressive work and efforts with the help of models to estimate future yield of crops sown under extreme or varying climatic conditions (Ahmad et al. 2018b; Rahman et al. 2018; Waqas et al. 2019). CERES-Rice is the most used crop model in scientific investigations. It has been improved to quantify the climate change impacts for future in many studies. In our study, we calibrated the CERES-Rice with a long series of transplanting dates for all three types of rice fine, coarse, and hybrid keeping two cultivars of each type of rice. This comprehensive study with such wide-ranging field experimentation and model calibration under five type of climatic conditions is limited globally and especially in Pakistan.

This study was carried out with the following objective, i.e., (1) to evaluate the performance of CERES-Rice with a series of sowing dates for simulation of mid-century rice crop under different climatic conditions and (2) to quantify the climate change impacts and developing adaptations through crop simulation modeling and field experimentations of rice.

Materials and methods

Two years experimental trials were conducted separately for fine, coarse, and hybrid rice during summer season of 2014 and 2015 at Research Area, Department of Agronomy, University of Agriculture, Faisalabad (31° 2 N°, 73° 2E°). Faisalabad lies in dry semiarid zone with mean annual rainfall of 346 mm and having altitude of 184 m. Daily weather condition, for both growing seasons (2014 and 2015), is shown in Fig. 2.

Soil samples were analyzed by the procedure reported by Piper (1966). Various chemical parameters were recorded by this methodology. Table 1 represents different variables of soil in which pH was closer to 8. Organic matter was deficit with less than 1%. Loamy soil was deficit in phosphorous and potassium as well. Physicochemical lab tests of soil were carried out just before preparing land for transplanting to check fertility status. Soil Auger was used to collect sample from 30 cm soil depth before sowing of rice crop, and later, a composite sample was prepared. Composite sample was further used for physicochemical analysis. Bouyoucos hydrometer method was used for determination of sand, silt, and clay percentage (Moodie et al. 1959). In this method, one percent sodium hexametaphosphate was used as a dispersing agent. USDA's textural triangle was used for the determination of textural classes of soil samples. Crop management practices for all experimental trails were kept the same during both growing seasons. Rice nursery was sown by dry method during both the seasons. The age of seedlings was 30 days, and it was transplanted manually in the puddled field in standing water. Fertilizer was applied according to recommended dose as reported by Government of Punjab, Pakistan, in which Nitrogen at rate of 150, 175, and 175 kg ha^{-1} for fine, course and hybrid rice respectively in the form of urea. Whereas, phosphorus was applied at the rate of 100 kg ha^{-1} for all rice type (fine, course, and hybrid) in the form of diammonium phosphate (DAP). Potassium was used at the rate of 75, 78, and 78 kg ha^{-1} for fine, Coarse and hybrid rice in the form of Sulfate of Potash (K_2SO_4). Nitrogen fertilizer was applied in two splits in which half dose was applied during land preparation and remaining dose was applied after 50 days from transplanting of nursery. Other fertilizers (P and K) were applied at full dose during land preparation and transplanting. Irrigation application, plant protection measures, and other agronomic practices were kept optimum for all three trials as recommended for rice.

Table 1 Soil analysis

Sr. #	Parameters	Unit	Values
1	Soil pH	-	8.3
2	Organic matter	Percentage (%)	0.55
3	Phosphorus	Parts per million (ppm)	7.4
4	Potassium	Parts per million (ppm)	196
5	Soil Texture	-	Loam
6	Soil Series	-	Lyallpur

Model description

The CERES-Rice model of DSSAT version 4.6 was calibrated and evaluated with experimental data. The calibrated and evaluated CERES-Rice model for fine, coarse, and hybrid rice

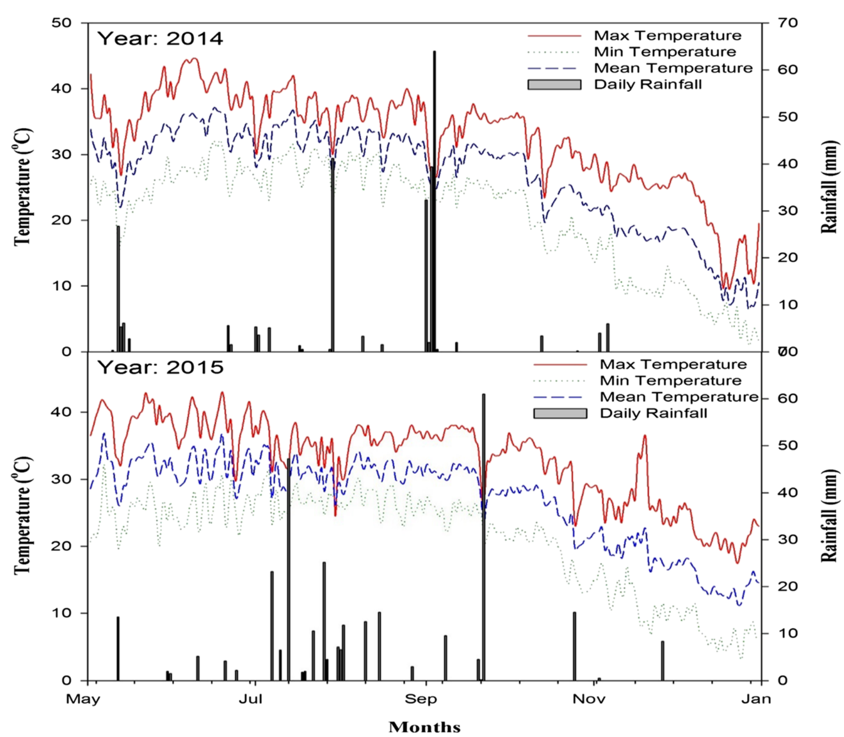

Fig. 2 Weather of Faisalabad, Pakistan, during 2 years crop season of 2014 and 2015

Table 2 Genetic coefficients of different rice types after CERES-Rice calibration

Varieties/Hybrids		P1	P2R	P5	P2O	G1	G2	G3	G4	PHINT
Fine Rice	Basmati 515	650.0	270.0	290.0	12.5	40.0	0.0195	1.0	1.0	83.0
	Super Basmati	660.0	333.0	160.0	12.5	40.0	0.0190	1.0	1.0	83.0
Coarse Rice	KSK 434	920.0	52.0	550.0	12.0	65.0	0.0210	1.0	1.0	83.0
	KSK133	720.0	70.0	514.0	11.6	54.0	0.0190	1.0	1.0	83.0
Hybrid Rice	RH-362	899.0	45.0	780.0	13.5	60.0	0.0290	1.0	1.0	83.0
	PHB-71	665.0	134.0	560.0	12.5	65.0	0.0230	1.0	1.0	83.0

varieties under optimum transplanting date was further applied to assess the climate change impact on paddy yield.

Future climate scenario generations

Observed climate data of 30 years (1980–2010) were taken from the weather observatory at Faisalabad district. Missing values in the observed data were corrected using process describe by Hudson and Ruane (2013). Future climate scenarios were generated using delta method for mid-century (2039–2069) under Representative Concentration Pathways (RCPs 8.5). General circulation models (GCMs) were drawn from the Coupled Model Inter-comparison Project (CMIP5) (Taylor et al. 2012). The five GCMs were selected to represent the uncertainty in projected temperature, and rainfall changes based on five possible climate characteristics (cool wet, cool dry, hot wet, hot dry, and middle), respectively. After selection of GCMs, mean variability scenarios were generated by calculating the monthly changes from mean temperature and precipitations. Monthly changes were calculated by comparing observed data with future 30-year data and were impose on baseline data to generate scenarios. Protocols used for climate change scenarios were described by AgMIP 2013; Ahmed et al. 2018; Ali et al. 2019. In this process, the solar radiation, winds, and relative humidity were assumed unchanged.

Model calibration and evaluation

Calibration is a very important step for the adjustment of model parameters under location agro-climatic conditions. Genetic coefficients for new varieties were determined using basic soil, weather, crop management, and finally, crop growth, development, and yield data (Hunt and Boote 1998). CERES-Rice model of Decision Support System for Agro-Technology Transfer (DSSAT) (Hoogenboom et al. 2016). DSSATV4.6.1 was used for this study. The genetic coefficients of rice cultivars were estimated using field experimental data. Generalized likelihood uncertainty estimation and sensitivity tools were used for determination of genetic coefficients. Similar methods were used by Ahmed et al. (2018). The field experiments were comprised of series of showing dates started from 2nd of May to 16th of September with 15 days interval. The model was calibrated for three rice genotypes (fine, coarse, and hybrid) using 2014-year data and evaluated with 2015-year data. The parameters used for model calibration and evaluation were days to anthesis, maturity, leaf area index (LAI) maximum, grain, and biological yield. Crop coefficients are categorized into phenological development coefficients (P1, P2O, P2R, and P5) and growth coefficients (G1 and G4) as described by Jones et al. (1987). Model was parameterized through adjustment of soil and genetic file factors for maximum matching of observed and simulated data. Evaluation is the process of checking accuracy and precision of the model simulations with second-year field experiments having series of planting dates which faced a long range of temperature and independent set of data. From evaluation, it was concluded that performance was model was reliable to simulate the future climate change impacts.

Climate change impact assessment

Many scientists in the world have assessed the impact of climate change on crop production trends in future using coupled climate-crop models (Amin et al. 2018b, a; Rahman et al. 2018; Tariq et al. 2018).

. Climate change impact assessment was done by using seasonal analysis tools which is inbuilt in DSSAT model. Thirty years historical weather data were used as baseline weather and future data from simulation of GCMs were used to assess the climate change impacts on rice productivity. The CO_2 concentration of 360 ppm was used for baseline climate, while 571 ppm for future scenarios under RCP8.5 (Rosenzweig et al. 2014).

Climate change adaptations

Recently, scientists in the world are applying adaptations to seek better solution under diverse climatic situations. The possible adaptations strategies were identified in the literature and series of meetings with agronomist, soil scientist, irrigation management, and social scientists. The identified adaptation strategies were prioritized and quantified through simulation model CERES-Rice under five climatic conditions of mid-century for all three types of rice. A proposed set of adaptation strategies includes readjusting transplanting date, increasing

Table 3 Future Scenarios of Carbon Dioxide

Scenario and time period	Planting year coverage	Mid-year	$[CO_2]$
Baseline	1980–2010	1995	360 ppm
RCP8.5 Mid-Century	2040–2069	2055	571 ppm

nutrient use efficiency, nursery age, planting density, and irrigation water.

Results

Model calibration

CERES-Rice was calibrated using data recorded on growth, development, and yield of fine, coarse, and hybrid rice types from field trials. P1, P2O, and P2R control vegetative growth, while P5, G1, G2, G3, and G4 control reproductive growth (Ahmad et al., 2018a). There is difference in values of genetic coefficients because of different vegetative and reproductive growth stages requirements of different types and cultivars of rice (Table 2).

To assess climate change impact on paddy yield of rice, CO_2 concentrations of 360 ppm and 571 ppm were considered for baseline and mid-century, respectively (Table 3). Future scenarios during mid-century period (2040–2069) were formulated with help of five general circulation models (GCMs), i.e., CESM1-BGC, inmcm4, IPSL-CM5A-MR, NorESM1-M, and CMCC-CMS under representative concentration pathways 8.5 (RCP8.5) (Table 4). Each GCM has its own features such as CESM1-BGC, and inmcm4 that were categorized as cool wet and cool dry, respectively. Whereas, IPSL-CM5A-MR and CMCC-CMS were grouped as hot wet and hot dry, respectively. But NorESM1-M GCM was recognized as in middle among other GCMs. A baseline of 30-year measured weather data from 1981–2010 was constructed for the comparison with future data of all GCMs. The outputs of all GCMs revealed a significant variation in weather elements during mid-century period (2040–2069). There would be an average increase of 2.6/3.4 °C in mean day/night temperatures over all GCMs as compared to baseline. Likewise, there would be average annual increase of 107.6 mm in rainfall than baseline. On individual GCM bases, there would be 1.7–3.5/2.8–4.3 °C and 57–248 mm per annum increase in mean day/night temperatures and rainfall, respectively, from CESM1-BGC and inmcm4 as compared to baseline. Furthermore, there would be 1.5–3/3.2–3.4 °C and 7–146 mm per annum increase in mean day/night temperatures and rainfall, respectively, from IPSL-CM5A-MR and CMCC-CMS than baseline period. But there would be 3.6/3.1 °C and 80 mm per annum + increase in mean day/night temperatures and rainfall, respectively, from NorESM1-M GCM as compared to baseline.

Paddy yield response of fine rice to different climatic conditions during mid-century

A significant reduction in paddy yield of fine rice was simulated under all GCMs except inmcm4 with RCP8.5 as compared to baseline. No reduction in paddy yield under this GCM (inmcm4) was due to its cool dry characteristics which indicated least increment in maximum temperature during mid-century period (Table 4). There would be 10–33% reduction in paddy yield of fine rice during mid-century period with all GCMs than baseline (Fig. 3). The maximum reduction (33%) in paddy yield during mid-century period was predicted from IPSL-CM5A-MR (hot wet climatic conditions) as compared to baseline (Table 5).

Paddy yield response of coarse rice to different climatic conditions during mid-century

Similarly, in the case of coarse rice, calibrated model under optimum conditions was run with baseline and future-generated climate with five GCMs. Model simulation results indicated that there was a significant decline in paddy yield due to climate change during mid-century period (2040–2069) as predicted from all GCMs under RCP8.5 as compared to baseline (Fig. 4). Results showed that there would be 18–

Table 4 Relative change in temperature and rainfall under all GCM with respect to baseline during mid-century period

GCMs	T max. (°C)	ΔT Max. (°C)	T min. (°C)	ΔT Min. (°C)	Rainfall (mm)	Δ Rainfall (mm)
Baseline	37.66	---	25.29	--	286	--
NorESMI-M	41.16	3.50	29.56	4.26	342	57
IPSL-CM5A-MR	39.33	1.67	28.08	2.79	533	248
CMCC-CMS	40.61	2.96	28.50	3.21	292	7
CESMI-BGC	41.29	3.63	28.42	3.13	366	80
INMCM4	39.10	1.45	28.65	3.36	432	146
Mean		2.64		3.35		107.6

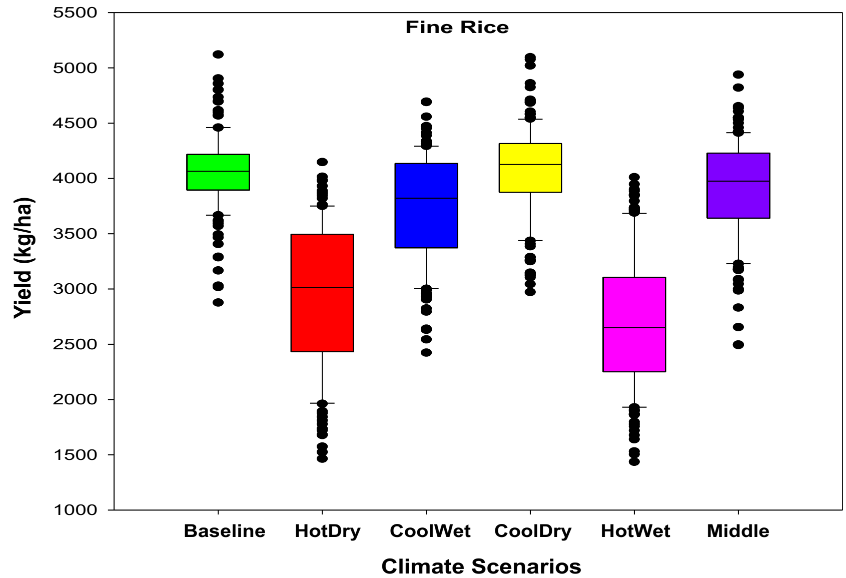

Fig. 3 Climate change impact on production of fine rice

54% decline in paddy yield of coarse rice during mid-century period (2040–2069) with all GCMs under RCP8.5 than baseline (Fig. 4). The maximum decline (54%) in paddy yield during mid-century period was predicted from IPSL-CM5A-MR GCM. The coarse rice would be more vulnerable to climate change in future as compared to fine rice.

Paddy yield response of hybrid rice to different climatic conditions during mid-century

Simulation results of hybrid rice revealed significant reduction in paddy yield of hybrid rice under all GCMs with RCP8.5 as compared to baseline. There would be 24–64% reduction in paddy yield of hybrid rice during mid-century period over all GCMs than baseline (Fig. 5). This indicated the highly sensitive behavior of hybrid rice to future hot climate change. Maximum reduction (64%) in paddy yield during mid-century period was predicted from IPSL-CM5A-MR (hot wet climatic conditions) as compared to baseline.

Potential adaptation package

Pakistan is among top ten most vulnerable countries to climate change in the world, while emission of greenhouse gases in Pakistan is far less than developed countries. Less emission minimizes scope of mitigating climate change. The only way to reduce vulnerabilities is to adapt changing climate. Following adaptation package (Table 6) was developed after consultations with range of scientists from academia, research, and agriculture extensions specialists. The modification in sowing time as adaptation will minimize the heat stress during crop season. The fertilizer amount was suggested to increase in future; the reason for increment of nitrogen is that the losses will be increased due to rise in temperature in future. The irrigation volume was suggested to decrease, because there will be shortage of irrigation in future and less water will be available for successful crop production, thus reduced irrigation is the valuable practice to save the water without significant loss in yield

Table 5 Percent change in rice yield in all GCMs under RCP8.5

GCMs	Fine rice	Hybrid rice	Coarse rice
Middle	− 10.0	− 24.3	− 18.1
Cool wet	− 25.1	− 46.8	− 41.7
Hot wet	− 30.4	− 58.5	− 51.3
Cool dry	− 27.4	− 47.7	− 46.2
Hot dry	− 33.1	− 64.1	− 54.4

Paddy yield response of fine rice with adaptations

The impacts induced by future climate change on rice paddy yield can only be minimized by adjusting management options as alternative adaptive strategies. Assessing climate change impacts on rice production and devising some viable adaptive approaches for better rice performance under future climate change is integral component of this study.

Model simulations after adaptations indicated significant improvement (5–15%) in paddy yield of fine rice as compared to baseline during mid-century period (2040–2069) under cool wet, cool dry, and middle conditions (Fig. 6). Maximum improvement (15%) in paddy yield of fine rice was simulated under cool dry conditions (inmcm4 GCM), while minimum yield improvement (5%) was simulated from NorESM1-M GCM (Fig. 6). NorESM1-M GCM was recognized as in middle between very harsh (hot wet and hot dry) and somewhat favorable (cool wet and cool dry) conditions.

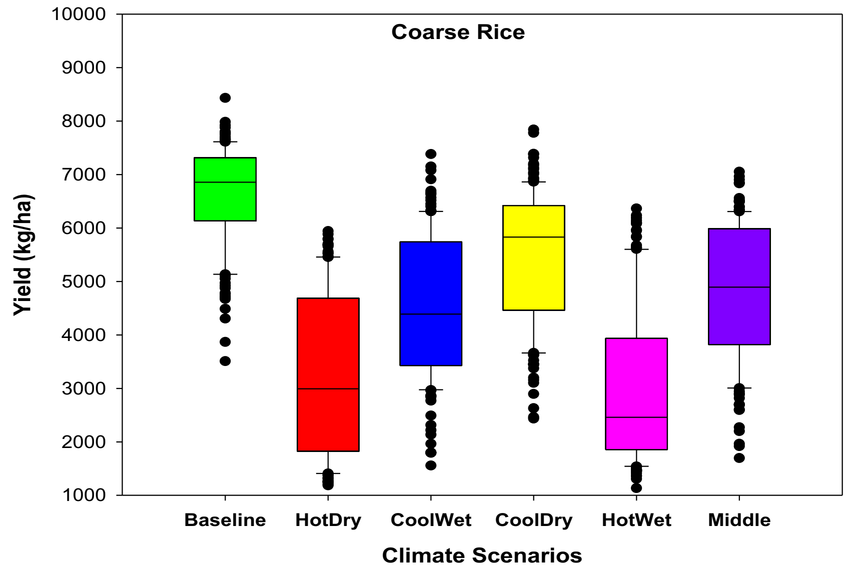

Fig. 4 Climate change impact on production of coarse rice

With adaptations, model simulated 26–29% improvement in fine paddy yield in hot wet and hot dry, but this increase was less than baseline. These improvements in fine paddy yield reveal that to combat harsh future climatic scenarios, devising adaptations, is very important.

Paddy yield response of coarse rice with adaptations

Simulation results revealed significant improvement (9–11%) in paddy yield of coarse rice as compared to baseline during mid-century period with adaptations (Fig. 7). Maximum improvement (11%) in paddy yield of coarse rice was predicted under cool dry conditions (inmcm4 GCM) during 2040–2069. Minimum yield improvement (9%) in coarse rice was simulated from CESM1-BGC GCM (Fig. 7). These both GCMs were recognized as cool dry and cool wet during mid-century period. These improvements were linked with inclusion of adaptation package. Moreover, no improvement in fine paddy yield was simulated under middle, hot wet, and hot dry conditions as compared to baseline. But there was significant improvement (28–75%) in paddy yield under middle, hot wet, and hot dry conditions (Fig. 7) than decline in yield that was simulated with climate change impact under middle, hot wet, and hot dry conditions during mid-century period (Fig. 7).

Paddy yield response of hybrid rice with adaptations

Model simulations after introduction of adaptations within model file of seasonal tool indicated significant improvement (3–15%) in paddy yield of hybrid rice as compared to baseline during mid-century period (Fig. 8). Maximum improvement (15%) in paddy yield of hybrid rice was simulated with CESM1-BGC GCM. This was mainly due to less impact of changing climate under cool dry condition during mid-century period. Minimum yield improvement (0.3%) was simulated

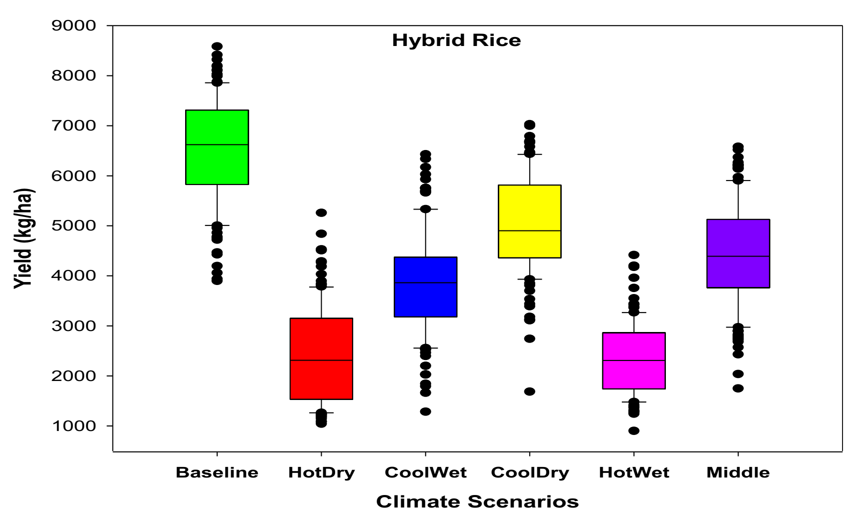

Fig. 5 Climate change impact on production of hybrid rice

Table 6 Potential adaptation package to mitigate climate change impacts

Sr. no.	Variables and direction of change	**Increase in yield**
1.	Sowing date: transplant rice five days earlier than current recommended sowing date	**2%**
2.	Nursery age: Transplant nursery of 25 days instead of 30 days	**3%**
3.	Fertilizer rate: Increase fertilizer rate by 10% than current recommended rate	**7%**
4.	Planting density: Increase planting density by 20%	**5%**
5.	Irrigation amount: 15% reduction in irrigation amount	**2%**

under cool dry condition revealed by inmcm4 GCM. The results also showed that model simulations were less uncertain under cool dry and cool wet during mid-century period. Moreover, no improvement in paddy yield of hybrid rice was simulated under middle, hot wet, and hot dry conditions as compared to baseline. But significant improvement (37–125%) in paddy yield of hybrid rice under middle, hot wet, and hot dry conditions (Fig. 8) than decline in yield that was simulated with climate change impact under middle, hot wet, and hot dry conditions during mid-century period (Fig. 8).

Discussion

Climate change scenarios

Global circulation models (GCMs) are diverse in their predictions of future climate due to uncertain socioeconomic scenarios, structure, and functions of models (Amin et al. 2018a; Nasim et al. 2018). These uncertainties are the main reasons behind the unreliability of future climate predictions by GCMs. In the near past, GCMs were selected for future climate simulation of a region based on their evaluation with past 30 years data, but it was not good idea to ignore other models. Recently, another method to give equal chances of selection to each GCM for future climate simulation without evaluation has been introduced. All 29 GCMs were distributed on temperature and rainfall change from baseline climate (1980–2010) in five quadrats cool wet, cool dry, middle, hot wet, and hot dry through stretched distribution approach. From each quadrat, one representative GCM was selected on median value base. This distribution created five plausible climatic conditions of the future. Chances of each climatic condition were calculated through number of models in each quadrat. This methodology was adapted in this study to develop adaptation package which could cater all kinds of future climate conditions (Ullah et al, 2019a).

Climate change impacts

The possible reason for reduction in yield of fine rice is hot wet conditions that would prevail as per outputs of this GCM. The main reason of this reduction is the nature of climate categorized as hot wet that would prevail during 2040–2069; as shown from the outputs of this GCM, it clearly indicated that hot wet climate would not be suitable for coarse rice production. That's why, there would be more declines in coarse production with hot wet climate. However, the

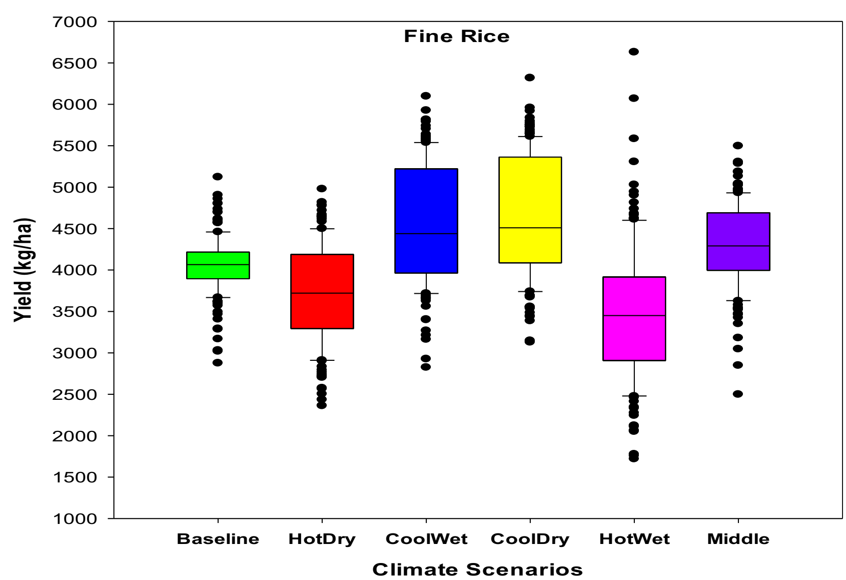

Fig. 6 Yield improvement in fine rice after adaptation

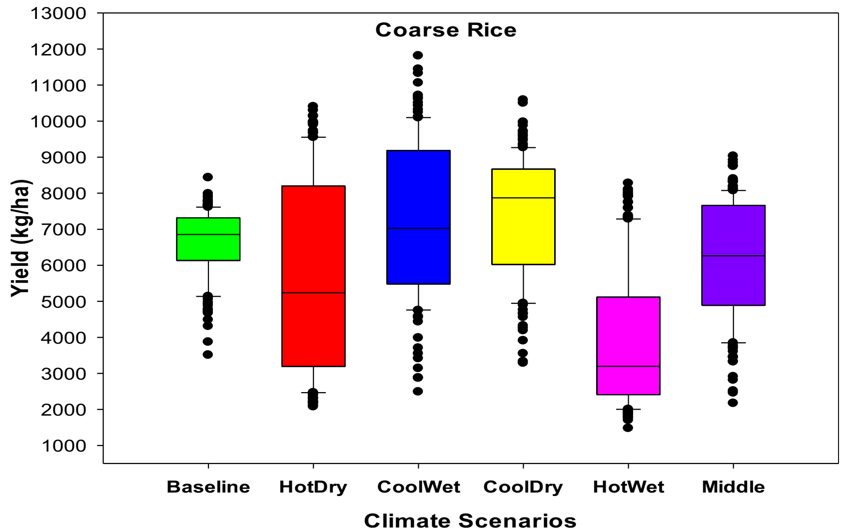

Fig. 7 Yield improvement in coarse rice after adaptations

minimum reduction (18%) in paddy yield during mid-century period was simulated from inmcm4 than baseline (Fig. 4). This was due to cool dry climatic conditions during mid-century, and coarse rice would get somewhat advantage from these conditions.

The possible reason of this decline in paddy yield might be due to hot wet conditions that would prevail during mid-century period as per outputs of this GCM. However, the minimum reduction (22%) in paddy yield during mid-century period was simulated from inmcm4 than baseline (Fig. 5).

Changes in temperature and intercepted photosynthetically active radiation (PAR) play a significant role grain yield and physiological maturity of rice crop (Basak et al. 2010). Delayed planting wreaked early physiological maturity and yield reduction. Low temperature enhanced yield by 26% while only 4 °C increment in minimum and maximum temperature, a drastic decline in grain yield up to 60 % (Oteng-Darko et al. 2012). Our results revealed that elevated carbon dioxide improved rice yield due to increased rate of photosynthesis. This showed that increase in carbon dioxide had positive effects on growth rate (leaf area, dry matter accumulation, and NAR) of rice crop (Basak et al. 2010). Contrary to this, extremely high concentration of carbon dioxide restricted stomatal movement and transpiration rate while speeding up the photosynthetic activity. But all physiological and biochemical processes are directly linked with temperature, hence the increase in temperature favors in rapid processes in any crop leading to have negative influence in yield formation According to estimates and findings from IRRI studies, rice yield could increase by 0.5 t /ha yield due to every increase of 75 ppm in CO_2. On the other hand, yield would decrease by 0.6 t ha^{-1} for every 1 °C increase in temperature (Caine et al. 2019).

Climate change adaptations

Climate change adaptations are developed to get sustained crop yield and to mitigate climate change impacts. Many

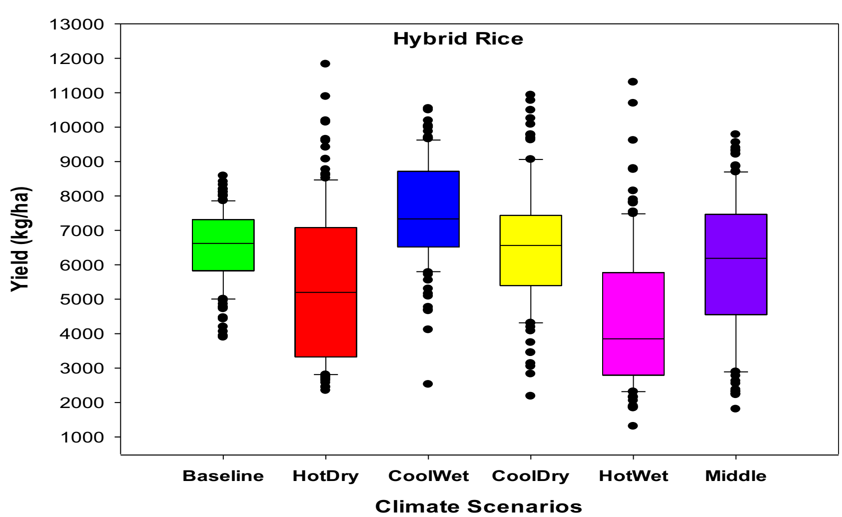

Fig. 8 Yield improvement in hybrid rice after adaptations

studies have focused on development of adaptations in the context of future climate change (Hu et al. 2018). Introducing climate resilient cultivars, stress management, and changing planting time according to climate are important strategies for rice crop (Van Oort and Zwart 2018) designed to combat the possible impacts of climate change on rice crop for better livelihood. In addition to these strategies, expert opinion (Ahmad et al. 2018b, 2019b; Ahmed et al. 2019; Ullah et al. 2019b) through RAPs is also important for climate change adaptation. Our study showed that adjusting planting time and raising nursery at different times, high fertilizer rates up to a certain amount, more dense plant population, and reducing irrigation amount could help mitigate the negative impacts of climate change on rice yield in future (Ahmad et al. 2019a). Simulating these adaptations strategies, vulnerabilities due to future climate have been reduced to a large extent. This shows that these adaptations could have a significant impact on rice growing areas.

Conclusions

The CERES-Rice model as parameterized with 2 years field experiments for the years 2014–2015. Model simulated the phenology, growth, and yield well, compared with observed parameters. The future projections showed that temperature is expected to rise by 3 °C in the middle of century under RCP8.5. The expected rise in temperature will reduced the rice yield of 10–33% in fine rice, 18–54% in coarse, and 24–64% in hybrid rice. The adaptations strategies were proposed through modification in current production technology. The used of proposed adaptation increased the yield by 5–15% in fine, 9–11% in coarse, and 3–15% in hybrid rice. The developed adaptations strategies will be useful for researcher, farmers, and policy maker to offsets the impacts of climate change.

References

AgMIP (2013) The coordinated climate-crop modeling project C3MP: an initiative of the agricultural model inter comparison and improvement project. C3MP Protocols and Procedures. AgMIP

Ahmad I, Saeed U, Fahad M et al (2018a) Yield forecasting of spring maize using remote sensing and crop modeling in Faisalabad-Punjab Pakistan. J Indian Soc Remote Sens 46:1701–1711. https://doi.org/10.1007/s12524-018-0825-8

Ahmad I, Wajid SA, Ahmad A et al (2018b) Assessing the impact of thermo-temporal changes on the productivity of spring maize under semi-arid environment. Int J Agric Biol 20:2203–2210

Ahmad A, Ashfaq M, Wajid A, et al (2019a) Development of climate change adaptation strategies for rice-wheat cropping system of Punjab Pakistan. In: Australian Agricultural and Resource Economics Society (AARES). Melbourne

Ahmad I, Wajid SA, Ahmad A et al (2019b) Optimizing irrigation and nitrogen requirements for maize through empirical modeling in semi-arid environment. Environ Sci Pollut Res 26:1227–1237. https://doi.org/10.1007/s11356-018-2772-x

Ahmed I, ur Rahman MH, Ahmed S et al (2018) Assessing the impact of climate variability on maize using simulation modeling under semi-arid environment of Punjab, Pakistan. Environ Sci Pollut Res 25: 28413–28430

Ahmed I, Ullah A, Rahman MH et al (2019) Climate change impacts and adaptation strategies for agronomic crops. Climate change and agriculture. IntechOpen, In, pp 1–15

Ajala AA, Muhammad A, Yakubu AI et al (2019) Correlation study on growth and yield components of rice (Oryza sativa L.) varieties grown under integrated weed management in Sudan Savanna of Nigeria. J Agric Ecol Res Int 5:1–6

Akhter M, Mahmood A, Haider Z, Saleem U (2019) Development of an aromatic high yielding basmati rice variety having extra long grains and short duration. J Rice Res 7:2

Ali S, Eum H-I, Cho J et al (2019) Assessment of climate extremes in future projections downscaled by multiple statistical downscaling methods over Pakistan. Atmos Res 222:114–133

Amin A, Nasim W, Fahad S et al (2018a) Evaluation and analysis of temperature for historical (1996–2015) and projected (2030–2060) climates in Pakistan using SimCLIM climate model: Ensemble application. Atmos Res 213:422–436

Amin A, Nasim W, Mubeen M et al (2018b) Simulated CSM-CROPGRO-cotton yield under projected future climate by SimCLIM for southern Punjab, Pakistan. Agric Syst 167:213–222

Baliarsingh A, Nanda A, Mohapatra AKB (2018) Effect of rainfall and temperature on rice yield in Puri district of Odisha in India.

Basak JK, Ali MA, Islam MN and Rashid MA. (2010). Assessment of the effect of climate change on boro rice production in Bangladesh using DSSAT model. J. Civil Eng. 38: 95-108.

Boonwichai S, Shrestha S, Babel MS et al (2019) Evaluation of climate change impacts and adaptation strategies on rainfed rice production in Songkhram River Basin, Thailand. Sci Total Environ 652:189–201

Caine RS, Yin X, Sloan J et al (2019) Rice with reduced stomatal density conserves water and has improved drought tolerance under future climate conditions. New Phytol 221:371–384

Fahad S, Adnan M, Hassan S, et al (2019) Rice responses and tolerance to high temperature. Adv Rice Res Abiotic Stress Toler 12: 201–224.

FAOSTAT (2018) FAOSTAT database collections. Rome

Ferrari S, Pagliari P, Trettel J (2018) Optimum sowing date and genotype testing for upland rice production in Brazil. Sci Rep 8:8227

Gupta R, Mishra A (2019) Climate change induced impact and uncertainty of rice yield of agro-ecological zones of India. Agric Syst 173:1–11

Hasan SA (2019) Price hike of staple food, nutritional impact and consumption adjustment: evidence from the 2005–2010 rice price increase in rural Bangladesh. Appl Econ 51:743–761

Hawkesford MJ, Griffiths S (2019) Exploiting genetic variation in nitrogen use efficiency for cereal crop improvement. Curr Opin Plant Biol 49:35–42

Hoogenboom G, Porter CH, Shelia V et al (2016) Decision support system for agrotechnology transfer (DSSAT) Version 4.7 (https://DSSAT.net). DSSAT Foundation, Gainesville

Hu Y, Fan L, Liu Z, et al (2018) Rice production and climate change in Northeast China: evidence of adaptation through land use shifts

Hudson N, Ruane A (2013) Guide for running AgMIP climate scenario generation tools with R. AgMIP. Available online: http://www.agmip.org/wp-content/uploads/2013/10/Guide-for-Running-AgMIPClimate-Scenario-Generation-withhttp://www. agmip. org/wp-content/uploads/2013/10/Guide-for-Running-AgMIPClimate-Scenario-Generation-with

Hunt LA, Boote KJ (1998) Data for model operation, calibration, and evaluation. Understanding options for agricultural production. Springer, In, pp 9–39
Jagadish SVK, Murty MVR, Quick WP (2015) Rice responses to rising temperatures–challenges, perspectives and future directions. Plant Cell Environ 38:1686–1698
Jones JW, Mishoe JW and Boote KJ. (1987). Introduction to simulation and modeling. Technical Bulletin 10. Florida, USA: ASPAC-Food and Fertilizer Technology Center.
Kaya-Altop E, Şahin M, Jabran K et al (2019) Effect of different water management strategies on competitive ability of semi-dwarf rice cultivars with Echinochloa oryzoides. Crop Prot 116:33–42
Khanal U, Wilson C, Hoang V-N, Lee B (2018) Farmers' adaptation to climate change, its determinants and impacts on rice yield in Nepal. Ecol Econ 144:139–147
Kontgis C, Schneider A, Ozdogan M et al (2019) Climate change impacts on rice productivity in the Mekong River Delta. Appl Geogr 102: 71–83
Li T, Hasegawa T, Yin X et al (2015) Uncertainties in predicting rice yield by current crop models under a wide range of climatic conditions. Glob Chang Biol 21:1328–1341
Liu L, Liao J, Chen X et al (2017) The microwave temperature vegetation drought index (MTVDI) based on AMSR-E brightness temperatures for long-term drought assessment across China (2003–2010). Remote Sens Environ 199:302–320
Moodie CD, Smith HW, McCreery RA (1959) Laboratory manual for soil fertility, Washington State College Mimeograph, Washington
Nasim W, Amin A, Fahad S et al (2018) Future risk assessment by estimating historical heat wave trends with projected heat accumulation using SimCLIM climate model in Pakistan. Atmos Res 205: 118–133
Oteng-Darko P, Kyei-Baffour N, Ofori E. (2012) Simulating rice yields under climate change scenarios using the CERES-Rice model. African Crop Science Journal. 20(2):401-8.
Patel AR, Patel ML, Patel RK, Mote BM (2019) Effect of different sowing date on phenology, growth and yield of rice–a review. Plant Arch 19:12–16
Piper CS (1966) Soil and plant analysis. Hans Publishers, Bombay
Rahman MH, Ahmad A, Wang X et al (2018) Multi-model projections of future climate and climate change impacts uncertainty assessment for cotton production in Pakistan. Agric For Meteorol 253:94–113
Rosenzweig C, Elliott J, Deryng D et al (2014) Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. Proc Natl Acad Sci 111:3268–3273
Saha S, Mukherjee A, Banerjee S (2019) Effect of transplanting dates, cultivars and irrigation regimes on microclimate and yield of rice. Int J Bio Res Stre Mang 10: 4-10
Sasaki T, Ashikari M (2018) Rice genomics, genetics and breeding. Springer, In, pp:44-60
Tariq M, Ahmad S, Fahad S et al (2018) The impact of climate warming and crop management on phenology of sunflower-based cropping systems in Punjab, Pakistan. Agric For Meteorol 256:270–282
Taylaran RD, Elmundo EM, Gonzaga Jr AB (2018) Response of high-yielding upland rice to fertilization for intensive nutrient production system. Prism 23: 15-30
Taylor KE, Balaji V, Hankin S, et al (2012) CMIP5 data reference syntax (DRS) and controlled vocabularies. Retrieved from C Coupled Model Intercomp Proj http//cmip-pcmdi llnl gov/cmip5 12–45
Tiamiyu SA, Eze JN, Yusuf TM et al (2015) Rainfall variability and its effect on yield of rice in Nigeria. Int Lett Nat Sci 49:63–68
Ullah A, Ahmad I, Ahmad A et al (2019a) Assessing climate change impacts on pearl millet under arid and semi-arid environments using CSM-CERES-Millet model. Environ Sci Pollut Res 26:6745–6757. https://doi.org/10.1007/s11356-018-3925-7
Ullah A, Ahmad I, Saeed U et al (2019b) Climate smart interventions of small-holder farming systems. Climate Change and Agriculture. IntechOpen, In, pp 1–16
Van Oort PAJ, Zwart SJ (2018) Impacts of climate change on rice production in Africa and causes of simulated yield changes. Glob Chang Biol 24:1029–1045
Vanli Ö, Ustundag BB, Ahmad I et al (2019) Using crop modeling to evaluate the impacts of climate change on wheat in southeastern turkey. Environ Sci Pollut Res 40: 1–12
Wang J, Vanga SK, Saxena R et al (2018) Effect of climate change on the yield of cereal crops: a review. Climate 6:41-50
Wang Y, Wang L, Chen H, et al (2019) Sowingdates have different effects on spikelet formation among different photoperiod-sensitive rice genotypes.
Waqas MM, Awan UK, Cheema MJM et al (2019) Estimation of canal water deficit using satellite remote sensing and GIS: A case study in lower chenab canal system. J Indian Soc Remote Sens 30:1–10
Zhang C, Zhou L, Zhu Z et al (2016) Characterization of grain quality and starch fine structure of two japonica rice (Oryza sativa) cultivars with good sensory properties at different temperatures during the filling stage. J Agric Food Chem 64:4048–4057