FINAL REPORT

Impact of Climate Change on Agriculture

Funded by

Global Change Impact Study Centre (GCISC), Islamabad, Pakistan

(Project Duration: July-December, 2018)

Contributing Authors:

Impact of Climate Change on Agriculture

Ashfaq Ahmad[12], Syed Aftab Wajid[1], Syeda Refat Sultana[1] and Ishfaq Ahmad[1]*

[1]Agro-Climatology Lab, Department of Agronomy, University of Agriculture, Faisalabad, Pakistan

[2]Centre for Advance studies, Agriculture and Food Security, Punjab Pakistan

[*]Corresponding Authors: ashfaqchattha@uaf.edu.pk, Cell No:+923007204372

ACKNOWLEDGEMENT

The Authors acknowledge this work to funding agency "Global Change Impact Studies Centre (GCISC), Islamabad, Pakistan. We are grateful to Mr. Muhammad Arif Rashid Goheer, Principle Scientific Officer/ Head Agriculture, Forestry & Land Use Section, for providing us an opportunity to do the project work.

Prof. Ashfaq Ahmad (Head, Climate Change Research Group, UAF & Chair Climate Change, CAS-AFS, UAF) has led the team throughout the project duration and provided editorial comments on the final report. Dr. Syed Aftab Wajid (Associate professor, Department of Agronomy, UAF) and Dr. Syeda Refat Sultana, contributed in doing the calibration and evaluation of DSSAT model. Dr. Ishfaq Ahmad (Agro-Climatology Lab, Department of Agronomy, UAF) has contributed in doing the statistical downscaling of Half a degree Additional warming, Prognosis and Projected Impacts (HAPPI) scenarios using Quantile mapping. He further studied the impact of HAPPI scenarios on Agriculture crops using advance IT tools

Authors extend gratitude to Mr. Burhan Ahmad and Syed Ahsan Ali (R&D), Pakistan Meteorological Department (PMD) for the provision of observed climate data and capacity building in statistical downscaling using Quantile mapping of the project staff.

CONTENTS

SUMMARY

Climate change is expected to increase the vulnerability of agricultural systems by increasing temperature, changes in rainfall patterns, and increased frequency of extreme weather events in most parts of the world and especially in Pakistan. Future projections also showed that surface temperature would be increased which would reduce the crop productivity. The current study was planned to study the impact of 2°C rise in temperatures on wheat, rice, maize and cotton, keeping in view the aim of Paris Agreement (COP-21) that was to limit global mean temperature rise below 2°C. For this purpose, Baseline (2006-2015) climate data for each site were taken from the Pakistan Meteorological Department (PMD), Pakistan. Future (2106-2115) scenarios with 2°C were created by statistical downscaling of global data of Half a degree Additional warming, Prognosis and Projected Impacts (HAPPI) project. The sites selected for study area were Bahawalnagar, Multan, Mianwali, Lahore, Sargodha and Sialkot. For climate change impact assessment Crop model "Decision Support system for Agro-technology Transfer (DSSAT) was used. DSSAT model was parameterized using already conducted field experiment. After calibration and evaluation, DSSAT were used to study the impact of climate change. Bassline and future data were used to create weather files of model. Climate scenarios results showed that maximum temperature of 1.01°C to 1.46°C and minimum temperature of 1.17°C to 1.43°C would increase in future (2115-2116) under 2°C HAPPI scenarios. Precipitation pattern also showed an increasing trend in central and south Punjab, while in Sialkot district decreasing trend of precipitation was observed. Climate change results showed that a huge reduction rice and cotton yield in Punjab as compared to Wheat and Maize. In north district of Punjab positive impacts of climate change were observed for wheat, rice and maize. Study results showed that with rise in temperature in future wheat yield of 1 to 4%, Rice 3 to 17%, Maize 2 to 10% and cotton yield of 6 to 18% would be reduced in Punjab Pakistan. In future there is dire need to work on adaptation measures to mitigate the negative impacts of climate change.

1: Introduction

Climate change is a real threat to agriculture and food security (Kang et al. 2009; Godfray et al. 2010; Downing 2013). Extreme weather events and uncertainty in rainfall patterns are affecting the agriculture productivity (Lobell and Burke 2008; Ahmed et al. 2018; Rahman et al. 2018). Future projections showed that global surface temperature would be increased by 2.5˚C up to 2050, which would negatively affect the crop production (IPCC, 2013). There is dire need to assess the climate change impacts on crops that would be helpful in developing adaptations measures.

The global community agreed with the Paris agreement to limiting global warming to 2.0˚C, with the stated ambition to attempt to cap warming at 1.5˚C (UNFCCC, 2015). While limiting the extent of climate change is critical, the more ambitious 1.5˚C mitigation strategy will likely require considerable mitigation effort in the agricultural land use sector (Fujimori et al., 2018)
Representatives from 196 countries signed the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement (UNFCCC, 2015) in December 2015 aiming for such a balance, setting a goal to limit global mean temperature rise below 2˚C above pre-industrial levels, with nationally determined commitments aiming to reach a stabilization at +1.5˚C above pre-industrial conditions.
Several simulation studies have assessed the changes of wheat, rice, maize and cotton production due to the changes in climate and CO_2 (Ahmad et al., 2015, 2019; Ahmed et al., 2018; Rahman et al., 2018b). However, previous studies have almost all considered more extreme warming and most of current studies investigated the impact of global warming >2.0˚C, which means that previous impact assessments lacked details for < 2˚C of warming. Also, many previous studies did not focus sufficiently on extreme events and yield interannual(Challinor et al., 2014). Therefore, in terms of food security, it is important to analyze the effect of the new 2.0˚C warming scenarios on the interannual variability of crop production. In particular, studies on impact of 2.0˚C global warming on wheat, rice, maize and cotton production at regional scale are missing.

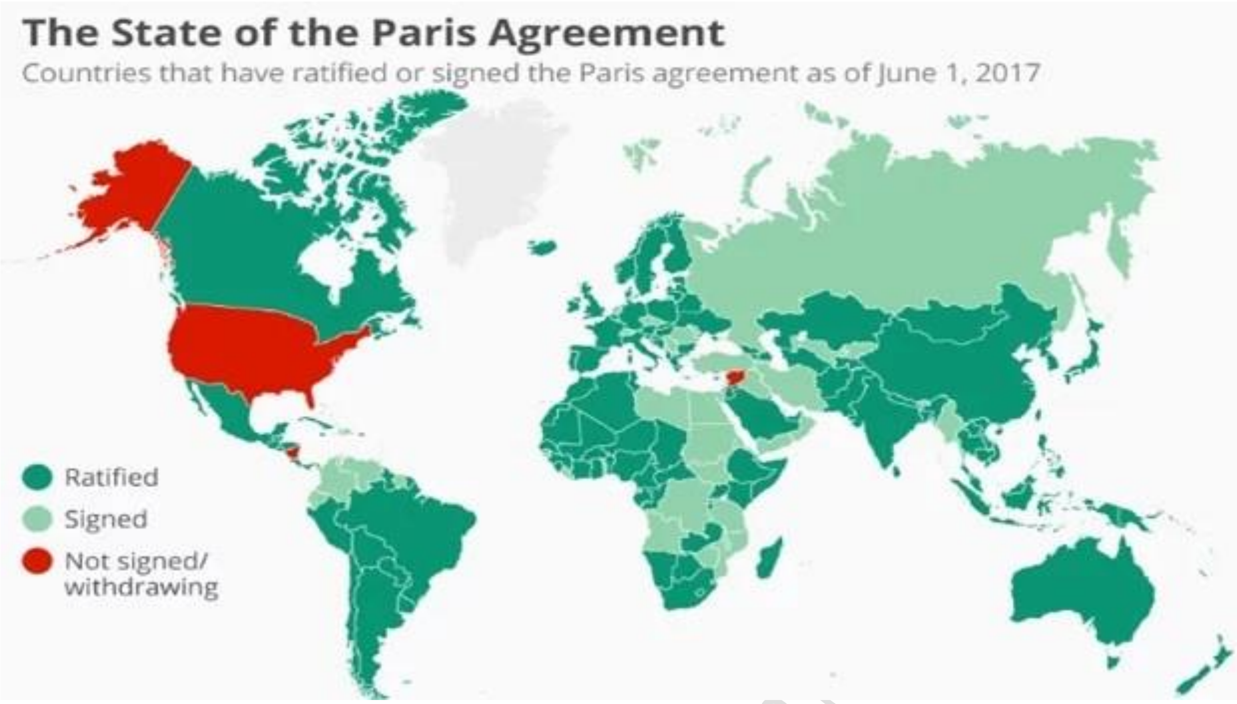
In this context, crop simulation models (CSMs) are often considered very useful. They can evaluate soil and crop management strategies for a crop rotation using soil and weather parameters. Crop simulation models have become more useful with the incorporation of Decision Support Systems, which also aid risk assessment and economic analysis of management strategies. Climate scenarios from five Global Climate Models (GCMs) from the Half a degree Additional warming, Prognosis and Projected Impacts (HAPPI) project (Mitchell et al., 2017) to evaluate the impacts of the 2015 Paris Agreement range of global warming (1.5°C and 2.0°C warming above the pre-industrial period, referred hereafter as '1.5 scenario' and '2.0 scenario') on crop production. We hypothesize that the mean impacts of warming may not differ greatly between the two scenarios as losses due to accelerated development are compensated by gains from elevated CO_2 (Rosenzweig et al., 2018). However, we expect that the higher frequency of extreme events under 2.0°C would result in greater damages of heat and drought stress, greater inter annual variability and higher risk of yield failures. Such information could supply important nuance in understanding the implications of the two levels of warming and associated mitigation efforts of the two warming scenarios. Keeping in view the above facts, the study was planned to assess the impacts of 2°C scenarios on wheat, rice, maize and cotton production

Paris Agreement

The COP-21 or the Paris Climate Conference led to a new international climate agreement, applicable to all countries, aiming to keep global warming below 2°C, in accordance with the recommendations of the Intergovernmental Panel on Climate Change (IPCC).

The number of participants and the force of the commitments made the Paris Agreement a landmark event unprecedented in the field of climate change negotiations.

The agreement formally came into force on 4 November 2016, several days before the COP-22, and has now been ratified by 169 countries (including the European Union 28) representing 87.75% of emissions.



Paris Agreement: The state of the Paris Agreement

As host and chair of the COP-21, France committed to supporting a multilateral negotiations process and listening to all stakeholders to reach an agreement that is:

- Universal and legally binding,
- Fair and differentiated,
- Sustainable and dynamic.

A universal legal agreement applicable to all

The 197 "Negotiating Parties" committed to drawing up long-term low greenhouse gas emission development strategies. This is the first time that a universal agreement was reached in the fight against climate change.

Certain legally binding rules apply to the States Parties, such as the obligation for developed countries to provide developing countries with financial support to enable them to implement the agreement.

A fair and differentiated agreement

In response to the climate challenge, the agreement recognizes that States have common but differentiated responsibilities, i.e. depending on respective capabilities and different national circumstances.

It considers the level of development and the specific needs of particularly vulnerable countries, for example. Beyond making financial commitments, industrialized countries will need to facilitate technology transfers, and more generally, adaptation to a low-carbon economy.

In terms of transparency, a system for tracking national commitments, which is slightly flexible for developing countries, has also kept track of everyone's efforts.

A sustainable and dynamic agreement

It is an agreement with an "Action Agenda" aimed at implementing accelerators to ensure more ambitious progress, above and beyond binding commitments.

The purpose is to hold the increase in global average temperature to well below 2˚C above pre-industrial levels and to ensure that efforts are pursued to limit the temperature increase to 1.5˚C. To achieve this, the Paris Agreement stipulates that all countries shall review their contributions to reducing greenhouse gas emissions every five years. Each new contribution set out on a national level should include a progression compared with the precedent. The Parties committed to reaching a global peak in greenhouse gas emissions as soon as possible, in order to achieve a balance between emissions and their removal in the second half of the century. The States are also required to increase their efforts to mitigate and reduce their greenhouse gas emissions.

A financial component to guarantee international solidarity for more vulnerable countries

Funding is crucial for supporting emerging countries and supporting the transition to carbon-free economies. The agreement provides that $100 billion in public and private resources will need to be raised each year from 2020 to finance projects that enable countries to adapt to the impacts of climate change (rise in sea level, droughts, etc.) or reduce greenhouse gas emissions. This funding should gradually increase, and some developing countries will also be able to become donors, on a voluntary basis, to help the poorest countries.

How did States contribute to the COP21?

Ahead of the COP, each country had to prepare and publish its Intended Nationally Determined Contributions (INDCs). This mechanism was new and allowed each State involved to participate in a universal effort through a concrete working plan with 2 key focuses:

- Reducing GHG emissions by 2025-2030,
- Adapting or reducing vulnerability to the effects of climate change.

The contributions were published as and when they were received on the website of the United Nations Framework Convention on Climate Change (UNFCCC). On 22 November 2015, a week before the conference, 170 countries, accounting for over 90% of emissions, had already published their national contributions to reduce greenhouse gas emissions. Each contribution had to include quantifiable elements, the benchmark year, the implementation timetable as well as methodologies to quantify greenhouse gas emissions.

The "major emitters", notably China and the European Union, undertook ambitious commitments. All countries participated, including the least developed countries which committed to taking steps to reduce their emissions. Several States (Cape Verde, Papua New Guinea, Samoa, Vanuatu) indicated that they wanted to transition to 100% renewable energy within 15 years.

2: Methodology

2.1: Description of study site

To study the impacts of climate change on crops, six different sites were selected from the Punjab Pakistan based on climatology. The sites for study were Bahawalnagar, Multan, Mianwali, Lahore, Sargodha and Sialkot as shown in figure 1. Soil and climatic characteristic of each sites are given below

2.1.1: Bahawalnagar

It is located 29.33°N, 73.85°E. Bahawalnagar has a hot desert climate with hot summers and mild winter by the Koppen-Geiger climate classification system. High temperature ranges from 22-41°C, low temperature ranges from 4-28°C and average precipitation 28.5 mm during the year. Precipitation mostly falls in the monsoon season from June to August, although some rain also falls from February to April. Texture of the soils varied from sandy loam to loam. The main crops of Bahawalnagar are sugarcane, cotton, wheat, rice, tobacco, and mustard seed.

2.1.2: Multan

It is located 30.20°N, 71.43°E. Multan features an arid climate with very hot summers and cold winters by the Koppen-Geiger climate classification system. Average high temperature 32.6°C, low temperature 16°C and average rainfall 957.9 mm were recorded during the year. Multan is an important agricultural centre. Wheat, cotton and sugarcane are the main crops grown in the district. Moreover, rice, maize, tobacco, bajra, moong, mash, masoor, oil seed such as rape, mustard and sunflower are also grown in minor quantities in the district.

2.1.3: Lahore

It is located 31.55°N, 74.33°E. Lahore has a semi-arid climate by the Koppen-Geiger climate classification system. Average high temperature 48.3°C, low temperature 17.8°C and average rainfall 628.8 mm were recorded during the year. The main crops grown in the district include wheat, cotton, rice, sugarcane, maize, oilseeds, pulses, fruits, vegetables, spices, fodders and a large range of other crops.

2.1.4: Sialkot

It is located 32.51°N, 74.53°E. Sialkot features a humid sub-tropical climate by the Koppen-Geiger climate classification system. Average high temperature 29.7°C, low temperature 17.9°C and average rainfall 186.8 mm were recorded during the year. The main crops of Sialkot are wheat, barley, rice, corn, millet and sugarcane.

2.1.5: Sargodha

It is located 32.05°N, 72.66°E. Sargodha features a climate of extreme heat in the summers and moderate cold in the winters by the Koppen-Geiger climate classification system. Average high temperature 30.6°C, low temperature 18.8°C and average rainfall 400 mm were recorded during the year. It is an agricultural district, wheat, rice, and sugarcane being its main crops. The Sargodha district is also famous for citrus fruit; kino is a widely developed variety. The province of Punjab ranks at the top in the production of wheat.

2.1.6: Mianwali

It is located 32.58°N, 71.53°E. Mianwali has an extreme climate, with a long, hot summer season and cold, dry winters by the Koppen-Geiger climate classification system. Average high temperature 31°C, low temperature 16°C and average rainfall 385 mm were recorded during the year. Wheat, Sugarcane, Gram and Guar Seed are the main crops grown in the district Besides, Ground Nut, Rice, Cotton, Moong, Mash and Masoor are also grown in minor quantities in the district.

.

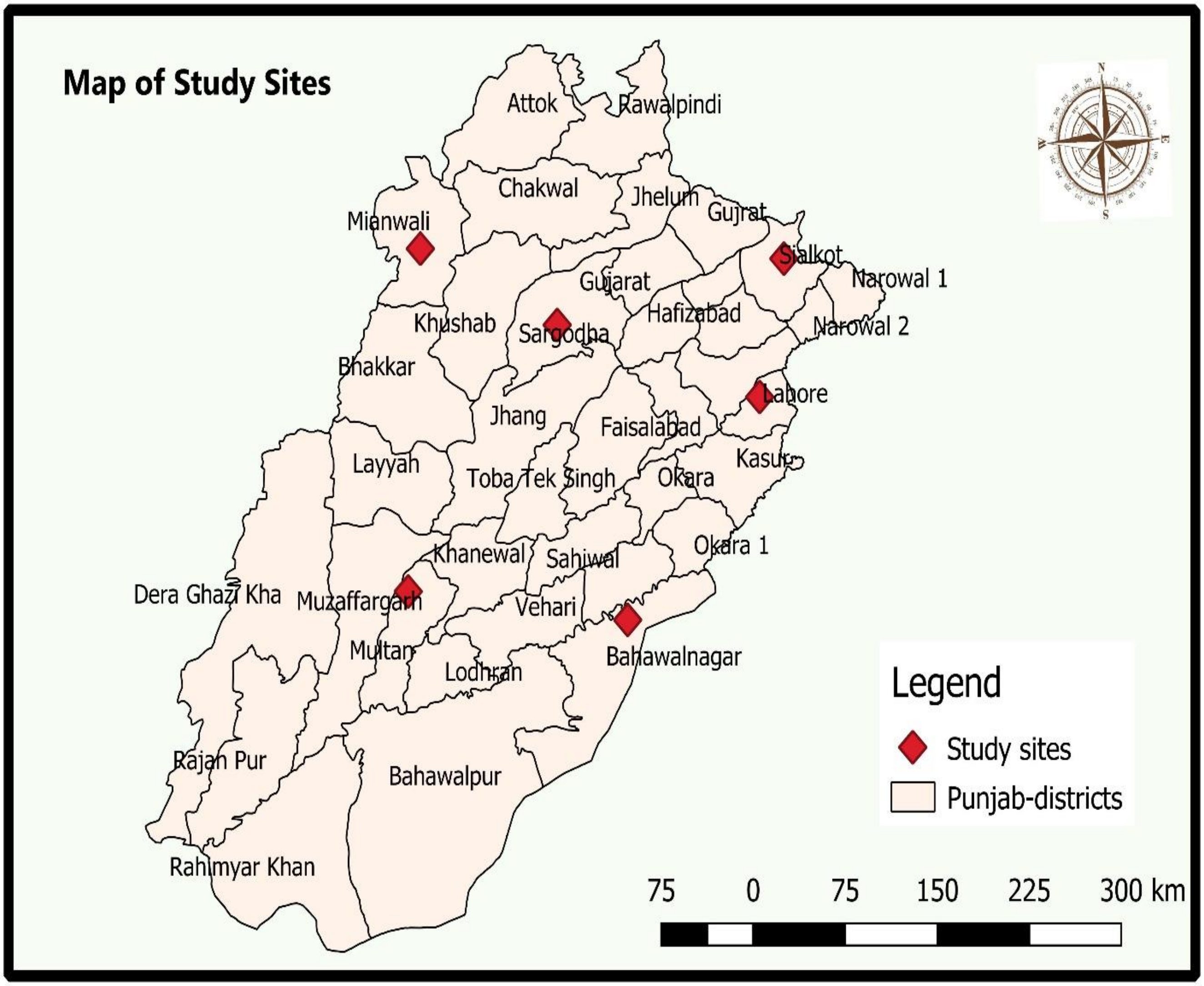


Figure 1: Map of study area

2.2: Calibration and Evaluation of DSSAT model

Crop model "Decision Support system for Agro-technology Transfer (DSSAT) was parameterized using already conducted field experiment. Parameterization includes categorizing parameters in crop model that would best predict the crop growth, development and productivity according to local climatic conditions at experimental sites. The model has specific parameters information related to crop in species and cultivar files which define day length sensitivity, and heat unit accretion required for each specific growth and development stage. It was parameterized for simulation of treatments studied during all growing seasons in field experiments. Crop management's inputs will be quantified during field experiments and include initial field conditions, planting details, fertilizer applications, irrigation schedules, tillage information and harvest dates.

2.2.1: Wheat

The experiments were laid out at Agronomic Research Area, University of Agriculture Faisalabad in with randomized complete block design (RCBD) with split plot arrangement having four replications. The plot size was 10m x 2.4m. The experiments considered ten cultivars (Faisalabad-2008, Lasani-2008, Sahar-2006) in subplots and four nitrogen levels (0, 55, 110, and 220 kg ha^{-1}) in main plots. The wheat crop was sown on 12th November during both the years of 2008-2009 and 2009-2010 with the help of single row hand drill, keeping row to row distance of 30 cm. The phosphorus and potassium were applied at the rate of 85 and 60 kg ha^{-1}, respectively. Urea, triple supper phosphate, and sulphate of potash were used as sources of N, P, and K fertilizers, respectively. The potash and phosphorus fertilizers were applied at the time of sowing, while the N was top dressed in two splits. Cultural practices such as weeding, and irrigation were kept uniform for all the experimental treatments. Two equal splits of nitrogen fertilizer were applied first at 35 (17th December) and 60 (11th January) days after sowing (DAS), respectively, during both the years (Sultana et al., 2013). A total of 19-acre inches of water were applied; four-acre inches for seed bed preparation, three-acre inches each at tillering, stem elongation, booting, anthesis, and grain formation stages (Sultana et al., 2013).

The dynamic crop growth model CSM-CERES-wheat was applied in this study because it has capabilities to simulate daily crop growth, development and yield under diversified climatic and soil conditions with different agronomic management practices. Model was calibrated with 110 N kg ha^{-1} for all cultivars and evaluated with remaining treatments. The available experimental data on anthesis date, maturity date, yield components, grain yield and total crop biomass was compared with simulated results.

2.2.2: Rice

CERES rice model was calibrated using the data of field experiment. A field study was conducted at Faisalabad, Kala Shah Kaku and Gujranwala to evaluate the application of the dynamic cropping system model to study the impact of climate change on rice yield in the Punjab, Pakistan. The experiments were laid out in randomized complete block design with split plot arrangement. Treatments were comprised on transplanting dates (1^{st} July, 15^{th} July, 30^{th} July) in main plots two genotypes (cv. Super Basmati, cv. Basmati-2000) in sub-plots. The nursery was sown by dry method in the 1^{st} week of June and 3^{rd} week of June during both the seasons at three sites. In each season the wetland preparation (Puddling) method was used for preparing the paddock for transplanting. Thirty days old seedlings were transplanted manually in the puddle field in standing water at 22.5cm x 22.5cm plant to plant and row to row distance. Recommended dose of phosphorous (79 kg ha^{-1}) as SSP, potash (62 kg ha^{-1}) as SOP were applied before transplanting while the nitrogen (N) fertilizer (136 kg ha^{-1}) as Urea was applied into three splits. Full N at transplanting, 1/3 N at transplanting + 1/3 N at 30 days after transplanting (DAT) + 1/3 N at 50 DAT. All plots were irrigated to maintain a flooded condition contentiously throughout the active growth period of the rice. All other cultural practices such as weeding, plant protection, etc. were kept normal for all the crops.

2.2.3: Maize

A field experiment was conducted under arid to semi-arid climatic conditions of Punjab, Pakistan (31° 22′ N, 73°01 ′ E), during the two spring seasons for the years 2015 and 2016. An experiment was comprised of four sowing dates (S1 = 27 January, S2 = 16 February, S3 = 08 March, S4 = 28 March) and three maize hybrids (H1 = pioneer-1543, H2=Mosanto- DK6103, H3 = Syngenta-NK8711). An experiment was laid out in randomized complete block design with split plot arrangement. Four sowing dates were kept in main plot and three maize hybrids in subplot. Seed rate of 25 kg ha^{-1} was applied. Plant to plant distance of 20 cm and row to row distance of 75 cm were maintained. Each treatment was replicated three times. Based on soil analysis, recommended dose of 200 kg ha^{-1} of nitrogen in the form of urea, 125 kg ha^{-1} phosphorus in the form of ammonium phosphate, and 125 kg ha^{-1} potassium in the form of sulfate of potash were used. All phosphorus (P), potassium (K), and one third dose of nitrogen (N) fertilizers was applied before planting, while the remaining doses were applied in two splits, one at six-leaf (V6) stage and second at tasseling (VT). Other agronomic practices like weeds, pest, and disease control were kept constant for all treatments.

This study used CERES-Maize model(Jones et al., 1986). CERES-Maize is under the shell of DSSAT (Decision Support System for Agro-Technology Transfer). DSSAT is a software program which comprised of dynamic crop growth models(Hoogenboom et al., 2015). Model simulates the combined effect of plant genotype, soil type, management practices, and weather conditions on phenology, growth, and yield of maize (Jones et al. 2003). Genetic coefficients of CERES-Maize were adjusted by using generalized likelihood uncertainty estimation (GLUE) and sensitivity analysis tools built in DSSAT V4.6.1. CERES-Maize was calibrated with best sowing date of 27 January 2015 from field experiment for three maize hybrids. The GLUE was run with non-stressed treatment. It takes initial coefficients from the genotype file and at the end gives best combinations of phenology, growth, and yield parameters, which were then evaluated by different statistical indices(Hunt et al., 1993). After calibration, CERES-Maize was evaluated with other sowing dates in 2015 and 2016 maize-growing year. Accuracy of model and reliability of genetic coefficients were assessed by calculating the different statistical indices.

2.2.4: Cotton

Field experiments were conducted during the cotton growing season of 2012 and 2013 at research farm of Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad (31°30N, East 73°26E, and altitude 213 m). The soil is classified as Aridisol, mixed, hyper thermic Ustalfic, Haplargid and Haplic Yermosol according soil taxonomy Soil Survey Staff and FAO-UNESCO, respectively. Planting dates and promising cotton cultivars (Bt. and non-Bt.) were considered as main treatments in these experiments. The experiments were arranged as split plot three replicates. Cotton cultivars (CIM-496, FH-142, MNH-886) were kept in sub plot while planting times (10-March, 30-March, 21-April, 10-May, 1-June and 21 June) were randomized in main plots. Crop management for all planting dates and both growing seasons was similar. Cotton seed was sown on beds. Seed was drilled along the edge of beds at the rate of 25 kg ha^{-1}. The planting density of 55,000 (plants ha^{-1}) was retained with the planting geometry of 23 cm distance from plant to plant and 75 cm between beds rows. Insect pests were controlled with recommended practices to keep their populations below threshold. Weed control included manual, and mechanical operations. Soil moisture was measured using a neutron moisture meter, and irrigation amounts were matched to crop requirements to avoid water stress. A basal dose of fertilizer (P = 90 kg P_2O_5 ha^{-1} in the form of triple super phosphate and K = 50 kg K_2O ha^{-1} in the form of potassium sulphate) was applied at seed bed preparation, while nitrogen 200 kg ha^{-1} (Urea) was applied in three splits, one third at sowing and the rest at sympodial branching and flowering stages.

The DSSAT-CSM version 4.6 was used in this study (Hoogenboom et al., 2015)due to its broad range applicability in variable climatic conditions for different cropping systems worldwide. The CSM-CROPGRO- Cotton model was developed from the CROPGRO-Soybean model. A process-oriented model within CSM-DSSAT computes cropping system process on daily basis and selected sub processes are also calculated at an hourly time step. The model simulates the carbon, nitrogen and hydrological processes in the soil plant systems as well as their transformation by utilizing mass balance principles within the cropping system (Jones et al., 2003). The model's dynamic simulation includes various developmental stages, growth rate and biomass portioning that are affected by weather and soil conditions. The CSM-CROPGRO-Cotton model simulates cotton growth and developmental stages (emergence, first leaf, first flower, first seed, first cracked boll (physiological maturity) and 90% open boll) based on photo thermal time or thermal heat unit accretion while soil, weather, management and cultivar genetic coefficients are used as input data set(Amouzou et al., 2018). Light interception and canopy photosynthesis simulations are based on leaf level photosynthesis equations from the hedgerow model(Boote et al., 2011) which consider the cotton row structure and canopy cover. Shortfall of water and nitrogen in soil layers is an indicator of stress computed by the model which ultimately causes a reduction in carbohydrate availability for plant growth. Carbon assimilates are partitioned to various plant components (leaves, stems, roots, bolls and cotton seed). Deficit and excess in soil water and nitrogen conditions are the cause of plant stress simulated by model.

Water deficit conditions, normal aging, nitrogen remobilization, light stress and maturity lead to leaf senescence in cotton while both water conditions either excessive or deficit are the cause of root senescence. Detailed description related sub modules structure, integration, methodologies and other processes used in CSM-DSSAT can be found in the documentation(Hoogenboom et al., 2015)

2.3: Statistical downscaling of HAPPI scenarios

Baseline (2006-2015) climate data for each site were taken from the Pakistan Meteorological Department (PMD), Pakistan. Future (2106-2115) scenarios with 2˚C were created by statistical downscaling of global data of Half a degree Additional warming, Prognosis and Projected Impacts (HAPPI) project. The HAPPI modelling protocol includes three 10-year periods with prescribed atmospheric forcing as well as sea-surface temperatures and sea-ice forcing conditions (Mitchell et al., 2017) for further details on the HAPPI protocol. Participating general circulation models (GCMs) have provided multi-member realizations for each of the three periods. The reference period for the HAPPI experiment is the 'current decade' from 2006–2015 forced by observations including observed CO_2 concentrations that have increased from 380.9 parts per million (ppm) to 402.9 ppm over this decade. Mean warming over this period corresponds to about 0.9˚C above the 1860-1880 period in the Berkeley Earth GMT dataset. The Future 2˚C experiment uses scaled atmospheric and sea-surface temperature forcing from RCP2.6 and RCP4.5 with CO_2 concentrations set to 486.6 ppm. For 2°C scenarios, one GCM MIROC5 was selected among five GCMs, NorESM1-M, CanAM4. CAM4-2degree (HAPPI), and HadAM3P for each location according to protocol given by (Ruane et al., 2018). After statistical downscaling biased correction of each parameter was done with observe data. The baseline and future data are presented in figure 2

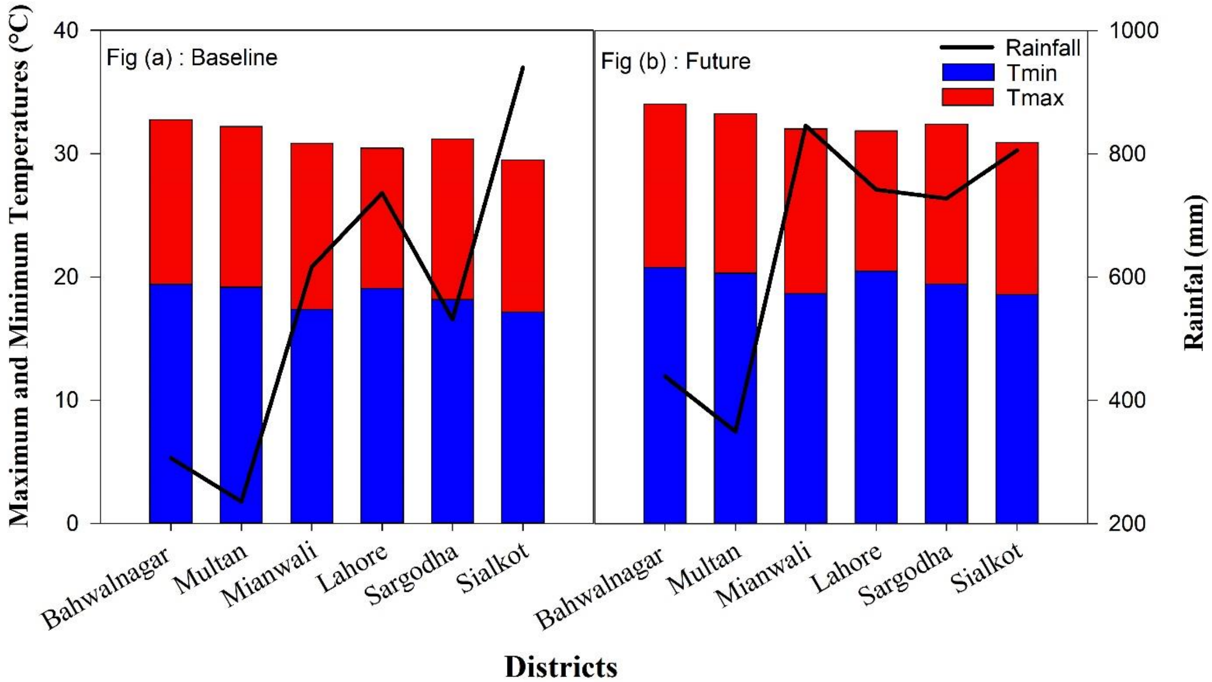


Figure 2: Mean maximum, minimum temperatures and rainfall of baseline and future for study sites

Data presented in Figure 2 is for baseline, which showed that high maximum and minimum temperatures and less rainfalls were recorded in Bahawalpur and Multan. Future data indicated an increase in temperatures and rainfall as compared to baseline. High rainfall pattern was observed in Mianwali, Sargodha and Sialkot.

Table 1: Future increase in temperatures and precipitation

Districts	∆Tmax (°C)	∆Tmin (°C)	∆Rainfall (mm)
Bahawalnagar	1.25	1.37	133.01
Multan	1.04	1.17	114.04
Mianwali	1.17	1.29	229.60
Lahore	1.41	1.41	5.96
Sargodha	1.25	1.26	196.52
Sialkot	1.46	1.43	-134.00

Change in maximum, minimum temperatures and rainfall is presented in Table 1, that showed an average increase in temperature of 1.3°C was recorded. High rainfall of 299 mm was observed in future for Mianwali district and then Sialkot at which rainfall of 196 mm was recorded.

2.4: Climate change Impact assessment

Decision Support system for Agro-technology transfer (DSSAT) V4.6.1 was used for this study. DSSAT is a software program which comprised of dynamic crop growth models (Hoogenboom et al., 2016). Model simulated the combined effect of plant genotype, soil type, management practices, and weather conditions on phenology, growth, and yield of maize (Jones et al., 2003). Model was calibrated and evaluated with data from the already conducted field experiment at Agro-Climatology Lab, Department of Agronomy, University of Agriculture, Faisalabad.

Accuracy of model and reliability of genetic co-efficients were assessed by calculating the different statistical indices. Statistical indices described by Willmott (1981) were used to determine the differences between observed and simulated values.

$$\mathbf{MAE} = \frac{1}{n}\sum_{i=1}^{n}|\mathbf{Y}_{Sim.} - \mathbf{Y}_{Obs.}| \qquad \textbf{(1)}$$

Mean Absolute Error (MAE) measures the magnitude of the errors in a set of estimates.

$$\mathbf{ME} = \frac{1}{n}\sum_{i=1}^{n}(\mathbf{Y}_{Sim.} - \mathbf{Y}_{Obs.}) \qquad \textbf{(2)}$$

Mean Error (ME) is an observational error that refers to the average of all the errors in observed and simulated values.

$$\mathbf{RMSE} = \sqrt{\left(\frac{1}{n}\sum_{i=1}^{n}(\mathbf{Y}_{Sim.} - \mathbf{Y}_{Obs.})^2\right)} \qquad \textbf{(3)}$$

Root Mean Square Error (RMSE) indicated the size of the error produced by the model, a model performance assessment criterion.

$$\mathbf{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\frac{|Y_{Sim} - Y_{Obs.}|}{Y_{Obs.}} * \mathbf{100} \qquad \textbf{(4)}$$

The Mean Absolute Percentage Error (*MAPE*) shows that in relative terms the mistakes made by the estimates

$$\boldsymbol{d_r} = \mathbf{1} - \left[\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(|P_i'| - |O_i'|)^2}\right] \qquad \textbf{(5)}$$

Enhanced Willmott concordance index (d_r) shows the deviation between the observed and simulated values. The value of dr ranged between 0-1. If value closer to 1, indicate the batter simulation of model (Willmott et al., 2012). From all equations n shows the number of variables, i shows the ith quantity of observed (obs.) and simulated (sim.).

After calibration and evaluation, DSSAT were used to study the impact of climate change. Bassline and future data were used to create weather files of model. After getting simulations of each year, the % reduction in yield was calculated by formula given blow

$$\% \ \mathbf{Change} = \frac{\boldsymbol{Oberved - Simulated}}{\boldsymbol{Observed}} \times \mathbf{100} \quad \textbf{(6)}$$

3: Results

3.1: Calibration and Evaluation of DSSAT

3.1.1: Wheat

Genetic coefficients

The CSM-CERES-Wheat requires ten cultivars set for phenology simulation, yield and growth of the cultivar (Hoogenboom et al. 1994). As such type of data was not accessible for local cultivar of current study; the cultivar genetic coefficients were forecasted by repeating of interaction till close match between observed and simulated data of phenology, yield and growth of Wheat was achieved. Precise data simulation needs the proper genetic coefficient of cultivar. Ten recommended wheat cultivars were used in this study. The genetic coefficients used in CSM-CERES-Wheat are concise in (Table 2).

Calibration

Model calibration performance for all recorded parameters was good. Good agreement was gained between field-observed and model-predicted values for wheat cultivars Faisalabad-2008, Lasani-2008 and Sahar-2006 for phenology (anthesis and physiological maturity), leaf area index, total dry matter and grain yield. Percent Error (PE) value for anthesis was 0, 0.91 and 0% for Faisalabad-2008, Lasani-2008 and Sahar-2006, respectively. PE value for maturity was 1.47, 1.45 and 0 for Faisalabad-2008, Lasani-2008 and Sahar-2006, respectively. The value of PE was 5.76, 7.69 and 9.25 for maximum leaf area index for Faisalabad-2008, Lasani-2008 and Sahar-2006, respectively. The value of PE was 1.36, 0.04 and 0.51 kg ha^{-1} for grain yield for Faisalabad-2008, Lasani-2008 and Sahar-2006, respectively (Table 3).

Phenology

Anthesis and physiological maturity days were evaluated well by CSM-CERES model. There was a close agreement between model simulated and field observed data of anthesis and maturity at 0, 55 and 220 kg ha^{-1} N treatments. On an average, anthesis and maturity time for all varieties were delayed with increasing nitrogen levels, which indicated that nitrogen application rates have influence on time of anthesis and maturity days in field experiment. The difference in anthesis and maturity days among wheat cultivars at nitrogen rates were also genetic character of cultivar. At lower nitrogen increment days to anthesis were closely predicted but at higher nitrogen (220 kg N ha^{-1}) there was 1-day difference between observed and simulated anthesis days with the higher deviation of -0.93% for cultivar Faisalabad-2008 while at the same level sehar-2006 and Lasani-2008 had -0.92% deviation. This showed that days to anthesis were affected by nitrogen increment to the wheat crop, but it was not simulated by the model which predicted same days to anthesis at different nitrogen stress (Table 3).

Overall error between simulated and observed days to anthesis for all cultivars at different nitrogen increment was ranged from 0 to 0.93% during the calibrated year. Similar trend was observed for days to maturity predicted by the model CSM-CERES-Wheat as for days to anthesis. Model did not consider the effect of nitrogen increment on days to maturity by predicting same number of days for each nitrogen treatment. At lower nitrogen increment of 0 kg ha^{-1}, PE value between observed and simulated days to maturity ranged -0.74 for Faisalabad-2008, 0 for Lasani-2008 and 2.22 for Sahar-2006. At higher nitrogen increment of 220 kg ha^{-1}, PE value between observed and simulated days to maturity ranged -2.13 for Faisalabad-2008, -2.17 for Lasani-2008 and -1.43 for Sahar-2006 (Table 3). Overall performance of CSM-CERES-Wheat model was good in case of maturity days prediction. These results showed that model can predict phenology accurately at recommended level of nitrogen.

Leaf Area Index

Evaluation of CSM-CERES-Wheat model for leaf area index using the data of the experiment during 2007-08 and nitrogen increments showed that the best prediction was for the cultivar Sahar-2006 with an average error (2.52) Model predicted 0 and 2.94 percent error for Sahar-2006 at lower nitrogen levels (0 and 55 kg ha^{-1}) while higher percent error (4.62 %) was observed at higher nitrogen increment. Model over-simulated LAI in case of Lasani-2008, percent error ranged from 5.00 to 11.11% while overall percent error 9.62 % for the cultivar Model predicted LAI well at higher nitrogen rates as compared to lesser. Over all mean percent error for observed and simulated LAI was 5.66% only for observed and simulated values (Table 3).

Grain yield and Biomass (kg ha^{-1})

Higher error was recorded among all nitrogen increment against the application of 55 kg N ha^{-1} 6.37 for Faisalabad-2008. Highest error was recorded among all nitrogen increment against the application of 0 kg N ha^{-1} for all the cultivars ranged 5.83 for Lasani-2008. An error was recorded among all nitrogen increment at 220 kg N ha^{-1} ranged 0.24 for Sahar-2006. Model over simulated for cultivar Sahar-2006 against all nitrogen increment ranged 10.84, 17.65 and 11.36% for 0, 55 and 220 kg N ha^{-1}, respectively. Minimum error was observed against all nitrogen increments for Sahar-2006, -4.49 and -1.11% against 0, and 55 kg N ha^{-1}, respectively.

Minimum percent error was recorded for cultivar Sehar-2006 ranging from 4.10 to -6.01 between observed and simulated above ground biomass with different nitrogen increment while overall error was only -2.18. Lower error percentage was observed with lesser nitrogen increment as compared to higher levels, -0.77% for Faisalabad-2008, 6.08% for Lasani-2008 and -6.01% for Sehar-2006 @ 0 kg N ha^{-1} while higher doses of nitrogen showed percent error 6.08, 4.83 and 8.94% for Faisalabad-2008, Lasani-2008 and Sehar-2006 respectively for above ground biomass with the application of 220 kg N ha^{-1}, but mean error was 2.67, 6.90 and -2.18% for cultivar Faisalabad-2008, Lasani-2008 and Sehar-2006 respectively (Table 3). Over all mean error between observed and simulated above ground biomass for all the nitrogen increment in all cultivars was only 2.46% Time course between simulated and observed values were in good agreement for total above ground biomass at different phenological stages in all cultivars with different nitrogen increment.

Evaluation of CSM-CERES-Wheat

Phenology

For crop growth models, the accurate simulation of phenological development under different growth conditions is the major requirement for accurate prediction of crop growth and yield. The CSM-CERES-Wheat model simulated same number of days for all anthesis and maturity for different nitrogen increments (0-220 kg N ha^{-1}) as compared to observed. Observed anthesis data (days) for all cultivars (Faisalabad-2008, Lasani-2008 and Sahar-2006) were recorded different up to the application of 220 kg N ha^{-1} produced one day more due to higher nitrogen application enhanced vegetative growth and delayed anthesis and maturity of wheat crop (Table 4). Same trend for maturity in observed data (days) was recorded for all cultivars, where higher nitrogen increments delayed the maturity (Table 4). Data for anthesis dates revealed that minimum error were recorded between observed and simulated at lower nitrogen application while maximum at higher nitrogen. Averaged PE value was 0.70 for cultivar Faisalabad-2008, 0.45 for cultivar Lasani-2008 and 2.10 for cultivar Sahar-2006. Overall average percent mean error were only up to 0.78. Overall mean error between observed and simulated days to anthesis for cultivar Faisalabad-2008, Lasani-2008 and Sahar-2006 was 0.70, 0.45 and 2.10 respectively (Table 4). maximum percent difference while same number of days and minimum percent difference were documented at initial nitrogen increments. Mean error E ranged from 0.00 to 1.47 for Faisaabad-2008, 0.00 to 0.75 for Lasani-2008 and 2.19 to 2.90 for Sahar-2006. While average mean error E value was 0.74 for Faisaabad-2008, 0.00 for Lasani-2008 and 2.54 for Sahar-2006. Maturity days difference was higher at maximum nitrogen level and minimum at lower nitrogen level for cultivar Sahar-2006. Overall average E value for simulated and observed maturity days was 1.09 (Table 4).

Leaf Area Index (LAI)

Evaluation of LAI with CSM-CERES-Wheat model using the data from experiment conducted in 2009-10 with cultivars and nitrogen levels showed that the best prediction was for the cultivar Sahar-2006 with an average error (1.21 %). In case of cultivar Lasani-2008 average percent error (5.29), RMSE 0.27 and d-value (0.99) was recorded between observed and simulated leaf area index. Overall there was an underestimation of LAI in model predictions for all cultivars and nitrogen levels with an average error of 4.52%. This simulation error was more (10.57%) at higher level of nitrogen. The CSM-CERES-Wheat model under-estimated leaf area index from 55 N ha^{-1} to 220 kg N ha^{-1} for all cultivars during the year 2008-09. While at 0 N, mean error E value was 0 among cultivars.

Grain yield (kg ha^{-1})

The corresponding simulation results of grain yield are shown in Table 4. There was good agreement between observed and simulated grain yield, model over-estimated 3109 kg ha^{-1} average grain yield that is more as compared to average observed grain yield (3046). Overall mean percent error for all nitrogen increments among cultivars was 0.02%. Model simulated reasonably well for all nitrogen levels with an average error ranging from 6.09 to 7.96%. The model performance was better in year 2007-08 with 0.02% error as compared to year 2008-09 during that error between simulated and observed grain yield was 0.63%. It might be due to difference in environmental condition especially precipitation during the growing season 2007-08 as compared to 2008-09. Model over simulated grain yield for nitrogen increments with cultivars, error percent ranged 1.94 to 8.53% for cultivars Faisalabad-2008 and 4.91 to 11.60%

for Lasani-2008 while in Sehar-2006 error percent ranged 1.82 to 8.20%. Average error between observed and simulated grain yield was observed 1.95% for cultivar Faisalabad-2008, 1.59% for Lasani-2008 and 0.41% for Sehar-2006 which is minimum per cent difference as compared to rest of other cultivars for model evaluation during the year 2009-10 (Table 4). In general, the results for simulated grain yield with the observed data sets indicated that the CSM-CERES-Wheat model was able to simulate yield accurately for wheat cultivars with different nitrogen increments under irrigated conditions for a semiarid environment in Faisalabad, Pakistan. Nitrogen stress and difference in precipitation during growing season might affect the performance of model. These evaluation results showed that genetic coefficients estimated for each variety are robust and model calibrated once for a cultivar can accurately simulate growth and yield.

Total above ground biomass (kg ha^{-1})

Table 4 showed that there was good agreement between observed and simulated total dry matter, model simulated 7532 kg ha^{-1} average TDM that was less as compared to average observed TDM (7690 kg ha^{-1}) for all treatments in model validation during the year 2008-09. Model simulated reasonably well for all nitrogen levels with an average error ranging from 2.97 to 7.97%. Model showed the same trend here as in case of other variables. Lower percent error was observed at higher nitrogen increment (220 kg N ha^{-1}) for each cultivar as compared to lower nitrogen level. Error percent ranged 1.39 to 11.25, 1.56 to 12.35 and 0.24 to 10.37% for Faisalabad-2008, Lasani-2008 and Sehar-2006, respectively and mean percent difference for nitrogen increment was observed 0.01% while average per cent error for each cultivar was 1.51% in Faisalabad-2008, 4.52% for Lasani-2008 and 2.99% for Sehar-2006.

Overall, results showed that performance of the CSM-CERES-Wheat model was good during evaluation under given set of conditions and this could further be used to design precise agronomic practices for sustainable yield of wheat crop in semi-arid climatic conditions.

Table 2: Genetic coefficients of three wheat cultivars Faisalabad-2008, Lasani-2008 and Sahar-2006

Cultivars	P_1V	P_1D	P_5	G1	G2	G3	PHINT
Faisalabad-2008	9	48	30	34	20	2.9	100
Lasani-2008	10	51	401	30	20	2.9	102
Sahar-2006	10	50	421	33	20	2.9	100

P1V = Days, optimum vernalizing temperature, required for vernalization.
P1D = Photoperiod response (% reduction in rate/10 h drop in pp).
P5 = Grain filling (excluding lag) phase duration (˚C.d).
G1= Kernel number per unit canopy weight at anthesis (#/g)
G2 = Standard kernel size under optimum conditions (mg).
G3 = Standard, non-stressed mature tiller wt (including grain) (g dwt)
PHINT = Interval between successive leaf appearance (˚C.d)

Table 3: Summary of observed and simulated results during model calibration with data recorded at 110 kg N ha^{-1} in 2008-09 for Cultivars Faisalabad-2008, Lasani-2008 Sahar-2006

Parameters	Faisalabad-2008			Lasani-2008			Sahar-2006		
	Obs.	Sim.	%Error	Obs.	Sim.	%Error	Obs.	Sim.	%Error
Days to anthesis (Days)	106	106	0	109	108	-0.91	108	108	0
Days to maturity(Days)	136	134	-1.47	137	135	-1.45	135	135	0
Leaf area index	5.2	5.5	5.76	5.2	5.6	7.69	5.4	5.9	9.25
Grain yield (kg ha^{-1})	4485	4546	1.36	4147	4145	-0.04	4504	4527	0.51
Biological yield (kg ha^{-1})	12133	12445	2.57	11973	12804	6.94	12375	12431	0.45

Table 4: Comparison of observed and simulated variables of Wheat cultivars related to phenology, growth and grain yield during model evaluation at different levels of nitrogen in growing years of 2008-09 and 2009-10

Cultivars Name	Nitrogen Levels	Days to anthesis		Days to Maturity		LAI		Grain Yield		Biological Yield	
		2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10
		% Error	% Error	% Error	% Error	% Error	% Error	% Error	% Error	% Error	% Error
Faisalabad-2008	0 kg ha^{-1}	0.95	0.93	-0.74	0.00	-11.11	0.00	2.90	8.53	-0.77	2.42
	55 kg ha^{-1}	0.00	0.00	-1.47	0.74	3.12	7.41	6.37	7.95	2.69	4.19
	110 kg ha^{-1}	-	1.87	-	0.74	-	10.00	-	6.72	-	11.25
	220 kg ha^{-1}	-0.93	0.00	-2.13	1.47	3.33	10.87	0.19	1.94	6.08	1.39
Lasani-2008	0 kg ha^{-1}	0.00	0.00	0.00	0.75	11.11	0.00	5.83	10.56	6.08	12.35
	55 kg ha^{-1}	0.00	0.00	-1.46	0.00	9.68	3.85	0.59	4.91	6.21	9.58
	110 kg ha^{-1}	-	0.90	-	0.00	-	6.67	-	11.60	-	2.29
	220 kg ha^{-1}	-0.92	0.90	-2.17	0.74	5.00	10.64	-4.82	10.25	8.41	1.56
Sahar-2008	0 kg ha^{-1}	0.93	3.77	2.22	2.19	0.00	0.00	-4.49	1.82	-6.01	0.24
	55 kg ha^{-1}	0.93	1.85	2.22	2.19	2.94	8.74	-1.11	8.20	-4.62	4.61
	110 kg ha^{-1}	-	1.85	-	2.90	-	3.33	-	5.56	-	10.37
	220 kg ha^{-1}	-0.92	0.92	-1.43	2.90	4.62	10.20	0.24	6.09	4.10	5.95

3.1.2: Rice

Genetic Coefficient

The calibrated genetic coefficients (cv. Super Basmati and Basmati-2000) as derived by GENCALC for CERES rice are given in Table 5.

Model calibration and evaluation for 2nd experiment (2009 and 2010)

Calibration of the model

Calibration results (Table 6) revealed that model predicted one day less to anthesis as observed in field with 1.58 percent error (PE) for the variety Basmati-2000. The CERES-Rice simulated one day less in physiological maturity as compared to observed days with 1.02 percent error. The observed and simulated grain yield was 4656 kg ha^{-1} and 4721 kg ha^{-1}, respectively with 1.39 percent difference. The harvest index and biological yield had PE zero and 1.28, respectively. The PE variable showed the model simulation was good under studied conditions.

Model simulated exact number of days to anthesis with zero percent error (PE) Super Basmati in 1st July, 2010 transplanting. The CERES-Rice simulated exact number of days to physiological maturity as anthesis. The tops weight and grain yield simulation was close to observed value having PE 1.6 and 3.03, respectively. These results were reliable to evaluate and validate the model against other treatments.

Evaluation of the model

To check the performance of the model it was run with other treatments, 2nd transplanting (15th July, 2010) and 3rd transplanting (30th July, 2010) of both cultivars Basmati-2000 and Super Basmati while 1st July transplanting date was used for calibration of the model.

Days to flowering and physiological maturity

Table 7 show the observed and simulated values of days to anthesis for 2nd transplanting (15th July) and 3rd transplanting (30th July). In 2nd transplanting date error percent were -3.22 to -1.63% with an average value of -2.42% for varieties Basmati-2000 and Super Basmati, respectively. In case of 3rd transplanting error percent range was 0.90% to -0.76% with an average value of 4.30% of two genotypes.

Table (7) show observed and simulated days for different transplanting with cultivars, Basamti-2000 and Super Basmati to maturity with percent error. Transplanting with variety Basamti-2000 had maximum error (-4.04%) and there was minimum error (-2.01%) in variety Super Basmati in 2nd transplanting (15th July) with percent difference of -3.04. In third transplanting (30th July) maximum error % (-2.51) was observed for Basmati-2000 under second transplanting.

Harvest index %

Data given in Table (7) revealed the results in case of harvest index of two transplanting dates and two varieties percent error ranged 0% to 9.06%. Maximum error (9.06%) was noticed in variety Super basmati and minimum (0%) in second transplanting date of same variety. In 2nd transplanting the mean error percent of two varieties was 4.60%.

Grain Yield kg ha^{-1}

Simulated and observed grain yield for different transplanting dates with two cultivars (Super Basmati and Basmati-2000) demonstrated in the Table (7). The results of error percentage ranged between 4.45% to 7.34% for both the transplanting dates and cultivars. In cultivars, the observed (1120 kg ha^{-1}) and simulated yield (1129 kg ha^{-1}) with percentage error of 0.80. The percentage error (7.34%) was the higher in variety Basmati-2000, transplanted at 3rd transplanting date. The mean percent error of two varieties in two different transplanting dates was 5.46%.

Table 5: Genetic coefficients of two rice cultivars Super Basmati and Basmati-2000

Cultivars	P_1	P_2O	P_2R	P_5	G_1	G_2	G_3	G_4
Super Basmati	400.0	102.0	510.0	11.0	48.0	0.0220	1.0	1.0
Basmati-2000	400.0	104.0	495.0	11.0	50.0	0.0191	1.0	1.0

P_1 Time period (expressed as growing degree days (GDD) in ◦C above a base temperature of 9 ◦C from seedling emergence during which the rice plant is not responsive to changes in photoperiod.
P_2O Critical photoperiod or the longest day length (in h) at which the development occurs at a maximum rate.
P_2R Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in ˚C) for each hour increase in photoperiod above P20.
P_5Time period in GDD ˚C) from beginning of grain filling (3 to 4 days after flowering) to physiological maturity with a base temperature of 9˚C.
G_1Potential spikelet number coefficient as estimated from the number of spikelets per g of main culm dry weight (less lead blades and sheaths plus spikes) at anthesis.
G_2Single grain weight (g) under ideal growing conditions, i.e., nonlimiting light, water, and nutrients and absence of pests and diseases.
G_3 Tillering coefficient (scaler value) relative to IR64 cultivar under ideal conditions.
G_4 Temperature tolerance coefficient. Usually 1.0 for varieties grown in normal environments.

Table 6. Comparison of observed and simulated variables of maize hybrids related to phenology, growth and grain yield during model calibration (27 January 2015)

Parameters	Super Basmati			Basmati-2000		
	Obs.	Sim.	%Error	Obs.	Sim.	%Error
Days to anthesis (Days)	62	62	0.00	62	63	-1.58
Days to maturity(Days)	98	98	0.00	97	98	-1.02
Harvest index	0.40	0.41	-0.97	0.40	0.40	0.00
Grain yield (kg ha^{-1})	4828	4686	3.03	4721	4656	1.39
Biological yield (kg ha^{-1})	11881	11690	1.63	11800	11650	1.28

Table 7: Model evaluation of simulated and observed anthesis, maturity days, harvest Index, grain yield (kg ha^{-1}) and maturity yield (kg ha^{-1}) for Super Basmati and Basmati-2000, transplanted at different dates during 2009-2010

Hybrids Name	Transplanting	Days to anthesis		Days to Maturity		HI		Grain Yield		Biological Yield	
		2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
		% Error	% Error	% Error	% Error	% Error	% Error	% Error	% Error	% Error	% Error
Super Basmati	1st July	-3.22	-	-2.10	-	-2.56	-	-6.84	-	-3.86	-
	15th July	-6.34	-3.22	-2.06	-4.04	4.44	4.85	-1.19	4.45	-6.63	1.07
	30th July	-1.69	1.69	-2.97	-0.99	3.142	4.54	-4.70	7.34	-7.40	2.80
Basmati-2000	1st July	-3.22	-	-2.06	-	-2.00	-	-4.16	-	0.23	-
	15th July	-4.83	-1.63	-3.03	-2.04	4.05	0.00	-0.28	4.70	-2.17	3.22
	30th July	11.53	3.44	-5.66	-2.88	4.85	9.06	-7.32	5.42	-5.97	4.84

3.1.3: Maize

Maize genetic coefficients

Maize crop phenology and growth-related parameters were calibrated first in ecotype file. Thermal time or days taken for the completion of different phenological events like thermal time from seedling emergence to end of juvenile phase and silking to physiological maturity are crucial in phenology module of CERES-Maize (Table 8). Monsanto-DK6103 is long day hybrid took more number of degree days (274) from seedling emergence to the end of juvenile phase (P1) above a base temperature of 8°C than others two cultivars. Syngenta-NK8711 took lower thermal time (219) from seedling emergence to the end of juvenile phase (P5), it seemed short duration cultivar. Same the case was found for thermal time from silking to physiological maturity of hybrids, Monsanto-DK6103 took more number of degree days (766) to reach physiological maturity while Syngenta-NK8711 took minimum degree days (702). Comparison of phenological parameters P1 and P5 showed that more number of degree days was taken by hybrid Monsanto-DK6103 while minimum number of degree days was achieved by Syngenta-NK8711 than others. More maximum possible number of kernels per plant (770.7) was recorded in hybrid Pioneer-1543 than others while kernel filling rate during grain filling stage under optimum conditions was found non-significant among hybrids. Phylochron interval between successive leaf tip appearances in degree days (°C days) was found lower (18.90) in Pioneer-1543 than other two hybrids (22). Details of genetic coefficients can be seen in Table 8.

Table 8. Genetic coefficients of cultivars adjusted during CERES-Maize model calibration.

Cultivar	P1	P2	P5	G2	G3	PHINT
Pioneer-1543	265	0.683	736	770.7	24	18.90
Monsanto-DK6103	274	0.751	766	751.0	23	22.00
Syngenta-NK8711	219	0.490	702	611.0	25	22.00

P1: Thermal time from emergence to end of juvenile phase (days)
P2: Photoperiod sensitivity (0-1)
P5: Thermal time from silking to physiological maturity (days)
G2: Potential kernel per plant
G3: kernel growth rate under optimum condition (mg/day)
PHINT: Thermal time from leaf tip to emerge (°C /day)

Calibration of CERES-Maize model

Monsanto-DK6102 and Poineer-1543 accumulated more number of photo thermal days (75 and 76; 115 and 114) from sowing to anthesis and maturity respectively. These hybrids finally contributed higher growth and grain yield and other related parameters than Syngenta-NK8711 (Table 9). Close fit between observed and simulated phenology parameters was found with highest error percent of 2.63 and 2.80 for anthesis and maturity respectively among all studied hybrids (Table 9). Model generally under simulated the peak LAI for all hybrids and percent difference ranged -3.14% to -6.75%. Comparison of observed and simulated top weight (kg ha^{-1}) of hybrid revealed the closer fit while percent error ranged 0.075 to 0.89 (Table 9). Comparison of simulated and observed grain yield of all hybrids during model calibration showed the best fit with percent error of -1.08 to 4.94 only. Monsanto-DK6102 and Poineer-1543 are being long duration hybrid than Syngenta-NK8711 produced higher grain yield (9380 kg ha^{-1} and 9036 kg ha^{-1}) than Syngenta-NK8711 (7990 kg ha^{-1}). Performance of CERES-Maize model revealed the best fit between observed and simulated of all studied parameters.

Table 9. Comparison of observed and simulated variables of maize hybrids related to phenology, growth and grain yield during model calibration (27 January 2015)

Parameters	**Poineer-1543**			**Monsanto-DK6103**			**Syngenta-NK8711**		
	Obs.	**Sim.**	**%Error**	**Obs.**	**Sim.**	**%Error**	**Obs.**	**Sim.**	**%Error**
Days to anthesis (Days)	76	78	2.63	74	75	1.35	71	69	-2.81
Days to maturity(Days)	114	114	0	113	115	1.77	107	110	2.80
Leaf area index	6.081	5.89	-3.14	6.265	6.05	-3.43	5.748	5.36	-6.75
Grain yield (kg ha^{-1})	9380	9463	0.89	9036	9046	0.11	7990	7996	0.075
Biological yield (kg ha^{-1})	21364	22331	4.53	22850	22604	-1.08	19051	19994	4.94

Crop growth and development and grain yield response of CERES-Maize

Duration of major phenological events

The model simulations for major phenological events sowing to anthesis and grain maturity revealed the good predictions for all hybrids over sowing dates. The model slightly under simulated both days to anthesis and maturity for few sowing dates in hybrids while generally simulations revealed the marginally over prediction. There is no defined trend of under simulation and over simulations about sowing dates for phenological parameters. Generally, the model did not typically predict high variations in maize crop phenological development among sowing dates during model evaluation and precise simulation of phenological events are crucial in crop models as these influence model performances based on real field data. There was not significant difference between observed days to anthesis and maturity for the two growing years (2015 and 2016). Genotypic variations also existed, hybrids had different crop growth cycle as model well predicted the variations in phenological development; Syngenta-NK8711 is a short duration than others. Statistical indices were found quite well during both growing years for phenological events. Percent error (PE) for days to anthesis ranged -10.71 to 8.20% and -4.08 to 5.71% in 2015 and 2016 maize growing years respectively when all hybrids and sowing dates were evaluated. Similarly, lower PE was recorded for days to maturity of different hybrids at different sowing dates. The PE ranged -3.30 to 2.80% and -3.09 to 4.55% in 2015 and 2016 growing year respectively. These results confirmed ability of CSM-CERES-Maize model for simulating the duration of phenological events of promising hybrids sown at various dates under semi-arid climatic conditions of Faisalabad.

CSM-CERES-Maize model response to maize growth (Leaf area index and biomass)

Leaf area index (LAI)

The CSM-CERES-model evaluation response for maize hybrids regarding time course LAI, predicted well with good statistical indices during growing seasons for different hybrids at different sowing dates. Generally, model evaluation of peak LAI was good at all sowing dates during both growing years, but PE ranged -8.45 to 4.80% in 2015 while it ranged -14.34 to 5.96% in 2016 growing years. Overall, model showed under simulation of LAI for majority of the sowing dates but it statistical indices lies in acceptable range (Table 10). Early season LAI was well predicted up to peak (55 DAS) then under simulated during late season especially for 16 February and 8 March sowing dates with all hybrids during both growing years. Model evaluation revealed the good prediction for LAI in 2015 growing year for all hybrids studied.

Biomass (kg ha^{-1})

A close fit between time series observed total dry matter (TDM) and simulated was found at all studied sowing dates and hybrids. Statistical indices showed the best prediction of models for TDM during both maize growing years (2016 and 2016). Close fit was found up to 60 days after sowing for three hybrids in all sowing dates during 2015 and 2016. Model slightly over predicted after 100 days after planting in Poineer-1543 and Syngenta-NK-8711 at 27 January sowing date during 2015. Model evaluation revealed the good prediction for TDM during both growing year for all hybrid studied. Generally, model evaluation of TDM at harvest was good at all sowing dates during both growing years, but PE ranged -5.79 to 5.03% in 2015 while it ranged -10.46 to 7.48% in 2016 growing years for all hybrids studied. Overall, model showed over simulation for majority of the sowing dates but under simulated in few sowing dates however statistical indices lies in acceptable range (Table 10). Hybrid produced biomass in both growing years by adopting this order Monsanto DK-6103 > Pioneer-1543 > Syngenta NK-8711. More dense canopy and biomass was developed by hybrid Monsanto DK-6103 than others.

Grain yield (kg ha^{-1})

Maize grain yield was well simulated by the model for all hybrids during temporal variations (sowing dates) assessment in growing seasons (2015 and 2016). Generally model capability for maize grain yield simulations was found to be good with lower PE for hybrid Pioneer-1543 while slightly high under simulation of 10.42% and 10.56% was recorded for Monsanto-DK-6103 and Syngenta-NK-8711 respectively in 2016 (Table 11). Sowing dates adopted the following order in producing the grain yield during both the years, 27-Jan > 16-Feb > 8-March > 28-March. Hybrids performance in relation with different sowing dates revealed higher grain yield production at early sowing then decline for later sowing. Generally, hybrids Monsanto-DK-6103 and Poineer-1543 performed reasonable good at early sowing (27-Jan) while Syngenta-NK-8711 produced more yield at later sowing (8-March and 28 March). Temporal variation analysis revealed that model fairly well simulated grain yield for early sowing for all hybrids but model under predicted grain yield at 8-March and 28-March sowing dates during both growing years. Generally, PE varied -9.64 to 3.52% in 2015 while -10.56 to 8.97% in 2016 growing year. Generally model simulation was good but slightly under simulated with marginal high difference for 8-March and 28-March sowing dates in both hybrids Monsanto-DK-6103 and Syngenta-NK-8711 in 2015

Table 10. Comparison of observed and simulated variables of maize hybrids related to phenology, growth and grain yield during model evaluation at different sowing dates in growing years of 2015 and 2016.

Hybrids Name	Sowing Dates	Days to anthesis		Days to Maturity		LAI		Grain Yield		Biological Yield	
		2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
		% Error	% Error	% Error	% Error	% Error	% Error	% Error	% Error	% Error	% Error
Pioneer- 1543	27-Jan	2.63	1.39	0.00	1.80	-2.99	2.78	0.88	5.06	4.53	2.87
	16-Feb	8.20	5.26	1.87	-2.88	-0.12	-5.63	-3.87	-5.34	1.39	5.55
	08-Mar	-5.26	3.77	-2.00	-3.09	1.04	-8.73	-3.79	-7.48	-3.19	-1.48
	28-Mar	-3.85	-4.08	-2.04	-1.05	3.37	5.96	-0.50	-9.50	3.06	-3.09
Monsanto-Dk6103	27-Jan	1.35	5.71	1.77	4.55	-3.43	-0.65	0.11	4.99	-1.08	1.68
	16-Feb	4.55	3.23	-1.90	0.98	-8.45	-14.34	-5.20	-9.28	-1.37	-5.30
	08-Mar	-8.33	1.79	-2.04	-2.11	0.32	-10.87	-6.30	-9.61	-4.40	-6.43
	28-Mar	6.00	4.26	-3.13	-1.08	0.80	3.30	-8.42	-10.42	3.96	-10.46
Syngenta-NK-8711	27-Jan	-2.82	2.99	2.80	2.88	-6.75	0.96	0.08	6.10	4.95	6.79
	16-Feb	0.00	-3.33	-2.00	-3.09	3.00	-4.00	3.52	8.97	5.03	7.48
	08-Mar	-10.71	1.92	-2.17	-3.37	2.97	-1.05	-9.64	-10.56	-5.79	-9.66
	28-Mar	-2.08	-2.22	-3.30	-2.27	4.80	3.48	-4.68	-7.76	-3.08	-7.54

3.1.4: Cotton

The model calibration process provided a set of genetic coefficients (GCs), those were estimated for all cultivars tested. Cotton phenology and development parameters were calibrated first while growth (LAI, TDM temporal changes) followed by yield-related attributes. Longer growing season cv. MNH-886 took more photo thermal days (PTDs) from planting to boll maturity (BM) and contributed higher growth and SCY than others, while CIM-496 took 7 less photo thermal days being a short duration cultivar as compared with MNH-886. The reproductive duration of cultivars (flowering to boll maturity) ranged from 70–72 PTDs (Table 11). Default cotton GCs related to leaf growth, maximum leaf photosynthesis rate (LFMAX) affect photosynthesis in the leaf as well as carbon assimilation. Therefore, a broad range of these GCs were tested, to improve simulation. Since it affects many parameters including LAI, canopy growth and evapotranspiration (ET), LFMAX was adjusted to 1.47, 1.42 and 1.11 (mg CO_2 m^{-2} s^{-1}) for MNH-886, CIM-496 and FH-142 respectively (Table 12). The model simulations for major phenological events from planting to flowering and boll maturity revealed good predictions for all cultivars irrespective of the sowing windows. The model slightly under-estimated both number of days to flowering and boll maturity for early planting windows and over-estimated those for later planting windows. Model simulations between observed and simulated number of days to flowering and boll maturity of all studied treatments revealed a good performance with close agreement as shown in Table 12. Model evaluation results also indicated that performance model was good in simulating the boll maturity with % error ranged from 0 to 7 days (Table 13). Biomass was also very well simulated for the cultivars CIM-496, FH-142 and and NIAB-886, with % error ranged from 0.17 to 6.96 as shown in Table 12. However, in model evaluation the % error ranged from 3.30 to 14% (Table 13). Model capability for SCY simulations was very good overall, with lower values o % error which ranged from 0.97 to 2.13 for cultivars CIM-496, FH-142 and NIAB-886. Simulated SCY matched with observed values better than previous studies, reflecting a good calibration of yield related GCs (WTPSD and THRESH). More field observations were available, allowing for a more robust calibration. Final boll dry weight at harvest was best predicted for cultivar FH-142 with % error of 0.97. Generally, the model predicted well for CIM-496 and NIAB-886 cultivars at harvest with lower 5 errors with all planting dates during both growing years (Table 12, 13). Model simulated well to leaf area index with % error ranged from 1.16 to 16% difference for all cultivar (Table 12). These results confirm that the CSM-CROPGRO-Cotton model has the ability to simulate the phenological events, growth (LAI and TDM) and yield attributes of cultivars planted at various dates under arid to semi-arid climatic conditions. CSM-CROPGRO-Cotton model was well parametrized using a high-quality data set of field trials and estimated genetic coefficients (GCs) of cultivars simulated phenology, growth, seed cotton yield, yield components very well, with reasonably good statistical indices.

Table 11: Genetic coefficients results of cultivars adjusted during CSM-CROPGRO-Cotton model calibration

Cultivars	PL-EM	EM-FL	FL-SH	FL-SD	SD-PM	FL-LF	LFMAX	SLAVR	SIZLF	XFRT	SFDUR
CIM-496	5	44	13	20	51	71	1.42	138	264	0.63	35
FH-142	5	42	13	17	53	70	1.11	141	290	0.64	33
MNH-886	5	45	12	23	49	70	1.47	136	280	0.61	34

CSDL= Critical Short-Day Length under which reproductive growth progress with no day duration cause (for short day plants) (hour)
PPSEN= Slope of the comparative reaction of growth to photoperiod by (positive for short-day plants) (1/hour)
EM-FL= Time among plant appearance and flower emergence (R1) (photothermal days)
FL-SH= Time among first flower and first pod (R3) (photothermal days)
FL-SD= Time among first flower and first seed (R5) (photothermal days)
SD-PM= Time among first seed (R5) and physiological maturity (R7) (photothermal days)
FL-LF= Time among first flower (R1) and end of leaf extension (photothermal days)
LFMAX= greatest leaf photosynthesis speed at 30 C, 350 vpm CO_2
SLAVR= precise leaf area of cultivar under average growth situation (cm^2/g)
SIZLF= Maximum size of full leaf (three leaflets) (cm^2)
XFRT= Maximum division of daily development that is partitioned to seed + shell
WTPSD= Maximum weight per seed (g) S
SFDUR= Seed filling interval for pod cohort at standard growth situation (photothermal days)
SDPDV= standard seed per pod under standard growing situation (#/pod)
PODUR= Time required for cultivar to reach final pod load under optimal conditions (photo thermal days)
THRSH= Threshing percentage. The maximum ratio of (seed/(seed+shell)) at maturity. Causes seeds to stop growing as their dry weight increases until the shells are filled in a cohort.

Table 12: Comparison of observed and simulated variables related to phenology, growth and cotton seed yield and yield components during model calibration. (20 April 2012)

Parameters	CIM-496			FH-142			MNH-886		
	Obs.	Sim.	%Error	Obs.	Sim.	%Error	Obs.	Sim.	%Error
Days to Anthesis	58	58	0	60	60	0	62	62	0
Days to Maturity	149	149	0	154	155	0.64	158	158	0
LAI	4.3	4.25	-1.16	4.64	4.49	-3.23	5.2	6.05	16.34
Cotton Seed Yield (kg ha^{-1})	3979	4064	2.13	4287	4329	0.97	4545	4635	1.98
Biological yield (kg ha^{-1})	12066	12907	6.96	13200	13626	3.22	14097	14121	0.17

Table 13: Model evaluation of simulated and observed anthesis, maturity days, leaf area index, cotton seed yield (kg ha^{-1}) and maturity yield (kg ha^{-1}) for CIM-496, FH-142 and MNH-886 during 2012-2013

Hybrids Name	Sowing Dates	Days to anthesis		Days to Maturity		LAI		Cotton seed Yield		Biological Yield	
		2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
		% Error	% Error	% Error	% Error	% Error	% Error	% Error	% Error	% Error	% Error
CIM-496	20-April	1.72	-	7.09	-	4.71	-	16.82	-	11.78	-
	10-May	1.72	0.02	7.14	0.67	9.33	3.50	14.67	7.56	9.46	10.55
	01 June	3.57	0.00	0.00	0.00	4.57	0.27	55.91	7.14	21.75	6.64
	20 June	3.64	0.00	14.48	0.00	1.60	0.32	29.61	24.82	14.31	10.97
FH-142	20-April	1.64	-	0.00	-	6.79	-	4.92	-	8.04	-
	10-May	1.67	0.02	0.00	0.00	5.92	5.16	6.37	6.17	8.82	3.83
	01 June	1.69	0.00	0.00	0.00	0.73	4.17	53.33	0.33	21.62	3.30
	20 June	7.27	0.02	0.65	0.68	1.52	1.15	30.06	24.69	15.60	5.91
MNH-886	20-April	0.00	-	0.00	-	36.61	-	2.02	-	5.20	-
	10-May	5.00	0.03	1.38	0.00	27.95	15.58	1.97	5.90	3.54	3.83
	01 June	6.78	0.00	1.38	0.65	11.64	18.85	53.33	12.85	18.93	3.30
	20 June	1.67	0.02	0.65	0.62	2.61	14.60	0.00	29.95	10.07	5.91

3.2: Climate Change Impact assessment

3.2.1. Wheat

Climate change impacts on wheat showed a less reduction in wheat yield in future. Higher reduction was found in south as compared to central Punjab. Bahawalpur and Multan districts showed a reduction in yield of 4.5% and 2.40%, respectively. Lahore and Sargodha showed and decrease of average wheat yield of 2.8 and 1.65%, respectively. However, north areas of Punjab like Sialkot showed a positive impact of climate change on wheat yield. Wheat yield would increase by 13% in north areas of Punjab due to climate change. The reason for lower yield in south and central Punjab is due to relatively high temperatures and less rainfall, while increase in yield in northern area is due to less increase in temperature and more rainfall lead to increase in yield. Year variability of simulation is given in figure 3, which showed the comparison of grain yield with baseline and future climate scenarios

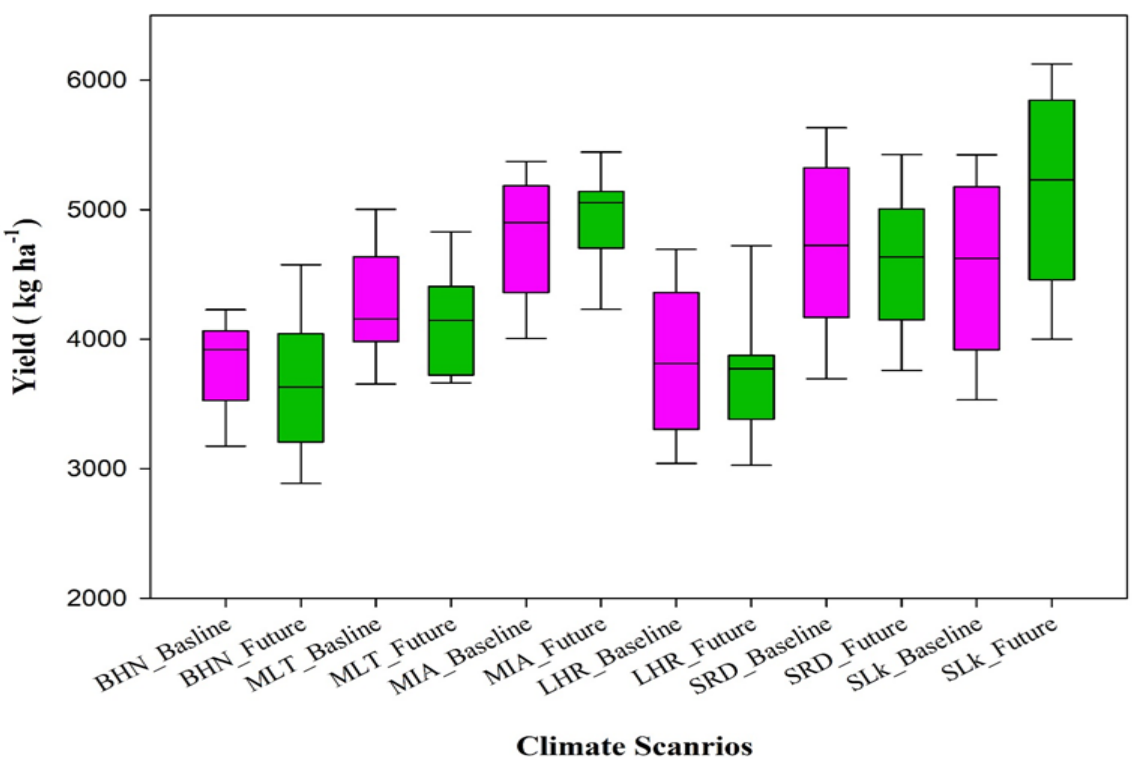


Figure 3: Simulated yield of baseline and future of sites under study for wheat

Table 14: % Change in Yield of wheat from baseline (2006-2015) to future (2106-2115) in different districts of Punjab Pakistan

Years	Bahawalnagar	Multan	Mianwali	Lahore	Sargodha	Sialkot
1	-19.97	-9.00	-14.83	9.76	-17.18	13.52
2	-18.71	-5.60	6.73	-9.41	-3.05	13.26
3	1.67	-13.37	-0.71	-18.47	-12.68	12.97
4	1.94	2.09	16.03	3.18	15.53	13.73
5	-11.75	-15.94	6.87	-23.93	-12.30	12.49
6	18.16	17.14	-7.06	2.54	-0.56	13.84
7	-10.94	2.87	2.44	-3.07	1.58	13.08
8	11.13	-3.60	5.69	11.72	-0.76	13.01
9	-12.32	4.26	22.48	3.21	15.66	12.19
10	-4.75	-2.86	2.80	-3.62	-2.78	12.76
Mean	**-4.55**	**-2.40**	**4.05**	**-2.81**	**-1.65**	**13.08**

3.2.2: Rice

Impact of climate change on Rice is presented in Table 14. Huge reduction in rice yield was observed in south Punjab. District Bahawalpur showed an average 17% reduction in rice yield, however, in few years 26% reduction was also found. Rice yield would reduce by 6.3% in Multan and 18% in Mianwali. Less yield losses were observed in central Punjab like in Lahore 3% reduction was observed, while in north Punjab positive impacts of climate change were observed. Rice yield would increase by 5.3% in Sialkot. The reason could be due to less increase in temperatures and more rainfall north as compare to central and south Punjab. Year variability was shown in figure 4. Baseline simulated yield were higher then the future, except in Sialkot at which future yield was higher then baseline.

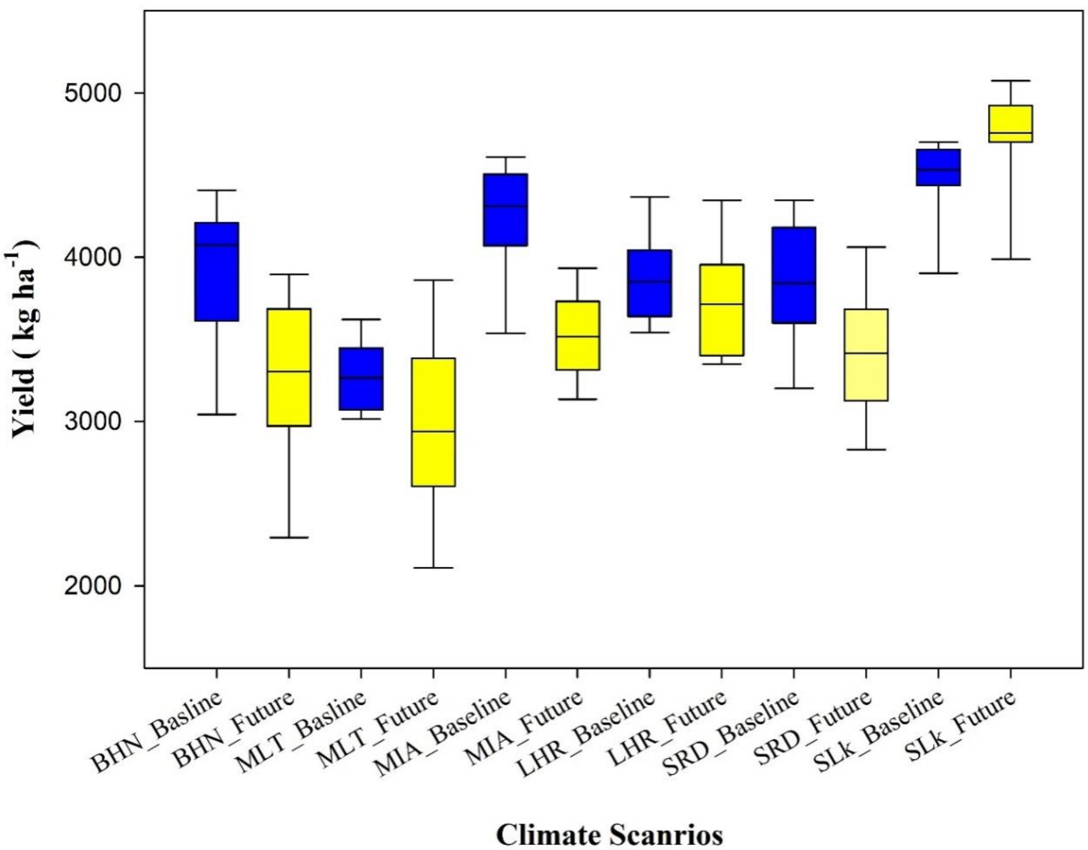


Figure 4: Simulated yield of baseline and future of sites under study for Rice

Table 15: % Change in Yield of Rice from baseline (2006-2015) to future (2106-2115) in ^different districts of Punjab Pakistan

Years	Bahawalnagar	Multan	Mianwali	Lahore	Sargodha	Sialkot
1	-15.91	-4.64	-9.33	-0.50	9.04	1.58
2	-19.28	-6.61	-14.07	-4.71	-16.91	8.20
3	-11.53	-21.93	-15.21	-0.66	4.79	5.10
4	-20.56	13.23	-23.69	-4.99	-9.55	5.37
5	-11.47	-14.19	-17.29	0.54	-12.43	5.59
6	-26.23	-6.85	-30.12	-0.39	-24.25	5.05
7	-25.39	-9.94	-22.12	-13.43	-6.06	6.76
8	-11.70	-2.98	-15.57	-2.61	-4.79	4.93
9	-12.74	-5.33	-18.40	-8.55	-32.36	8.06
10	-17.44	-4.35	-17.20	-1.01	-9.78	3.21
Mean	-17.22	-6.36	-18.30	-3.63	-10.23	5.38

3.2.3: Maize

Climate change impacts on maize are showed in Table 16. Less reduction in maize yield was found in Punjab. However, few districts such as Multan and Mianwali showed higher yield losses. Few of districts in south Punjab indicated an increased in yield of maize like in Bahawalpur maize yield would increase by 1.4%, which could be due to suitable soil conditions for maize. Increased in yield was also observed in Sialkot, that could be due to more rainfalls. Overall less reduction in yield of maize due development of maize hybrids. The figure 5 showed variation in maize yield. Huge yield losses were observed in Mianwali. Higher yield of 9000 kg ha^{-1} was recorded in Sialkot district, which could be favorable soil and environmental conditions.

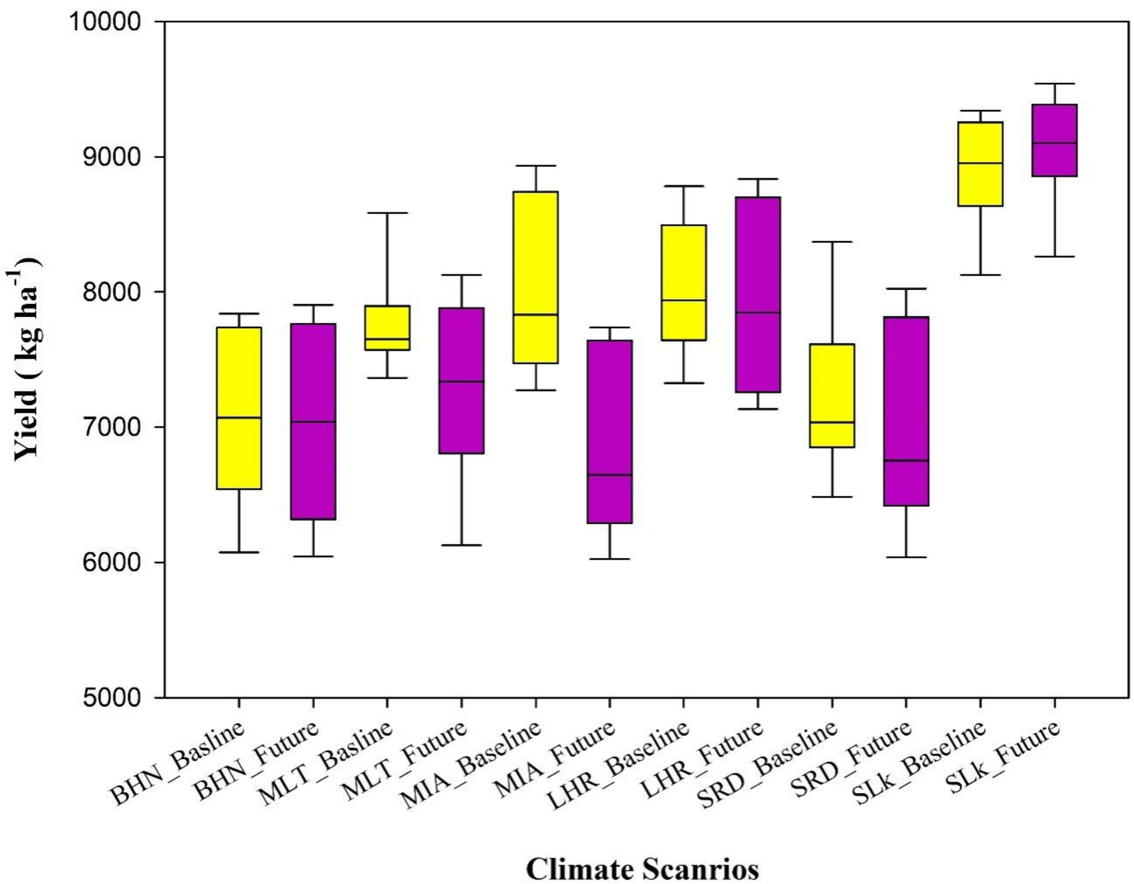


Figure 5: Simulated yield of baseline and future of sites under study for Rice

Table 16: % Change in Yield of Maize from baseline (2006-2015) to future (2106-2115) in different districts of Punjab Pakistan

Years	Bahawalnagar	Multan	Mianwali	Lahore	Sargodha	Sialkot
1	1.32	-8.64	-8.06	-11.52	16.99	5.64
2	-10.18	-1.32	-0.83	-0.99	7.17	1.88
3	-28.08	-7.67	3.96	-4.58	1.85	0.29
4	12.75	-7.77	17.21	11.75	-1.60	2.38
5	29.31	0.71	0.03	15.37	4.28	3.09
6	-40.78	-20.46	-14.35	-35.72	-22.53	2.01
7	-13.39	-9.08	-36.06	-4.46	-8.15	2.05
8	31.44	2.49	-17.90	-15.38	-20.58	5.14
9	35.05	-2.18	-41.22	0.52	3.93	1.60
10	-3.42	-5.88	-12.38	6.07	-2.64	2.70
Mean	**1.40**	**-5.98**	**-10.96**	**-3.89**	**-2.13**	**2.68**

3.2.4: Cotton

Cotton is very sensitive to high temperature. Climate impacts showed huge yield losses in cotton in whole Punjab. Mean yield reduced by 6 to 18% in Punjab (Table 17). Higher reduction in cotton yield was found in south Punjab. In Multan and Bahawalpur cotton yield would reduce by 18% due to increase in 1.2°C mean temperature. Few districts in central Punjab showed less reduction in yield as compared to South Punjab. Sargodha and Lahore districts indicated that cotton yield would be reduced from 7 to 10%, However less reduction in cotton yield was found in north Punjab. The Sialkot district showed a decreased in yield of 6% in future. Higher reduction in cotton yield was due to increase in temperature and less rainfall that lead to shorten the length of growing periods which caused the reduction in yield. The years variation in yield is shown in Figure 5, which indicates that all districts showed decreased in yield, compared with baseline.

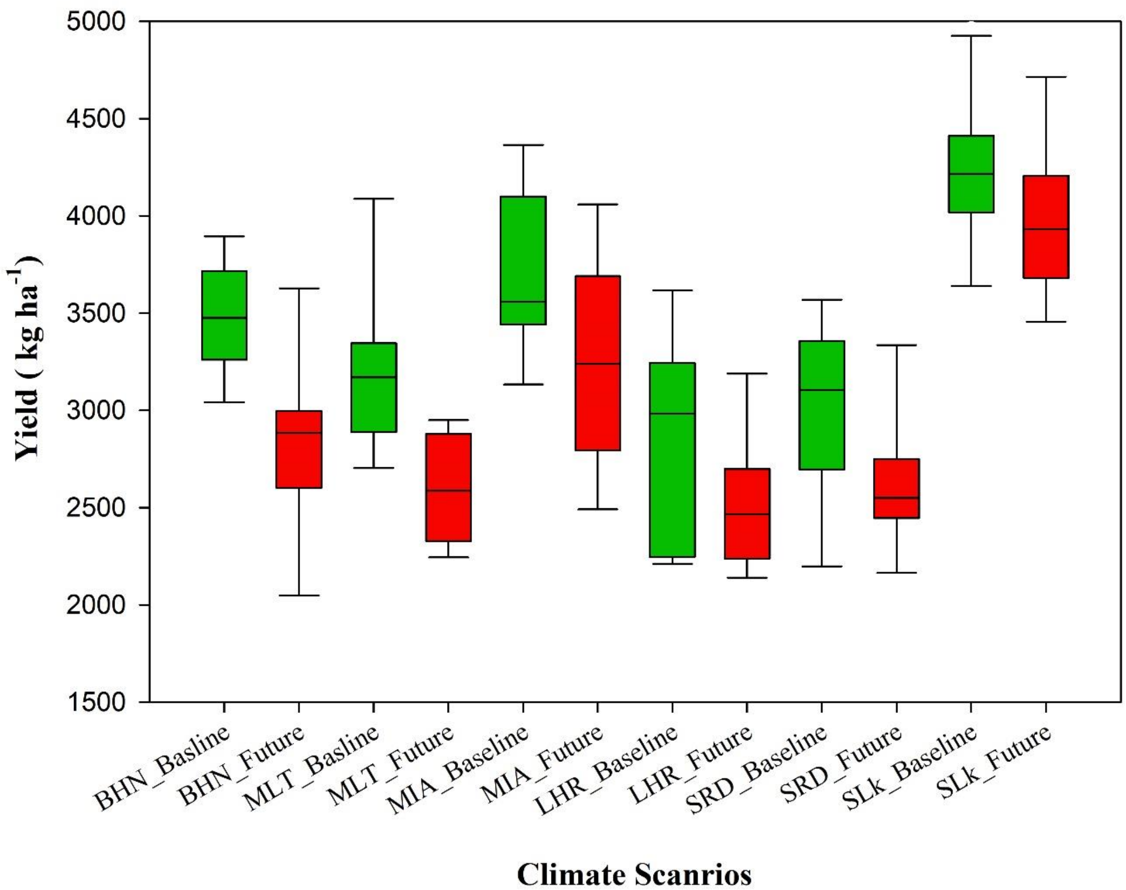


Figure 5: Simulated yield of baseline and future of sites under study for Rice

Table 17: % Change in Yield of Cotton from baseline (2006-2015) to future (2106-2115) in different districts of Punjab Pakistan

Years	Bahawalnagar	Multan	Mianwali	Lahore	Sargodha	Sialkot
1	6.80	-9.01	14.40	46.52	-0.26	-3.40
2	-45.05	-13.16	-26.05	-28.72	-36.05	-4.67
3	-11.94	-10.20	-10.80	22.16	-12.61	-8.77
4	-4.19	-23.26	-3.59	11.04	31.23	-4.66
5	-9.04	-36.41	-14.23	-36.35	-22.40	-8.09
6	-11.67	-23.56	-21.41	-0.47	5.24	-5.71
7	-25.91	-19.68	-2.09	-31.94	-21.08	-8.07
8	-29.34	-12.66	-11.23	-21.43	-8.68	-9.15
9	-31.03	-11.21	-32.86	-26.05	-29.04	-3.88
10	-17.75	-20.86	-12.12	-11.39	-11.88	-5.95
Mean	-17.91	-18.00	-12.00	-7.66	-10.55	-6.23

4: Conclusion

Future projections showed that maximum temperature of 1.01°C to 1.46°C and minimum temperature of 1.17°C to 1.43°C would increase in future (2115-2116) under HAPPI scenarios. Precipitation pattern also showed an increasing trend in central and south Punjab, while in Sialkot district decreasing trend of precipitation was observed. Climate change results showed that a huge reduction rice and cotton yield in Punjab as compared to Wheat and Maize. In north district of Punjab positive impacts of climate change were observed for wheat, rice and maize. Study results showed that with rise in temperature in future wheat yield of 1 to 4%, Rice 3 to 17%, Maize 2 to 10% and cotton yield of 6 to 18% would be reduced in Punjab Pakistan. In future there is dire need to work on adaptation measures to mitigate the negative impacts of climate change.

5: Reference

Ahmad, S. G. Abbas M. Ahmed Z. Fatima M.A. Anjum G. Rasul M.A. Khan and G. Hoogenboom. 2019. Climate warming and management impact on the change of phenology of the rice-wheat cropping system in Punjab, Pakistan. F. Crop. Res. 230: 46–61.

Ahmad, A. M. Ashfaq G. Rasul S.A. Wajid T. Khaliq F. Rasul U. Saeed M.H. ur Rahman J. Hussain and I.A. Baig. 2015. Impact of climate change on the rice–wheat cropping system of Pakistan. p. 219–258. *In* Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP). C. Rosenzweig, and D. Hillel, Eds., ICP Series on Climate Change Impacts, Adaptation, and Mitigation. Imperial College Press, London.

Ahmed, I. M.H. ur Rahman S. Ahmed J. Hussain A. Ullah and J. Judge. 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.

Amouzou, K.A. J.B. Naab J.P.A. Lamers C. Borgemeister M. Becker and P.L.G. Vlek. 2018. CROPGRO-Cotton model for determining climate change impacts on yield, water-and N-use efficiencies of cotton in the Dry Savanna of West Africa. Agric. Syst. 165: 85–96.

Boote, K.J. L.H. Allen Jr P.V.V. Prasad and J.W. Jones. 2011. Testing effects of climate change in crop models. p. 109–129. *In* Handbook of climate change and agroecosystems: Impacts, adaptation, and mitigation. World Scientific.

Challinor, A.J. J. Watson D.B. Lobell S.M. Howden D.R. Smith and N. Chhetri. 2014. A meta-analysis of crop yield under climate change and adaptation. Nat. Clim. Chang. 4: 287.

Downing, T.E. 2013. Climate change and world food security. Springer Science & Business Media, University of Oxford, Oxford, U.K.

Fujimori, S. T. Hasegawa J. Rogelj X. Su P. Havlik V. Krey K. Takahashi and K. Riahi. 2018. Inclusive climate change mitigation and food security policy under 1.5° C climate goal. Environ. Res. Lett. 13: 74033.

Godfray, H.C.J. J.R. Beddington I.R. Crute L. Haddad D. Lawrence J.F. Muir J. Pretty S. Robinson S.M. Thomas and C. Toulmin. 2010. Food security: the challenge of feeding 9 billion people. Science (80-.). 327: 812–818.

Hoogenboom, G. J.W. Jones P.W. Wilkens C.H. Porter K.J. Boote and L.A. Hunt. 2015. Decision Support System For Agrotechnology Transfer (DSSAT). Version 4.6. DSSAT Foundation, Prosser, WA.

Hoogenboom, G. C.H. Porter V. Shelia K.J. Boote U. Singh J.W. White L.A. Hunt R. Ogoshi J.I. Lizaso J. Koo S. Asseng A. Singels L.P. Moreno and J.W. Jones. 2016. Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.7 (https://DSSAT.net). DSSAT Foundation, Gainesville, Florida, USA.

Hunt, L.A. S. Pararajasingham J.W. Jones G. Hoogenboom D.T. Imamura and R.M. Ogoshi.

1993. GENCALC: software to facilitate the use of crop models for analyzing field experiments. Agron. J. 85: 1090–1094.

IPCC. 2013. Climate Change 2013: The physical science basis. working group I contribution to the IPCC 5th assessment report—changes to the underlying scientific/technical assessment.

Jones, J.W. G. Hoogenboom C.H. Porter K.J. Boote W.D. Batchelor L.A. Hunt P.W. Wilkens U. Singh A.J. Gijsman and J.T. Ritchie. 2003. The DSSAT cropping system model. Eur. J. Agron. 18: 235–265.

Jones, C.A. J.R. Kiniry and P.T. Dyke. 1986. CERES-Maize: A simulation model of maize growth and development. Texas A& M University Press.

Kang, Y. S. Khan and X. Ma. 2009. Climate change impacts on crop yield, crop water productivity and food security–A review. Prog. Nat. Sci. 19: 1665–1674.

Lobell, D.B. and M.B. Burke. 2008. Why are agricultural impacts of climate change so uncertain? The importance of temperature relative to precipitation. Environ. Res. Lett. 3: 34007.

Mitchell, D. K. AchutaRao M. Allen I. Bethke U. Beyerle A. Ciavarella P.M. Forster J. Fuglestvedt N. Gillett and K. Haustein. 2017. Half a degree additional warming, prognosis and projected impacts (HAPPI): background and experimental design. Geosci. Model Dev. 10: 571–583.

Rahman, M.H. A. Ahmad X. Wang A. Wajid W. Nasim M. Hussain B. Ahmad I. Ahmad Z. Ali and W. Ishaque. 2018a. Multi-model projections of future climate and climate change impacts uncertainty assessment for cotton production in Pakistan. Agric. For. Meteorol. 253: 94–113.

Rahman, M.H. ur A. Ahmad X. Wang A. Wajid W. Nasim M. Hussain B. Ahmad I. Ahmad Z. Ali W. Ishaque M. Awais V. Shelia S. Ahmad S. Fahd M. Alam H. Ullah and G. Hoogenboom. 2018b. Multi-model projections of future climate and climate change impacts uncertainty assessment for cotton production in Pakistan. Agric. For. Meteorol. 253–254: 94–113Available at http://linkinghub.elsevier.com/retrieve/pii/S0168192318300455.

Rosenzweig, C. A.C. Ruane J. Antle J. Elliott M. Ashfaq A.A. Chatta F. Ewert C. Folberth I. Hathie and P. Havlik. 2018. Coordinating AgMIP data and models across global and regional scales for 1.5 C and 2.0 C assessments. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 376: 20160455.

Ruane, A.C. J. Antle J. Elliott C. Folberth G. Hoogenboom D.M.-D. Croz C. Müller C. Porter M.M. Phillips and R.M. Raymundo. 2018. Biophysical and economic implications for agriculture of+ 1.5° and+ 2.0° C global warming using AgMIP Coordinated Global and Regional Assessments. Clim. Res. 76: 17–39.

UNFCCC. 2015. Draft decision CP 21. http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf.

Willmott, C.J. 1981. On the validation of models. Phys. Geogr. 2: 184–194.

Willmott, C.J. S.M. Robeson and K. Matsuura. 2012. A refined index of model performance. Int. J. Climatol. 32: 2088–2094.