Assessment of Climate Change Impact on Yield and Crop Water Productivity of Wheat in Faisalabad, using DSSAT-Wheat Model

By

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Institute of Geographical Information Systems
School of Civil and Environmental Engineering
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Thesis Acceptance Certificate

Certificate

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Dedication

To
My Parents

Thanks for their love, care and motivation all the way since the start of my studies, and also to all those who encouraged me and prayed for me for the completion of this thesis.

ACKNOWLEDGMENTS

All praises to Allah, the Almighty, who is perfect in all of His creations, who has given us the gift of wisdom and enabled us to complete our tasks successfully, and on whom we ultimately depend for sustenance and guidance; blessings upon Prophet Muhammad (peace be upon him) for leading us in the right direction. I owe my sincere gratitude and pleasure to my esteemed research supervisor, Dr. Muhammad Azmat, for his devoted guidance and motivating attitude during the time of research. I'm also thankful to all of the members of my instruction and review committees for their collaboration and constructive criticism, which helped me gain a deeper understanding of research and successful accomplishment of its objectives. Without the sincere cooperation and constant encouragement of IGIS NUST, which assisted me in all of my activities, this research would not have been possible. It gives me great pleasure to thank all of my sincere friends, colleagues, and family members, particularly my parents, for their sincere attitude, encouragement, patience, and prayers, which motivated me to complete my tasks successfully at every turn.

Muhammad Talha Yaqoob

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List of Abbreviations

NDVI	Normalized Difference Vegetation Index
LAI	Leaf Area Index
RCP	Representative Concentration Pathways
CWP	Crop Water Productivity
CORDEX	Coordinated Regional Climate downscaling Experiment (CORDEX)
GCM	Global Climate Model
RCM	Regional Climate Model
GDD	Growing Degree Days
ETc	Evapotranspiration

ABSTRACT

Wheat crop is one of the most significant crops in Pakistan to fulfill food requirements, however slight change in temperature and precipitation pattern can change reduce the yield and cropping pattern of the wheat crop. Moreover, according to International Monetary fund (IMF), Pakistan is third among the nation facing severe water shortage, which if not catered properly, will severely affect the agriculture of the country. Therefore, the objective of the study was to calibrate and validate well known DSSAT crop model for wheat yield and crop water productivity and evaluate the impact of climate change on wheat and crop water productivity under changing climate projections using CORDEX-SA-RCMs data for RCP4.5 and 8.5. Furthermore, the wheat crop model was calibrated and validated for crop phenology including (Biomass, yield and Leaf area index) and two cultivars namely (Faisalabad-2008 and Sehar-2006). The experiment data at different nitrogen level was obtained from Ayub Agriculture Research Institute, Faisalabad. After calibration and validation of the model present climate data was replaced with the CORDEX-SA RCM-projections for climate change impact analysis. A significant rise and declining tendencies were observed in temperature and precipitation patterns, respectively, for particular study area. Therefore, substantial impact of climate change on wheat phenology (anthesis day, maturity day) growing degree days, biomass (kg/ha), yield (kg/ha) and crop water productivity (kg/ha) was observed under scenario periods for RCP4.5 and 8.5 at different nitrogen levels. Generally, it was detected that changes in crop phenology had a stronger impact in terms of crop yield for RCP4.5 and far drastic in RCP8.5 and this change in yield also indicates that decline in crop water productivity under both RCP4.5 and 8.5.

CHAPTER 1

INTRODUCTION

1.1 Wheat

Wheat the second-most-common crop in the world, after rice (FAO, 2021) and in addition to the rising need for high nutrient for a good nutrition, the growth of this segment is expected to increase by 2050 (UN, 2020). Wheat is one of the earliest cultivated crop and it is a major diet component of living organisms It is adapted to extensive variety of environmental circumstances and is the best of cereals foods providing more nourishment to human being. Due to its greater agronomic flexibility, ease of food storage, and the ability to turn grain into flour to make nutritious, palatable, and healthier food, wheat is farmed on a huge scale (Aslam et al, 2018).

Pakistan's main food grain is wheat whereas wheat is the most significant crop and main source food for the peoples of Pakistan (PARC, 2016). 9.1 % of the value-added products comes from wheat in farming and 1.7 percent of Pakistan's Gross Domestic Product. Its significance is obvious because it makes up 60 percent of the average Pakistani person's daily intake. In Pakistan, the average annually per capita wheat utilization is 120 kilograms. Pakistan has made outstanding strides in the wheat industry ever since Agricultural Revolution and by help of the Pakistan Agricultural Research Council's initiatives (PARC), and by the intergovernmental research center on wheat support, The government of Pakistan was the emerging nation in Southeast Asian countries to attain wheat sufficiency (USAID, 2007). Due to negligence of the concerned authorities and change in climate of Pakistan it is having an adverse impact on agriculture production of the country and it can be observed as according to (Finance Division, 2019) a total of 8,734 thousand hectares of wheat were planted in 2017–18, a decline of 2.6 % in contrast to

8,972 thousand hectares in the same cropping period . In 2017, there were 25.492 million tonnes of wheat cultivated 4.4 percentage fewer than the 26.674 million tonnes of output from the preceding year. The position over the last five years is given in Figure 1.

1.2 Irrigation

Groundwater irrigation is essential for growing agricultural output and rural people' standard of living, globally. For instance, since 1950, the area in South Asia with irrigation facilities has tripled. The three countries with the highest annual groundwater extraction rates in South Asia are India, Pakistan, and Bangladesh (India = 230 bm^3; Pakistan = 60 bm^3; Bangladesh = 30 bm^3) moreover, farming practices consists further than 85% of the total, compared to 40% elsewhere in the world. These three nations use groundwater to irrigates 48 million ha (mha), or 42 percent of the world's groundwater-fed crops. (Qureshi, 2020). Approximately, 22 mha, or 27 percent of the total land area, are available for agriculture while 6 mha of land is rain-fed and about 16 mha are irrigated. More than 90% of the total agricultural and livestock production is produced in the irrigated area(Asghar et al., 2018). As it can be observed that Actual rainfall throughout the monsoon season (July to September) in 2017 was 22.8 percent lower than the expected 140.9 mm. The actual rainfall in the post-monsoon season of 2017 (October to December) maintained 26.5 millimeter, or 39.0 %, under the average precipitation where else, the observed rainfall from January to March of 2018 was 56.7% less than the season's normal of 74.3 millimeter. Table 1. shows the total amount of precipitation that was measured throughout the monsoon, post-monsoon, and winter.

1.3 Food Security and Climate Change

The developing countries are facing an acute shortage of food. According to UN’s FAO: ‘when everyone has constant availability of sufficient food in terms of the physical, social and

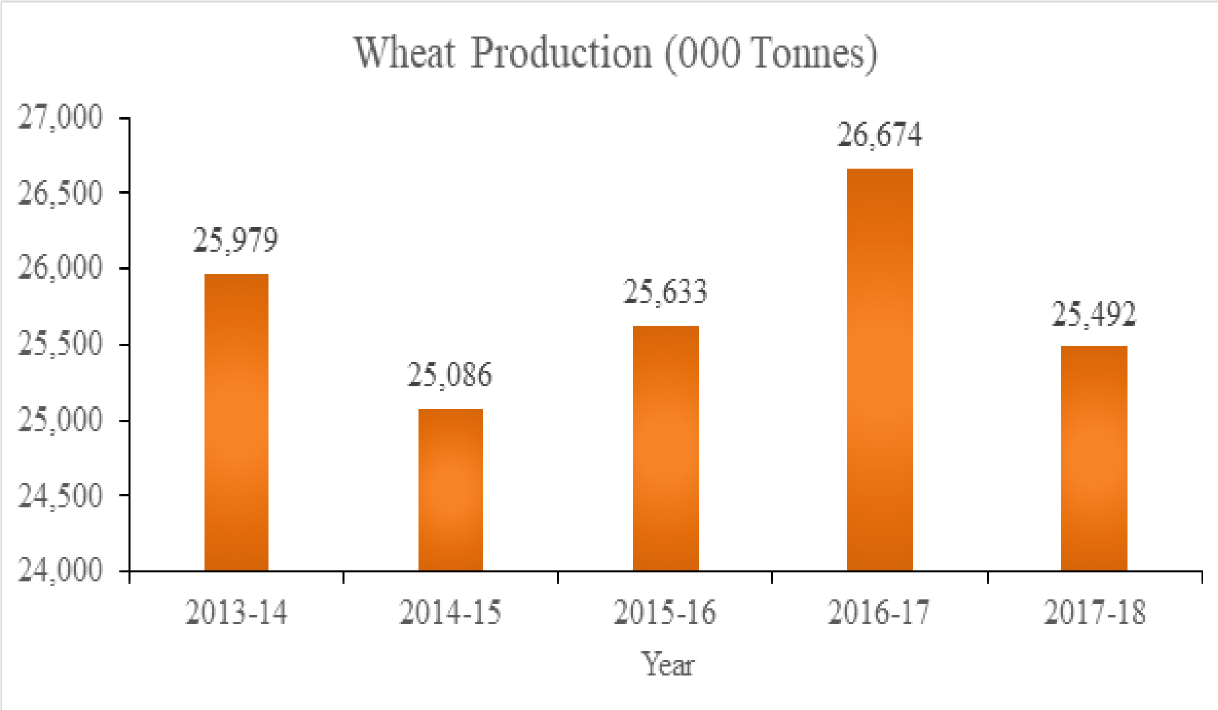

Figure 1.Total area, production and wheat yield production for 5 years (2013-18).

Table 1. Rainfall recorded during 2017-2018.

	Monsoon Rainfall (Jul-Sep) 2017	Post Monsson Rainfall (Oct-Dec) 2017	Winter Rainfall (Jan-Mar) 2018
Normal**	140.9	26.4	74.3
Actual	108.8	16.1	32.2
Shortage(-)/excess(+)	-32.1	-10.3	-42.1
% Shortage(-)/excess(+)	-22.8	-39	-56.7
**: Long Period Average (1961-2010)			

Source: (Finance Division, 2019)

socio - economic factors, for a suitable way of living, they need nutritious foods that are both healthy and wholesome. In the other terms, food needs to be both easily accessible and nutritious.

Overall, 60 percent of the world's population, or more than 12.4 million people, experienced food insecurity in 2020, up 5.4 million from the previous year, according to the World Food Programme (WFP). development of nutrition and agricultural commodities are affected by global warming in several different ways. Agricultural conditions can directly influence how much food is generated, while indirect effects on income development and distribution have an impact on demand for agricultural products. Additionally, variations in temperature and precipitation brought on by continued release of greenhouse gases might change the suitability of the soil and crop production. The IPCC Assessment on climate change's special report on radiative forcing examines four families of socioeconomic development and related emission scenarios (Rivera et al., 2017). Additionally, relevant to this assessment, the SRES scenarios A1 and B1 correspond to the highest and lowest emissions, respectively, under the "business as usual scenario". Between these two are the other possible outcomes. According to the United Nations' (UN) strong projection, SRES A2 considers the four scenarios with the greatest expected population growth, it has implications for farming and the distribution of food around the planet. Considering the business - as - usual climate projections and climate models, the world's average temperature rise is predicted to increase by 1.8 degrees Celsius (with a range spanning 1.1 degree Celsius to 2.9 degrees Celsius for SRES B1) to 4.0 by 2100 (Solomon, S. et al., 2007). In addition, climate projections indicate reduced soil moisture levels and higher evapotranspiration in drier regions (Rivera et al., 2017; Solomon, S. et al., 2007). Resultantly, some cultivated areas could no longer be viable for growing crops, while some tropical grasslands might grow drier. Additionally, as temperatures rise, the ability of a wider range of agricultural insects to endure the wintertime and damage springtime harvests. If environmental oscillations grow harsher and widespread, extreme weather events are the main factors in narrow alterations in food production in semi-arid and spatial units also get worse and happen more frequently. Famines can significantly lower food yields, animal numbers, and productivity in semi-arid regions. (Thornes, 2002).

In 2021, the state of food security has gotten progressively worse(Supply et al., 2022). According to (Clark et al., 2003) as a matter of fact that increase in world mean temperature is only 1.5°C, the climate emergency, which is also a humanitarian disaster, is expected to worsen significantly. In all scenarios, there will be a worldwide food crisis brought on by climate change, biodiversity loss, an increase in climate patterns, and decreasing total growing seasons. Disease and starvation will increase, and freshwater availability will worsen. Additionally, world agriculture is becoming more and more weakened by it because of climate change impacts yields, harvests, plus nutrition. Due to the expanding income and poverty inequality in the global South, these consequences are particularly prominent there.

Malnutrition will be made worse by climate change since fewer nutrients are available and food is of worse quality. 2.37 billion people would be impacted by lack of food and erratic access to dietary needs in 2020, with women more likely than men to experience food insecurity in nearly two thirds of countries (Nations, 2018). Due to gendered property ownership regulations and their limited ability to make decisions, many women struggle to diversify their sources of income, manage their own properties, and use government programs or services that may favor men (Byrnes, 2011). Additionally, the amount and value of yields, reproduction, growth rates, and swelling climate related issues and livestock mortality will all be impacted by climate change (Thornton et al., 2015) in addition to feed quality, pests, ruminant health, and zoonotic illnesses (Izaurralde e t al., 2011). The accessibility of irrigation water for livestock will decrease because of amplified overflow and diminished underground water means. The volume of water in valleys and the outflow of waterways would change as the planet warms, causing water stress in human and livestock populations, particularly in the parched localities for example. Africa and Asia. Methane production is increased by rising temperatures. At 2°C, a 7–10% global drop in livestock is anticipated, along with financial damages of between US dollar 9.8 and US dollar 12.7 billion (Boone et al., 2018).

They are crucial for supplying the world's protein requirement and are crucial to the food security of many fragile, least developed nations (Mcclanahan et al., 2015). Fisheries and hatching grounds are being impacted by changing temperature, change in acidic level of ocean, imported and invading organisms, disease, and parasites. In addition to the risk posed by storm intensity and rising sea levels, crucial ecosystems like coral reefs, seagrass, and mangroves are degrading quickly (Weatherdon et al., 2016). These changes have caused several artisanal fisheries to operate much underneath the ecological collection thresholds required to maintain the availability of these assets for usage as a source of food.

1.4 Food Prices

Food prices are increasing day by day and will continue to do so as climate change's consequences become more pronounced. There will be other rising pressures on production costs in addition to the direct effects of climate change, including greater demand for finite resources, modifications to tax and subsidy policies, and changes in the availability and pricing of fossil fuels. The global transition to a more resource extraction, diet dependent on livestock would put more pressure on price increases (Clark et al., 2003)

Climate change is frequently referred to as a threat multiplier because it affects current issues. Global economic and commercial networks are impacted by the interrelated effects of famines, storms, and floods as they become more frequent. For instance, the values of the several major transacted food crops. Wheat is produced in major states and are vulnerable to failures occurring at the same time. There are signs that this led to rise in food price and, maybe, skirmishes when it has happened in the past. As an illustration, wheat crops were destroyed by famines and heat waves in the Ukraine and Russia in 2007 and 2009, which sharply increased wheat prices worldwide (Trostle et al., 2011). These breadbaskets may see more water stress due to climate change, which will put more strain on the food chain and pricing (UNDP, 2021). As seen with Covid-19, individuals who can least afford food are frequently the ones affected when increase in price occurs.

Increases in food values have a special impact on communities with lower and moderate socioeconomic status, which are primarily made up of women and children. At least 70 percent of individuals who are underdeveloped live in rural regions and depend on smallholder farming for their daily needs. Due to the necessity to purchase less nutrient-dense but more adaptable crops as a result of limited purchasing power for food and seeds, there are difficulties with food insecurity (OXFAM, 2019). Children in nations where food prices have risen are likewise more at risk of malnutrition. A major chunk of starving children in world lived in India in 2015. Moreover, the world is facing food crises as food is not able to reach places and there is increase in disparity among the nations with respect to food availability as food costs increased, wasting (28 percent) and overall malnutrition increased significantly (Vellakkal et al., 2015). A whole picture of the global production of the different crops and area been cultivated is given in Table 2.

Table 2. Area, Production and Yield of some major crops in the main growing countries.

AREA, PRODUCTION AND YIELD OF SOME MAJOR CROPS IN THE MAIN GROWING COUNTRIES									
Countries	Area (000 Hectares)			Production (000 Tonnes)			Yield (kgs per hect.)		
	2015	2016	2017	2015	2016	2017	2015	2016	2017
China	24698	24510	24269	133277	134341	131447	5396	5481	5416
India	30420	30790	29580	92290	98510	99700	3034	3199	3371
Russia	27313	27517	26472	73346	86003	72136	2685	3125	2725
United States of America	17745	15198	16028	62832	47380	51287	3541	3118	3200
France	5542	5332	5232	29316	38678	35798	5290	7254	6842
Australia	11282	12191	10919	22275	31819	20941	1974	2610	1918
Canada	8976	8983	9881	32140	29984	31769	3581	3338	3215
Pakistan	9224	8972	8797	25633	26674	25076	2779	2973	2851
Ukraine	6206	6377	6620	26099	26209	24653	4205	4110	3724
Germany	3202	3203	3036	24464	24482	20264	7640	7643	6675
Turkey	7610	7662	7289	20600	21500	20000	2707	2806	2744
Argentina	3953	5566	5822	11315	18395	18518	2862	3305	3181
United Kingdom	1823	1792	1748	14383	14837	13555	7890	8280	7755
Kazakhstan	12373	11912	11354	14985	14803	13944	1211	1243	1228
Iran	5929	6700	6700	14592	14000	14500	2461	2090	2164
Source: (Finance Division, 2019)									

1.5 Climate Change and agriculture sector of Pakistan

There are two harvest seasons in Pakistan, the first known as (Kharif) which runs from April through December. These crops contain rice, sugarcane, cotton, maize. (Rabi) or the next cropping period begins in October and ends with harvest in April. "Rabi" crops include wheat, lentils, and mustard etc. Water must be available when it is needed for Pakistan's agricultural output (Finance Division, 2019; World Food Programme, 2018). Unfortunately, crop output will decline as an outcome of change in temperature. Since agriculture is a sector that is affected by environmental transformation and is one of those who is most susceptible to its consequences. Crop advancement, maturity, and productivity are being impacted by extreme weather events and precipitation fluctuations (Mumtaz et al., 2019). Increased temperatures shorten the time grains may fill before becoming sterile and diminish production. Climate change is prevalent in Pakistan (Azmat et al., 2018) It immediately affects crop production, leading to a shortage of food. In addition, the temperature is rising, making it uncertain how frequently extreme weather events like floods and drought may occur. (Babel et al., 2019) whereas Table 2. represents summary of different crops grown in Pakistan with their production, yield and area cultivated which climatic change will have an influence on in the coming years. There have been complaints of extreme temps throughout the Asia-Pacific region over the past few decades (Preston & Bathols, 2006). When you consider that 38 percent of the world's emissions from agriculture production are produced in south Asia and the Pacific, the agriculture industry in those areas is mainly susceptible. Indonesia, Bhutan, Pakistan, Papua New Guinea, Sri Lanka, Thailand, Uzbekistan, and Vietnam are the maximum susceptible nations in these areas (Asian Development Bank). Table 2 gives an overview of different crops grown in Pakistan in year 2018-19.

1.6 Objectives

The purpose of this study is to evaluate the potential of wheat yield and crop water productivity of the crop. The objectives to be achieved toward this end:

- To calibrate and validate the DSSAT crop model using field experimental data for the current scenario.
- To explore the impact of climate change on the future trend of simulated yield and crop water productivity of wheat.

1.7 Scope of the study

According to Pakistan Bureau of Statistics agriculture contribute 20.9% to GDP of Pakistan and total area irrigated by different sources is 18.63 million acres and the Wheat, rice, sugarcane, cotton, and fodder are the major watered crops. According to FAO, Major crops take up 78 % harvested land and 82 percent of the total amount of water that is available. The same analysis indicates that agriculture will be greatly impacted by changing climate. Possible effects contain exposure of crops to heat stress, variations in productivity, changes in water availability and use. Moreover, the situation is deteriorated by poor water management, lack of vision on national water policy and irrigation system is not up to date and thus this all is contributing to food crisis.

Therefore, the study is focused on evaluating climate change's effects on agriculture water production and output and explore the aspects which will deteriorate existing practices of agriculture. Secondly, as per authors information hardly any study is conducted which incorporates a crop model to determine the irrigation regions' crop water productivity.

CHAPTER 2

LITERATURE REVIEW

LIU et al., (2017) utilized a decision support system for agrotechnology in their investigation incorporating with the CENTURT soil model to analyze the impacts of reduced nitrogen input on wheat (*Triticum aestivum L.*) yield on a long-standing experiment using a rotation of wheat and maize at Beijing, China. The DSSAT-CENTURY model effectively simulated wheat grain yield and grain N content measurements at no application of any treatment whereas, the result showed that nonorganic fertilizer application cannot maintain crop harvest and soil biological carbon levels moreover, the calibration of DSSAT crop model shows a significant part in defining the development of the research.

Sampaio et al., (2020) used crop models to study yield variations in response to change in plant densities using CSM-CROPGRO-Soybean for low latitudes. The crop model simulated phenology and different management scenarios across several locations resulting in satisfactory working of the crop model as minimum plant density suggested is 20 pl per m^2 moreover, different sowing dates and maturity level presented different yield and pattern throughout the local climate. Moreover, Mubeen et al., (2020) conducted experiment to observe the utilization of water by the two crops (Cotton and Wheat) in semi-arid situations of Southern Punjab using DSSAT crop model. Moreover, the model was run under two future CO_2 concentration conditions to simulate anthesis days, maturity days, total dry matter, grain yield, crop yield and crop ET. The DSSAT simulation showed that the cotton cultivar MNH-886 and wheat Cultivar Lassani-2008 are better at utilizing of inadequate water resources under different climate environments.

Zheng et al., (2020) in the study predicted harvest and rainwater assets utilization in 1961-2010 in rice farm areas of China were evaluated by rice model ORYZA2000.Consequently, impact of future climate projections from GCMs under four RCPs emission scenario over yield, water footprint and water productivity was evaluated. Moreover, to compute the water resources utilization the indices for water-footprint (WF) and water-productivity were incorporated for evaluating national agronomic water pressure.

Boonwichai et al., (2018) and Ullah et al., (2019) assessed change in climate situations for (RCP4.5 and RCP8.5) and estimated the impact on future yield and crop water and irrigation water requirement of the crops. Whereas, Boonwichai et al., (2018) used CORDEX global circulation models to evaluate the impact of changing climate. Moreover, Azmat et al., (2021) evaluated the impact of climate change on phenology and yield of winter wheat by using crops models (APSIM and STICS) with integration of CORDEX-SA regional climate models.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study Area

Faisalabad district, historically known as Lyallpur and after the city's founder, is Pakistan's 3 inhabited metropolis after Karachi and Lahore, respectively, and second biggest in Punjab's eastern province. Over time, Faisalabad has transformed into a global city. It is located between 31° 25’0 North and 73° 5’28 East at an elevation of 605 feet above sea level. Further, the city's overall size is 5856 $km^{2.}$ The geographical location of Faisalabad district is shown in Figure 2. Faisalabad's population expanded by 60 percent in 2017, going from 2.0 million to 3.2 million people, according to the 2017 census (Survey, 2018). Faisalabad's GDP was assessed at $43 billion in 2013 and was expected to expand by 5.7 percent to $87 billion in 2025(Government of Punjab, 2021). Further, the overall space of the district is 5856 km^2. Meanwhile, River Ravi meanders around 40 kilometers off the city in the southeast while River Chenab runs for roughly 30 km towards the northwest. Eighty percent of cultivated land's irrigation needs are met by the Lower Chenab Canal, which is the primary source of irrigation water. Additionally, Faisalabad's climate is such that it typically receives 350 millimeters of rainfall per year. It reaches its climax during the monsoon season in July and August, while western thunderstorms throughout the winter months also produce significant rainfall coupled with hailstorm (*Pakistan Climate*, 2021). Faisalabad's soil is composed of alluvial deposits mixed with loess that has calcareous properties, and it is typically fertile. Over 10% of the GDP of Punjab is contributed by Faisalabad, which has an average yearly GDP(nominal) of $20.5 billion whereas, Its defining characteristics are agriculture and industry (Government of Punjab, 2021).

3.2 General Methodological Design

The general methodological design/ methodology of the thesis is as follow: Sec.1 of the study deals with the Crop yield and water productivity crisis prevailing for current and future scenarios due to climate change. Sec.2 critical literature review of previous paper. In Sec. 3 a comprehensive description of the modelling theories has been presented. The finding of the research has been discussed in Sec. 4. While the conclusion has been discussed in Sec. 5. In this research, Mainly, the DSSAT crop model is incorporated to evaluate yield and crop water productivity of Wheat. Secondly, the projected climate data of CORDEX for present, middle, and far century is used to estimate crop water productivity and total grain yield of wheat moreover, also the impact of climate change on crop wheat is observed incorporating the effect on growing degree days which the total number of unit consumed by the crop over the season from sowing to harvesting moreover, long term climate change statistical analysis was also performed on the dataset to observe whether, there is any trend in the dataset involving RCP4.5 and RCP8.5 long term projection. Furthermore, effect of changing climate (change in temperature and precipitation) on growing season is also observed using the long term projections.

In addition to this, results were validated incorporating different statistical parameters. Furthermore, critical literature review is performed to calibrate the model for further use whereas, soil, weather and crop management data is used to perform experiment in the DSSAT model environment, the detail description of the datasets used is given in Table 3. Subsequently, the flow chart of the methodology adopted in this study is presented in Figure 3.

3.3 Data Collection

3.3.1 Field Experiment Data

For progress of the research an experiment data was required which can be used in DSSAT crop model environment for successful calibration and validation of the experiment. Generally, in irrigated regions the beginning in the first week of November and concluding in the last week of March, wheat is sown. In watered areas, the field experiment of Sehar-2006 and Faisalabad-2008 was carried out during 2007-2008 (Exp. 1 in Table 4) and 2008-2009 (Exp. 2 in Table 4) in Ayub Agriculture Research Institute (AARI), Faisalabad, Pakistan, by planting on 12 November 2007 and 12 November 2009, respectively. For both the experiment 1 and 2, different quantity of Nitrogen (0 kg, 55 Kg, 110 Kg, 220 Kg) were applied at different stages of the crop and same goes for the irrigation pattern; for both the experiment 1 and 2 four stages of irrigation was applied with same 75 mm each time. The description of experiments conducted in field is given in Table 2. The data for the phenological stages (e.g., day of anthesis, maturity and harvesting), biomass at specific intervals and final grain yield of wheat crop were recorded for each growing season in the experimental fields. The values of dry weight of grain yield and biomass recorded from the experimental field is given in Table 4. The obtained datasets from the experimental fields were used in DSSAT crop model as observed wheat crop data for the calibration and validation over irrigated region.

3.3.2 Soil Physical and Chemical Properties

The study area lies in the central Punjab region in which agriculture is dependent on irrigation. According to soil survey of Pakistan, Faisalabad soil falls in Lyallpur soil series.

Table 3. List of Datasets used to develop experiment with their source.

Datasets	**Type of Data**	**Source**
Crop Data	Field Data	National Agriculture and Research Center, Islamabad & Ayub Agriculture Research Institute Faisalabad
	Planting Date	
	Cultivar	
	Fertilizer	
	Harvest	
	Irrigation Method	
Soil Data	Bulk Density	Ayub Agriculture Research Institute Faisalabad & FAO soil data & ISRIC World soil information
	pH in Soil	
	Percentage of sand, silt & clay content	
	Organic Carbon	
	Soil type	
Weather Data	Max, Min Daily Temperature (°C)	Pakistan Meteorological Department
	Total Daily Precipitation	
	Daily values of Incoming Solar Radiation	
Regional Circulation Models (RCMS)	Representative concentration pathways 4.5 & 8.5	WCRP Coordinated Regional Climate Downscaling Experiment (CORDEX)

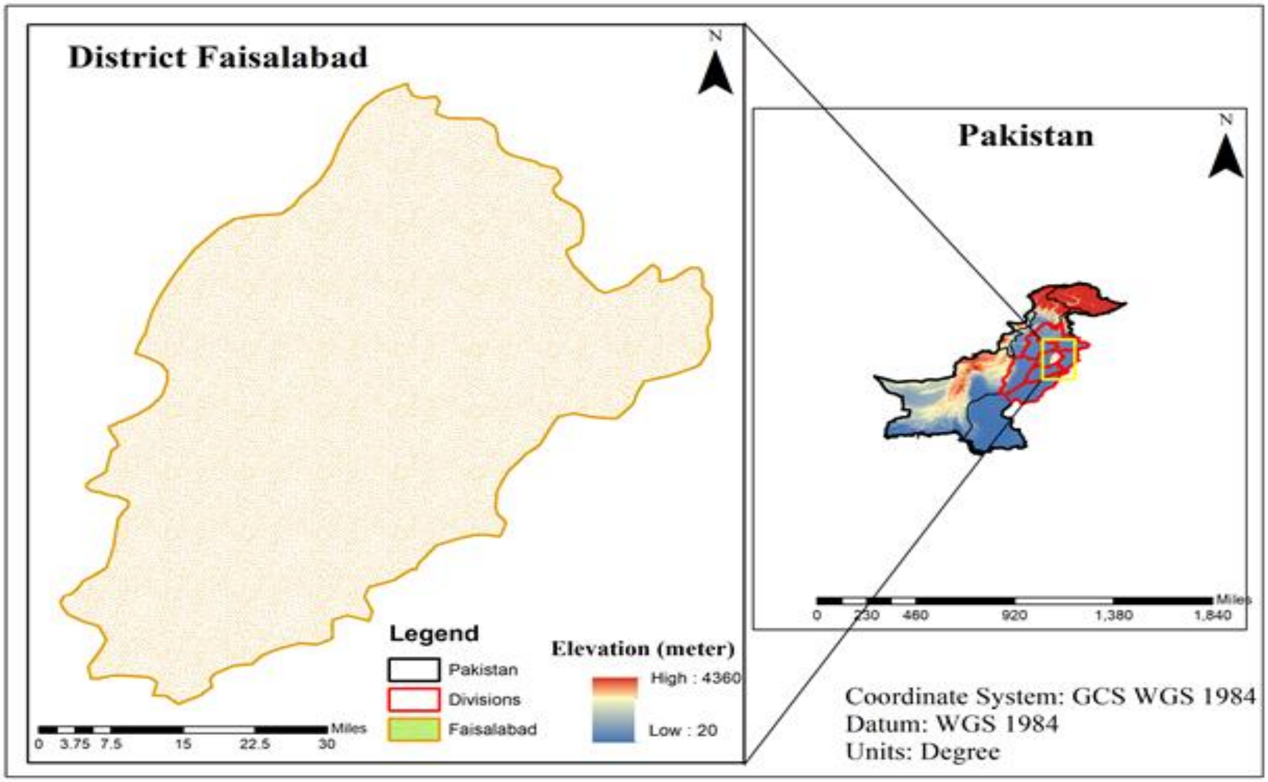

Figure 2. Study area map of District Faisalabad showing agricultural land.

Table 4. Summary of the variables of wheat crop taken for experiment.

Experiment	**Growing Season**	**Site**	**Treatment**	**Sowing Dates**	**Cultivar**
Exp. 1	2007-2008	Faisalabad (Lyallpur)	**Fertilizer application:** 1st 8th Dec 70kg/ha 2nd 15th Jan 40kg/ha **Nitrogen application:** 0 kg Nitrogen 55 kg Nitrogen 110 kg Nitrogen 220 kg Nitrogen **Irrigation Application:** 1st 8th Dec 75mm 2nd 15th Jan 75mm 3rd 10th Feb 75mm 4th 5th March 75mm	12 Nov, 2007	Faisalabad -2008
Exp. 2	2008-2009	Faisalabad (Lyallpur)	Same as Experiment 1	12 Nov, 2008	Sehar-2006

Table 5. Properties of soil at different soil depth for Faisalabad region (Irrigated Regions).

Soil Properties	**Soil depth (cm)**							
Irrigated Regions	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160
Wilting Point (%)	16	14	18	17	16	16	12	13
Field Capacity	0.61	0.62	0.67	0.66	0.55	0.53	0.51	0.46
Bulk density (g/cm^3)	1.19	1.29	1.36	1.39	1.42	1.35	1.31	1.30
Saturation (cm^3 cm^{-3})	0.42	0.35	0.35	0.35	0.35	0.33	0.32	0.31
Clay (%)	36	33	28	31	36	31	34	35
Silt (%)	35	35	33	36	23	32	31	22
Sand (%)	29	32	39	33	41	37	35	43
pH	7.1	7.3	7.7	7.4	8.4	8.8	8.1	8.6
EC (dS m^{-1})	1.9	2.1	2.3	2.5	2.5	1.8	1.9	2.2
SHC (cm/h)	0.95	0.92	0.89	0.82	0.80	0.77	0.74	0.70

EC: Electrical conductivity, SHC: Saturated Hydraulic Conductivity (cm/h)

Source: (Azmat et al., 2021)

Secondly soil type is sandy clayey loam and the Indus River and its tributaries transported alluvial deposits that make up the soil. (Shakoor et al., 2018). The soil chemical and physical properties can be observed in the given Table 5. While soil samples were analyzed chemically and hydrologically up to a depth of 160 cm with a 20-cm break before the experimental field crop was planted. At various depths of the soil layers, the collected soil samples were assessed for the existence of nutrients (N, P, K, and micronutrients), texture of the silt, clay, and sand percentage, and composition of soil, pH, ECe, organic carbon, and bulk density. The soil contour was separated into eight soil layers with an interval of 20 cm to account for the depth-based soil variability. Additionally, it was determined whether the soil samples had hydrological characteristics such field capacity, bulk density, saturation, and saturated hydraulic conductivity. The properties of soil data and variables incorporated with crop model are given in Table 5. For example, the soil properties in the study area is that in irrigated regions soil is clay loam in texture with range of pH values 7.1 – 8.3. ECe around 1.9 – 0.19 d Sm^{-1} and field capacity around 45% - 71%. The soil contains organic substance from 8.3 to 9.5 mg/g dry soil, amount of Nitrogen seems to be little, whereas other nutrients like K and P appear to be in fine quantity.

3.3.3 Climate Data

Furthermore, the Pakistan Meteorological Department (PMD) station located in the preferred study area provided the observed climate variables from 1980 to 2010 including daily heat (minimum and maximum), relative humidity, precipitation, solar ray emission, wind speed, vapour pressure, and dew point temperature.

Moreover, the coordinated regional downscaling experiment a framework called (CORDEX) is supported by the world climate research programme (WCRP) to improve the projection of climate variables at the regional level, build improved regional climate model (RCMS) experiments at fine resolution scale in comparison to general circulation models (GCMs) (Choudhary & Dimri, 2018). The initiative was taken to apply robust regional climate downscaling/ projection methodologies for the improvement of regional climate variables under future scenarios. In the study, the RCM CCCma-CanESM2-RegCM4-4 (RegCM4-4) experiment presented by the CORDEX-SA domain was employed in the selected regions for the weather projections for future schemes. The adopted experiment was employed in the study region for the weather projections for future schemes. The adopted experiment has daily temporal resolution spanning 1970 to 2099 (130 years) with 0.44° (~ 50 km) horizontal grid resolution. For the projection of climatic variables up to the 21st century, RCP4.5 and RCP8.5, two well-known representative concentration paths (RCPs), were chosen. With the integration of crop models, the future expected climate indicators were also used to mimic the phenology of wheat crops under climate change scenarios. The crop models were run for each year by replacing existing precipitation, temperature, and net radiations under scenario periods. After crop models simulation, three distinct time slots were selected 2020-2047 (2030s), 2048-2067 (2060s) and 2067-2088 (2090s) as future scenarios. The change in precipitation, days until onset of anthesis, number of days until maturity, temperature, wheat crop growing length and yield production were examined for the future scenario periods.

3.4 Experimental Design

Generally, for the research climate projections obtained from fine resolution CORDEX-SA RCMs experiment bias corrected was integrated with the physical properties of the study area with DSSAT crop model. DSSAT crop model calibration and validation were done by employing the available experiment based observed data for the specific study area; Faisalabad (irrigated region) for two wheat crop cultivars: (Faisalabad-2008 and Sehar-2006). After calibration, validation and evaluation of crop model, the soil and field management data were kept same and to run crop models and investigate anticipated changes in wheat crop phenology (anthesis, maturity stages in days), yield, and under hypothetical situations for the study region, climatic data was replaced. After bias-corrected CORDEX-SA RCM simulations were used to conduct the study region model's initial modification for three time periods 2020-2047 (2030s), 2048-2067 (2060s) and 2067-2088 (2090s) in RCP4.5 and RCP8.5 on decadal basis. Consequently, different treatment of Nitrogen at 0 kg, 55 kg, 110 kg and 220 kg and different application strategies of irrigation at different interval with same 75 mm for each irrigation supply was applied and assessed for potential future situations. Finally, For the investigation of the impact of climate fluctuations on wheat crop phenology and crop water productivity and yield, a series of simulations were generated from which the best fit future predictions.

3.4.1 Model Description

To enable the use of crop models in a systems approach to agronomic research, an international network of scientists working on the international benchmark sites network for agricultural technology transfer project originally developed the DSSAT (Decision Support System for Agrotechnology Transfer) (International Benchmark Sites Network for Agrotechnology Transfer, 1993). Its early creation was driven by the necessity to incorporate knowledge regarding soils, climate, agriculture, and management to assist people transfer agricultural technologies to places with different soils and climates. In addition to this, the DSSAT's goal is to model single - crop production practices while considering factors like meteorological, genomics, soil moisture, soils nitrogen and carbon and maintenance in single or many seasons as well as in intercropping at any site with minimal inputs. Moreover, The DSSAT models crop production, progress, and productivity as well as long-term changes in soil moisture, carbon, and nitrogen under an agricultural system. It also models specified or simulated management of the land (Jones et al., 2003).

The DSSAT has a main module programme, a module for the basic elements of a land unit in a cropping system, and modules for each of these given in Figure 4. There are six operational sets in each module, as shown in Figure 4. (run initialization, season initialization, rate calculations, integration, daily output, and summary output). The main components consist of different module: weather module, soil module, soil water sub module, soil temperature sub module and individual crop module interface (plant module). Further, the main function of ***weather*** module is to read or generate daily weather data. It reads data in daily weather values (maximum and minimum air temperatures, solar radiation and precipitation, relative humidity, and wind speed) from the weather file. Secondly, soil module; the soil in the land unit is represented as a one-dimensional profile, it is homogenous horizontally and consists of several vertical soil layers. The soil module integrates information from four sub modules: soil water, soil temperature, soil carbon, soil nitrogen, and soil dynamics.

Thirdly, the soil water balance model is mainly developed for CERES-Wheat model. this one-dimensional model computes the daily changes in soil water content by soil layer due to infiltration of rainfall and irrigation, vertical drainage, unsaturated flow, soil evaporation, and root water uptake processes moreover, soil-plant-atmosphere module computes daily soil evaporation and plant transpiration also This module brings together soil, plant and atmosphere inputs and computes light interception by the canopy, potential evapotranspiration (ET) as well as actual soil evaporation and plant transpiration (ICRISAT, 1984).

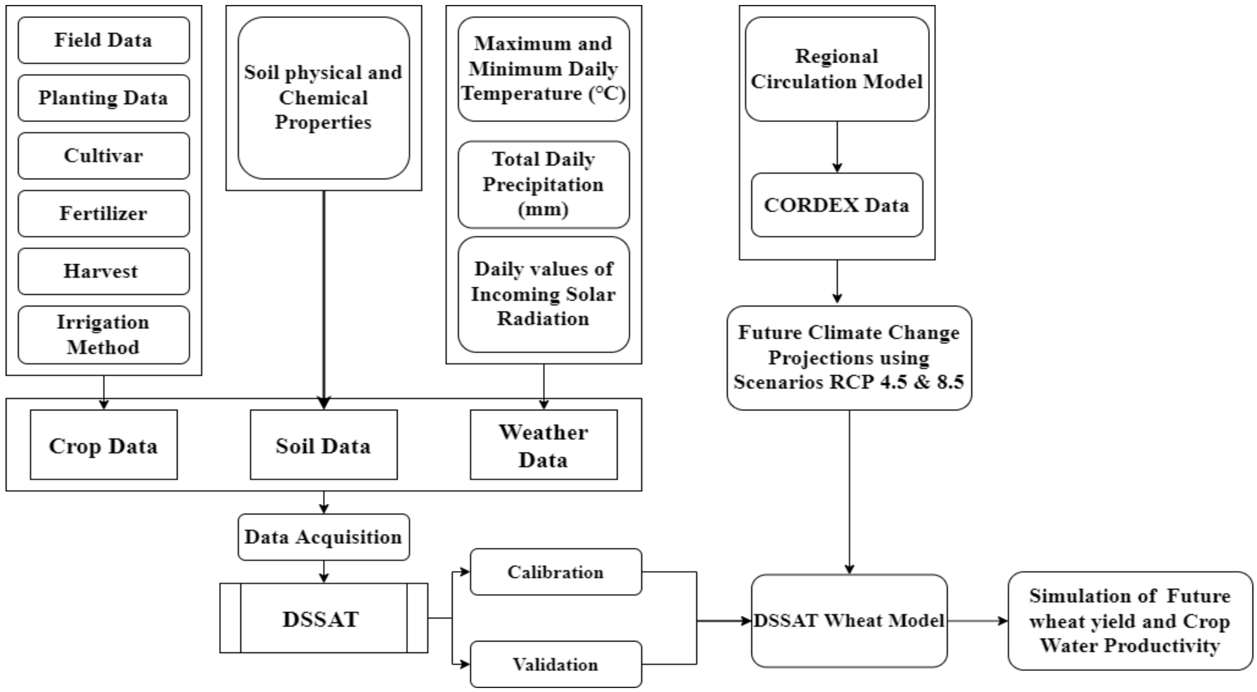

Figure 3. Methodology adopted in the research to achieve main objectives.

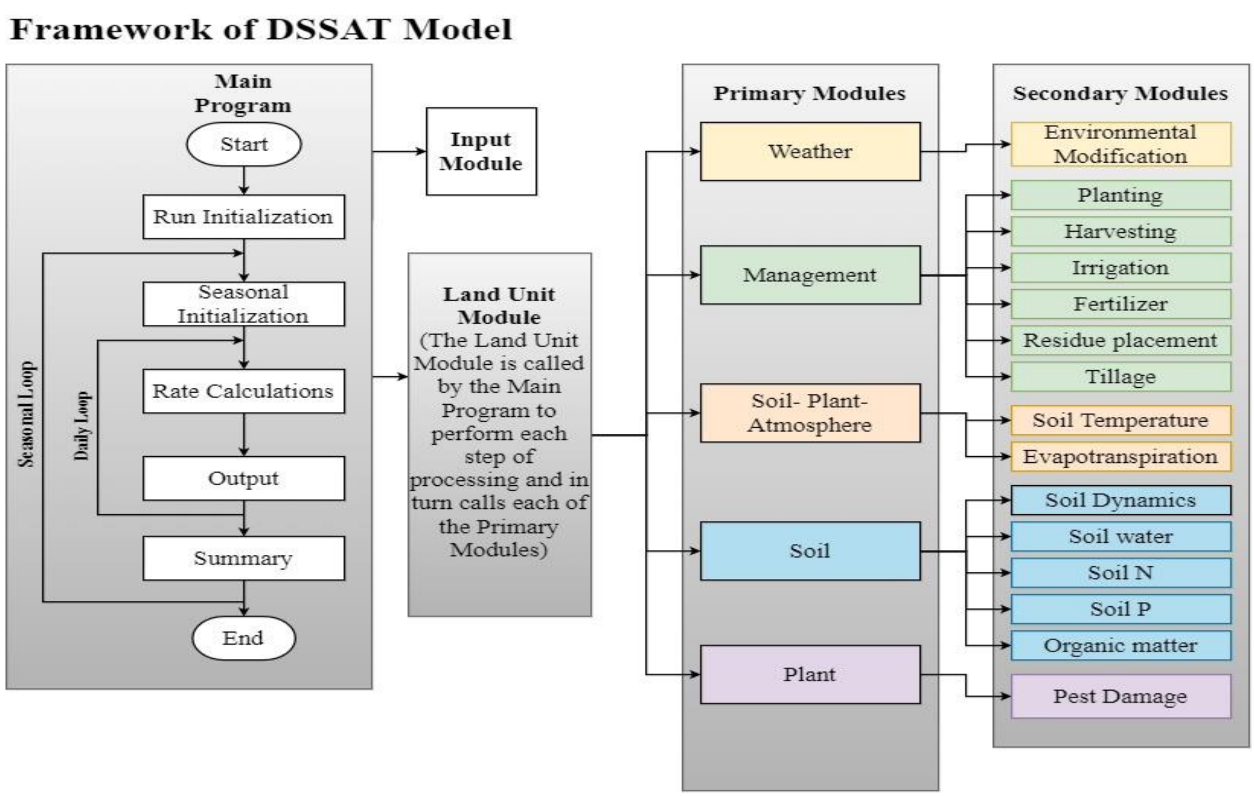

Figure 4. Main Framework of components essential for DSSAT crop model.

Furthermore, for CERES-Wheat crop model the plant life cycle is separated into many phases, and thermal time controls how quickly a plant develops or growing degree days (GDD), This is calculated using the daily high and low temperatures. In addition to this, Cultivar-specific inputs are for computing growth of plant, Using a crop-specific energy usage utilization measure, daily collected photosynthesis-active radiation is converted into plant dry matter to determine the regular growth of plants., further, biomass is calculated by the model on the genetic capacity of the cultivar, canopy weight, average amount of carbohydrates and temperatures stress, water stress, and nitrogen stress, and kernel counts per plant are calculated during flowering. Further, When the harvest is ripe, at specific times, or when the field's soil and water conditions are ideal for machine operation, harvests can take place. However, there are two ways to control irrigation: either by the plant's water availability or by applying irrigation at certain times and amounts. Therefore, With the help of these management options, users have a wide range of options when modelling research projects that have earlier been carried out for model assessment and enhancement. These requirements were used to carry out the simulation for the study area, and the data collected was altered to determine the consequences of temperature and rainfall on yield and crop water productivity, respectively (Jones et al., 2003).

3.4.2 Model Calibration

Crop model was adjusted for reproducing the phenology, biomass, and yield of both the cultivars of wheat (Faisalabad-2008 and Sehar-2006) using experimental data of growing season 2007-2008 for Faisalabad. Model was modified using field meteorological data, soil and crop management data with already incorporated genotype parameters. Simulations were run from November to April. Date of sowing and harvesting whereas properties of soil and crop management application was also incorporated with crop model to observe the performance of the model.

Further, the performance of cultivar was observed by selecting various studies conducted by other researches as reference for calibration of the cultivar(Ahmed et al., 2020; Azmat et al., 2021) further hit and trial run strategy was adopted for calibration of both the cultivars (Faisalabad-2008 and Sehar-2006) as details given in Table 6. Additionally, default values of the genetic coefficients were used to observe the observe the response of the model. Afterwards, the parameters which are controlled by phenology like LAI, Above Ground Biomass and Yield and Maturity were adjusted by hit and trail method. Subsequently, to remove any misrepresentation between observed and simulated values some parameters like emergence and intermediary parameters were adjusted to calibrate cultivar specific factors as shown in Table 6. For calibration of the model four parameters: 1) yield at maturity 2) total biomass at maturity 3) anthesis day and 4) maturity day were calibrated for Faisalabad site using an extensive trial method.

3.4.3 Model Validation

The validation of model's performance was computed by comparing the output generated by model with the field data. The field data of season 2008-2009 in which experiment was performed for irrigated Faisalabad region was used for model validation. The evaluation criteria used to measure the performance of plant growth variable was based on (days to anthesis, days to maturity, biomass and yield) were mean error (ME), root mean square error (RMSE), Coefficient of determinant (R^2) and DSTAT.

Table 6. Genetic coefficients for the DSSAT CERES-Wheat model used for calibration of the model.

Genetic coefficients for the DSSAT CERES-Wheat model		Faisalabad-2008	Sehar-2006
P1D	Photoperiod Response	17.9	13.7
P1V	Days, Optimum vernalizing temperature, required for vernalization	42.2	46.3
P5	Thermal time from the onset of linear fill to maturity(Grain filling)	461.9	470.4
G1	Kernel number per unit stem + spike weight at anthesis	20	16.5
G2	Potential kernel growth rate (mg/ (kernel d))	38.6	49.1
G3	Standard, non-stressed mature tiller (including grain)	1.9	1.8
PHINT	Interval between the appearance of leaf tips	100	100

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Model Calibration

The DSSAT model was calibrated by using experimental data of 2007-08 for Faisalabad region for cultivar of Faisalabad-2008, Lasani-2006 and Sehar-2006 respectively. Calibration results showed that yield at maturity, biomass at maturity, anthesis day and Leaf Area Index (LAI) simulated were closely aligned with the experimental results for all the cultivars in Table 6. In the beginning of the research cultivar specific parameters were calibrated to bring closer the simulated and observed values of all the crop coefficients. Moreover, specific parameters given in Table 6. were also calibrated to align the values of crop genetic coefficients with actual world scenarios. The P1D (Photoperiod sensitivity coefficient) was set to 42 and 50 for Sehar-2006. P1V (Vernalization sensitivity coefficient) was set to 17.90 for Faisalabad-2008 cultivar and 13.78 for Sehar-2006. P5 (Thermal time from the onset of linear fill to maturity) was set to 461.9 for Faisalabad-2008 cultivar and 420 for Sehar-2006. G1 (Kernel number per unit stem) was set at 20 for Faisalabad-2008 cultivar and 16 for Sehar-2006. G2 (Potential kernel growth rate) was set at 38 for Faisalabad-2008 cultivar and 49 for Sehar-2006 cultivar. G3 (Tiller death coefficient. Standard stem) was set at 1.97 for Faisalabad-2008 and 1.88 for Sehar-2006 and Lastly, PHINT (Thermal time between the appearance of leaf tips) was set at 100 for both the Cultivars Faisalabad-2008 and Sehar-2006. According to the literature G1, G2 and G3 effect the development stage of the crop like Anthesis day, days taken for maturity and biomass whereas, P1V, P1D and P5 effect the initial growing stages of the crop like seed sprouting, leaf at first stage respectively. All the details are provided in Table 7. which shows that the simulated and observed values quietly match with each other hence showing the robustness of the DSSAT crop model.

The calibrated results for both the wheat cultivars Faisalabad-2008 and Sehar-2006 shows that there is no difference in days to Anthesis between simulated and observed values. However, in case of total biomass at maturity and Yield at maturity there is a difference between the simulated and observed values as in both cases model under predicted both the factors. Whereas in case of Leaf Area Index (LAI) it can be observed that in both the cultivars Faisalabad-2008 observed 3.7 to simulated 3.8 and Sehar-2006 observed 3.7 to simulated 3.6. The values of statistical indices for simulated biomass, yield and LAI for each cultivar is given in Table 7. Moreover, the individual calibration values of Cultivars Faisalabad-2008 and Sehar-2006 are given in Table 8. and Table 9. The Dstat: 0.98 value showed the efficiency and performance of model for Biomass and RMSE: 1074 and R-square: 0.9 gave evidence for the robustness of the model as model simulated: 8246 kg/ha and observed: 8505 kg/ha values were close to each other. Further, same parameters for observation were selected for Yield and LAI as Dstat: 0.99 and 0.96 respectively and RMSE: 319.5 and 0.74 as well as model simulated: 3279 kg/ha against observed: 3312 kg/ha correspondingly. Likewise, same observational constraints were used to calibrate Sehar-2006 cultivar where Dstat: 0.985 value showed the effectiveness and performance of model for Biomass and RMSE: 1056 and R-square: 0.9 gave evidence for the robustness of the model as model simulated: 8227 kg/ha and observed: 8850 kg/ha values were close to each other. Further, same parameters for observation were selected for Yield and LAI as Dstat: 0.98 and 0.96 respectively and RMSE: 386.5 and 0.709 as well as model simulated: 3522 kg/ha against observed: 3500 kg/ha respectively.

Table 7. Calibration of DSSAT crop model for irrigated region using three wheat cultivars for anthesis day, total biomass at maturity, yield and leaf area index.

Crop traits	**Faisalabd-2008**		**Sehar-2006**	
	Observed	DSSAT	Observed	DSSAT
Anthesis day	106	106	107	107
Emergence day	6	4	6	4
Total Biomass at maturity kg/ha	8505	8246	8850	8227
Yield at Maturity kg/ha	3312	3279	3500	3522
LAI Maximum	3.7	3.8	3.7	3.6

Table 8. Calibration of DSSAT crop model for Faisalabad-2008 cultivar for anthesis day, total biomass at maturity, yield and leaf area index.

Variable Name	**Observed**	**Simulated**	**Ratio**	**r-Square**	**Mean Diff.**	**RMSE**	**d-Stat.**
Total Biomass at maturity kg/ha	8505	8246	0.85	0.81	-259	1074	0.98
Yield at Maturity kg/ha	3.7	3.8	0.89	0.84	0.2	0.74	0.96
LAI maximum	3312	3279	0.93	0.8	-32	319	0.99

Table 9. Calibration of DSSAT crop model for Sehar-2006 cultivar for anthesis day, total biomass at maturity, yield and leaf area index.

Variable Name	**Observed**	**Simulated**	**Ratio**	**r-Square**	**Mean Diff.**	**RMSE**	**d-Stat.**
Total Biomass at maturity kg/ha	8850	8227	0.82	0.79	-623	1056	0.98
Yield at Maturity kg/ha	3500	3522	0.91	0.91	22	386	0.97
LAI maximum	3.7	3.6	0.81	0.84	0	0.70	0.96

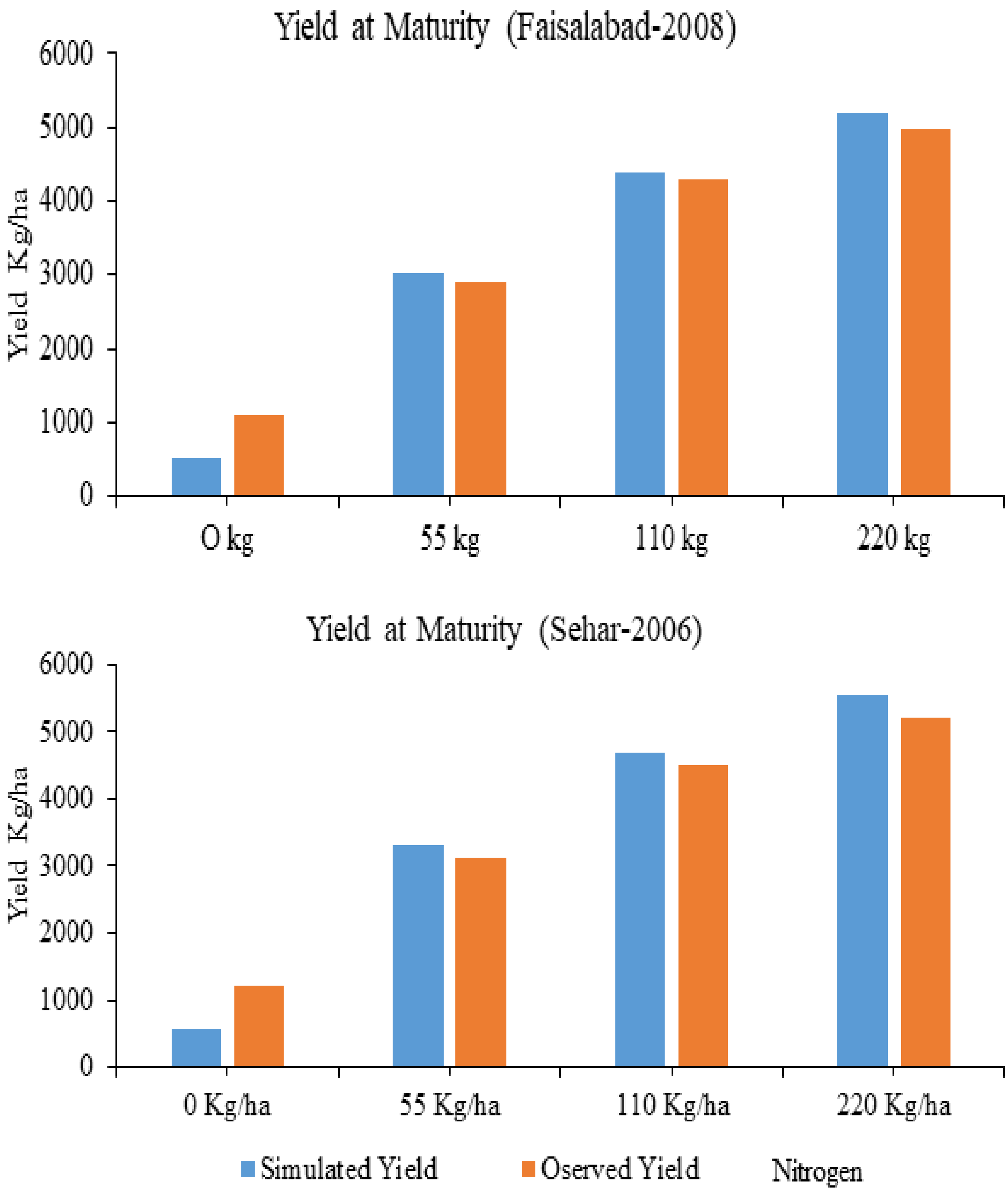

Figure 5. Comparison between simulated and observed yield for Faisalabad-2008 and Sehar-2006 cultivar.

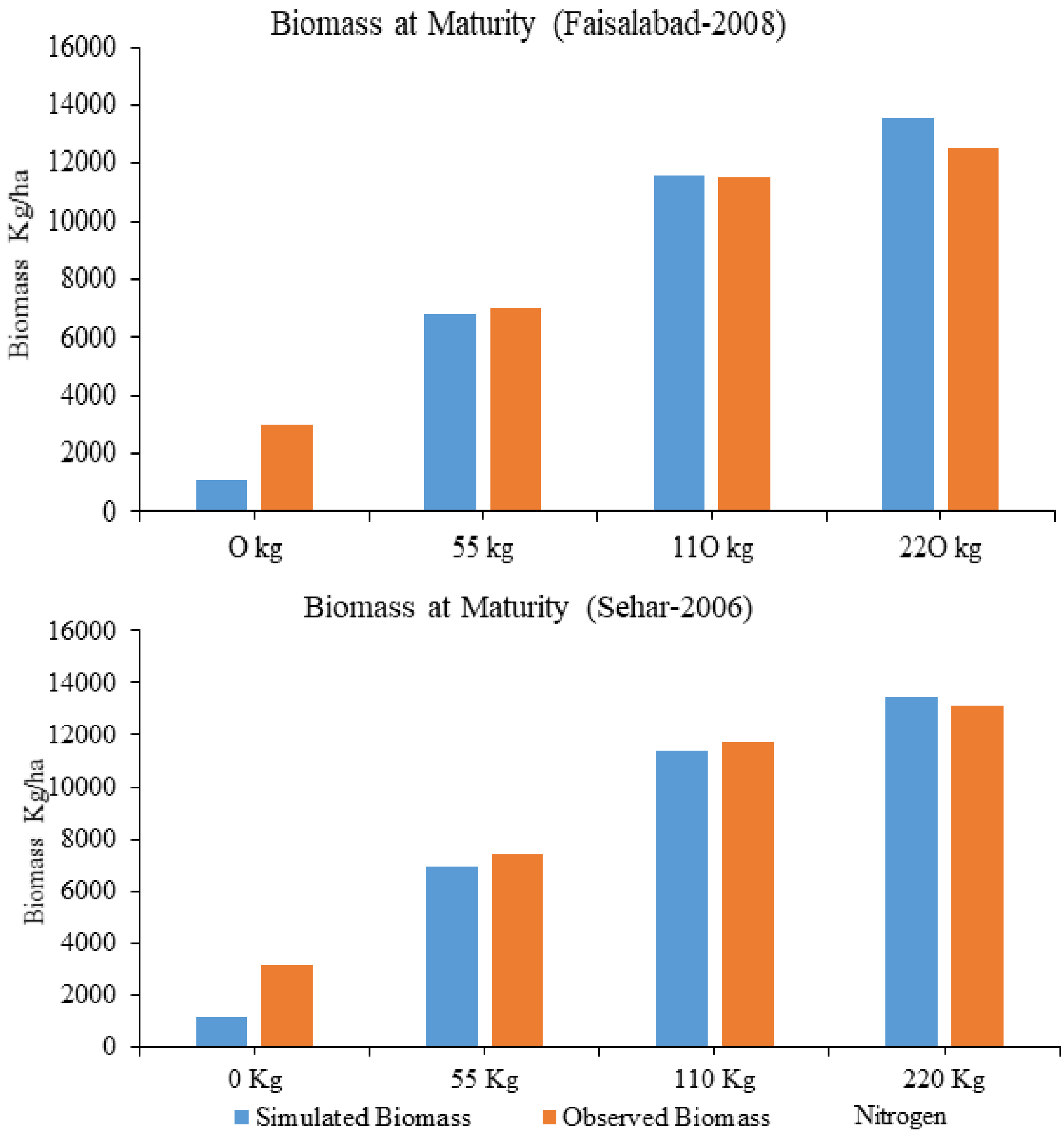

Figure 6. Comparison between simulated and observed yield for Faisalabad-2008 and Sehar-2006 cultivar.

4.2 Validation of the crop model

The validation of Crop model was done using the field experiment observed during the next crop season 2008-09 in Faisalabad irrigated region using different nitrogen levels (0-kg, 55 kg, 110 kg and 220 kg). Same technique and statistical parameters were applied to observe the robustness and performance of the model by comparing the observed Biomass, Yield and Leaf area index by the model with simulated values of the crop model.

4.2.1 Plant Phenology, Biomass and Yield

The model was validated by using the field experiment during 2008-09 season. The validation results show that anthesis day was efficiently predicted by the crop model as anthesis day predicted was 114 and 115 and observed was 110 day of the crop season for both the cultivar Faisalabad-2008 and Sehar-2006 respectively. Whereas for the biomass and yield and LAI the model gave result of 8034 kg/ha against 9036 kg/ha observed in the field experiment for Faisalabad-2008 cultivar and 7807 kg/ha was predicted by the model against 9917 kg/ha observed in the conducted experiment for Sehar-2006 cultivar. Furthermore, it can also be observed that in case of Yield simulation by the model which is a main objective of the research. The Yield observed was 3956 kg/ha and 3965 kg/ha was simulated by the DSSAT crop model for Faisalabad-2008 cultivar whereas for cultivar Sehar-2006 yield observed was 3656 kg/ha and the crop model simulated was 3427 kg/ha as shown in Table 10.

In addition to the above mentioned information, individual validation for each cultivar (Faisalabad-2008 and Sehar-2006) was carried out in order to confirm the effectiveness and performance of the model. The statistical indices as Dstat: 0.7, RMSE: 1021 and R2: 0.9 for Faisalabad-2008 cultivar for biomass showed that model is performing well in accordance with

Table 10. Validation of DSSAT crop model for irrigated region using three wheat cultivars for anthesis day, total Biomass at maturity, yield and leaf area index.

Crop traits	**Faisalabd-2008**		**Sehar-2006**	
	Observed	DSSAT	Observed	DSSAT
Anthesis day	110	114	110	115
Total Biomass at maturity kg/ha	9036	8034	9117	7807
Yield at Maturity kg/ha	3956	3965	3656	3427
LAI Maximum	4.1	4	3.8	4

Table 11. Validation of DSSAT crop model for Faisalabad-2008 Cultivar for anthesis day, total biomass at maturity, yield and leaf area index.

Variable Name	**Observed**	**Simulated**	**Ratio**	**r-Square**	**RMSE**	**d-Stat.**
Total Biomass at maturity kg/ha	9036	8034	0.76	0.85	1639	0.73
Yield at maturity kg/ha	3956	3965	0.95	0.81	894	0.85
LAI	4.1	4	0.92	0.87	0.87	0.87

Table 12. Validation of DSSAT crop model for Sehar-2006 Cultivar for anthesis day, total biomass at maturity, yield and leaf area index.

Variable Name	**Observed**	**Simulated**	**Ratio**	**r-Square**	**RMSE**	**d-Stat.**
Total Biomass at maturity kg/ha	9117	7807	0.82	0.82	1896	0.83
Yield at maturity kg/ha	3656	3427	0.84	0.87	711	0.89
LAI	3.8	4	1.1	0.86	0.73	0.92

the field experiment data as model simulated: 8034 kg/ha whereas for Sehar-2006 cultivar Dstat: 0.8, RMSE: 1898 and R^2: 0.9 as the model simulated 7807 kg/ha for Biomass respectively. Secondly, the statistical parameter for both the cultivar showed that Dstat: 0.8, RMSE: 894 and R2: 0.9 was observed Yield: 3965 kg/ha for Faisalabad-2008 cultivar and for Sehar-2006 cultivar Dstat: 0.89, RMSE: 711 and R2: 0.9 and Yield was simulated as 3427 kg/ha.

4.3 Climate Change Impact on Wheat production

4.3.1 Change in Anthesis length (days)

The calibration and validation of the model gave a positive response about the robustness and efficiency of the crop model. Further after the adjustment and authentication of the crop model, climate factors comprising daily (max & min) temperature, net radiation including daily rainfall records were replaced with projected climate change data (CORDEX) under future scenarios (2030, 2060 and 2090). The simulation was carried out for every decade starting from 2017 to 2088, therefore, impact of climate change on wheat crop production using DSSAT crop model was initiated using each cultivar. The climate projection under both RCPs4.5 and 8.5 incorporated to observe the effect of changing weather on wheat yield. Resultantly, in both the scenarios under RCP4.5 anthesis days declined from base period (107 day) to 107 in the 2030s period and to 103 in 2060 periods with decrease of 4 days and in 2090s period to 96 days a clear decline of 11 days moreover in case of RCP8.5 anthesis day declined from base period (107 day) to (101 day) in the 2030 period showing a decrease of 6 days, and in 2060 anthesis day dropped to 89 days a decline of 17 days was detected and in 2090 period anthesis day decreased to 82 days showing a fall of 23 days as shown in Table 15. The facts suggest that in both the climate change projection scenarios RCP4.5 and 8.5 a substantial decrease in anthesis days was observed which associates the impact of climate change on wheat production as with decline in anthesis days wheat will not get sufficient time and ample sun shine and optimum temperature to grow at its fullest. Therefore, a decline in yield of the crop will be observed if the anthesis days are occurring earlier in the crop growing season.

4.3.2 Change in Maturity (days)

The calibration and validation of the crop model also produced significant result about the phenology of the crop. After calibration and validation, the climate variables were changed and climate change projection data; RCP 4.5 and 8.5 was replaced to observe the impact of climate change. Therefore, in both the future scenarios it was observed that the maturity day of the crop was declining in both the climate change projections in comparison to base period. In the RCP4.5 scenarios a significant decrease in maturity day was not observed in the first two periods as from base period, maturity day: 137 a drop of 4 days was observed in the 2060 period and in 2090 period maturity day dropped to 124 (day) in comparison to 137 maturity day a decline of 13 days was witnessed. Moreover, in case of RCP 8.5 scenario a substantial fall in maturity day was observed in all the time periods. In 2030 period, maturity day was 127 (day) a drop of 10 days was detected and in 2060 period, maturity day was 116 and in 2090 period, maturity day was 108 days, a considerable decline was witnessed as 20 and 24 days respectively from the base period. Therefore, as consulted from different literature and observation from the simulated data it is observed that with a decline of the magnitude seen it will have a major impact on the crop production, stunted growth and immature development of the crop will take place as shown in Table 13.

4.3.3 Change in Growing Degree Days

The above analysis showed that the shortening of anthesis day and maturity day are associated with projected climate change under future scenarios. From this point of view, the research was also directed to inspect the consequence of changing climate on growing degree days as growing degree days represent the total amount of unit energy required by the crop to grow at its full potential. In order to examine this growing degree days were collected for each period 2030, 2060 and 2090 for both RCP4.5 and 8.5 future projections as shown in Table 13. The average growing degree days of base period were 1735 and for RCP4.5 under 2030 period degree days increased to 2238, in 2060 period to 2478 and in 2090 period it rose to 2702 showing a significant increase in long term future projections. Secondly for RCP8.5 under 2030 period growing degree days increased to 2612 and in 2060 period to 3095 and in 2090 period it increased to 3399 showing a drastic increase in growing degree days. Thus decline in growing degree days resulted in decrease in number of days required to reach crop maturity.

4.4 Impact of Climate Change on Wheat Crop Yield

The DSSAT crop model was used to simulate the change in wheat crop output under potential future climate change scenarios using CORDEX-RCM-projected climate variables. A significant amount of decline in crop yield was observed during 2030, 2060 and 2090 period under both the projections RCP4.5 and 8.5 respectively. Consequently, harvest dropped from 1010 kg/ha (2017) to 419 kg/ha (2088) decreasing from 35% to 59% in RCP4.5 as there were not so extreme temperature and drought condition as compared to rise in temperature and low precipitation recorded in the long term climate projection in RCP8.5 as yield decreased from 2931 kg/ha to 450 kg/ha (27% to 77%) showing a considerable amount of decline as shown in Figure 8.

Moreover, in every case in which different nitrogen treatment (0-kg, 55-kg, 110-kg and 220-kg) were applied to detect the yield production it was observed that in every treatment there was a significant amount of drop in yield owing to weather transformation.

Moreover, Table 13a and b, represent the factual representation of values as sign for claiming climate change's effects on agricultural output. In case of Faisalabad region, a major change in crop phenology was observed under RCP4.5 simulated by DSSAT model, with a significant back shift in anthesis and maturity stages to changing climate. The decrease in anthesis day was that from base period (107 day) to 4 and 11 days for 2060 and 2090 period respectively, moreover in case of RCP8.5 anthesis day declined from base period (107 day) to 6, 17 and 23 days for 2030, 2060 and 2090 periods. Likewise, back shift in maturity days was also observed that in case of RCP4.5 a drop of 4 days was observed in the 2060 period and in 2090 period a decline of 13 days was witnessed. Moreover, in case of RCP8.5 scenario a substantial fall in maturity day was observed in all the time periods. In 2030 period, a drop of 10 days in 2060 period 20 and in 2090 period, 24 days' decline was witnessed. Furthermore, change in precipitation is also associated with yield loss, causing water deficit in the region and in addition to this rise in temperature given in Figure 6 show that there is a significant rise of temperature and it was observed that due to rise on temperature there was decline in crop yield. The increase from baseline (16℃) to 19℃, 20℃ and 22℃ for 2030, 2060 and 2090 period for Regional circulation model 4.5 and in the same way under Regional Circulation model 8.5 increase in temperature stood 21℃, 24℃ and 26℃ for 2030, 2060 and 2090 period. Therefore, the above mentioned facts and change in crop phenology and alteration in temperature and precipitation and growing degree days had drastic impact on crop yield.

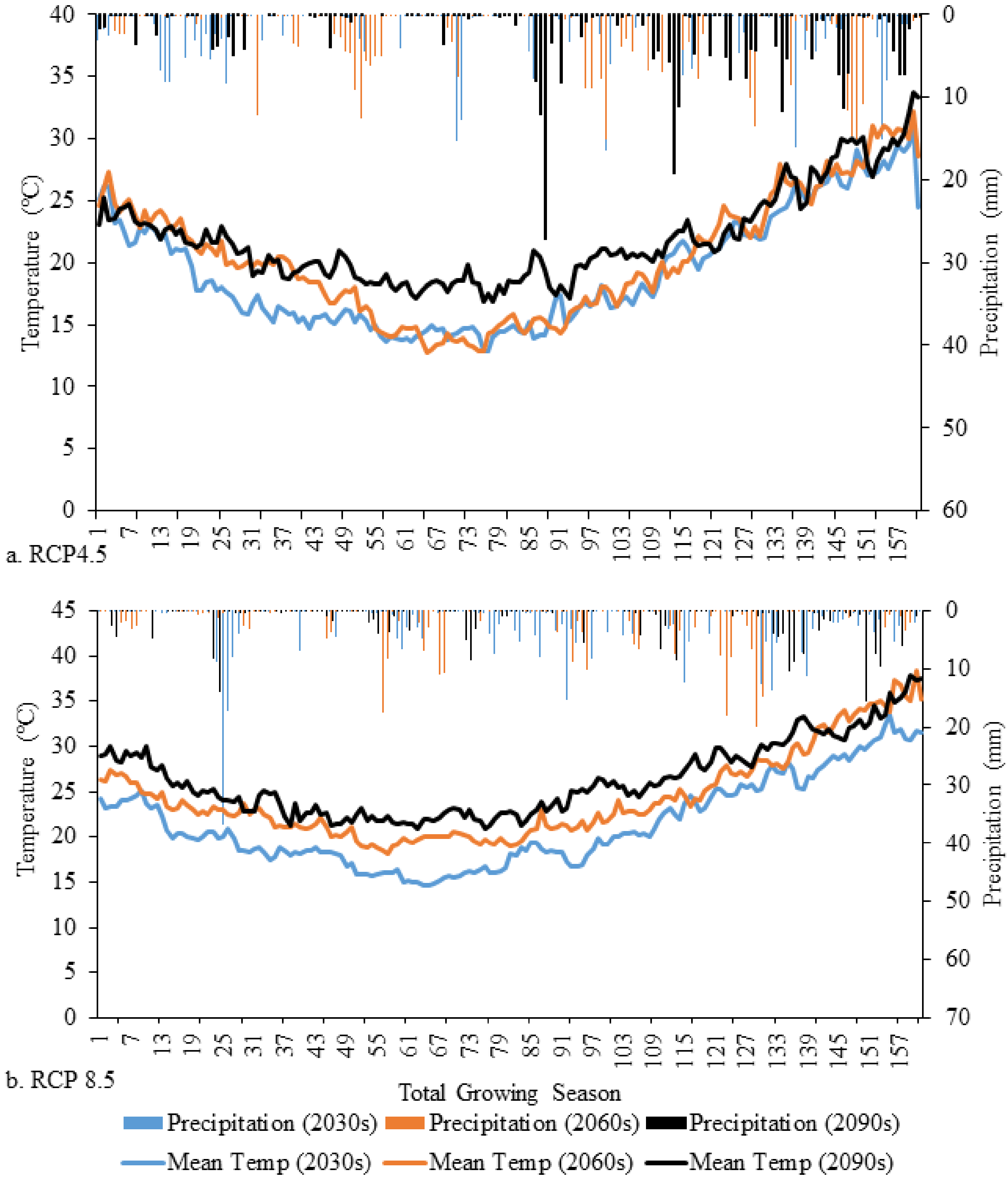

Figure 7. Mean Temperature and Precipitation under future climate change projections (2030, 2060 and 2090) for (a. RCP4.5, b. RCP8.5).

Figure 8. long term future (2006-2088) change in Yield (Faisalabad-2008) with different (a, b, c, d) nitrogen level under future climate change scenarios RCP4.5 and 8.5.

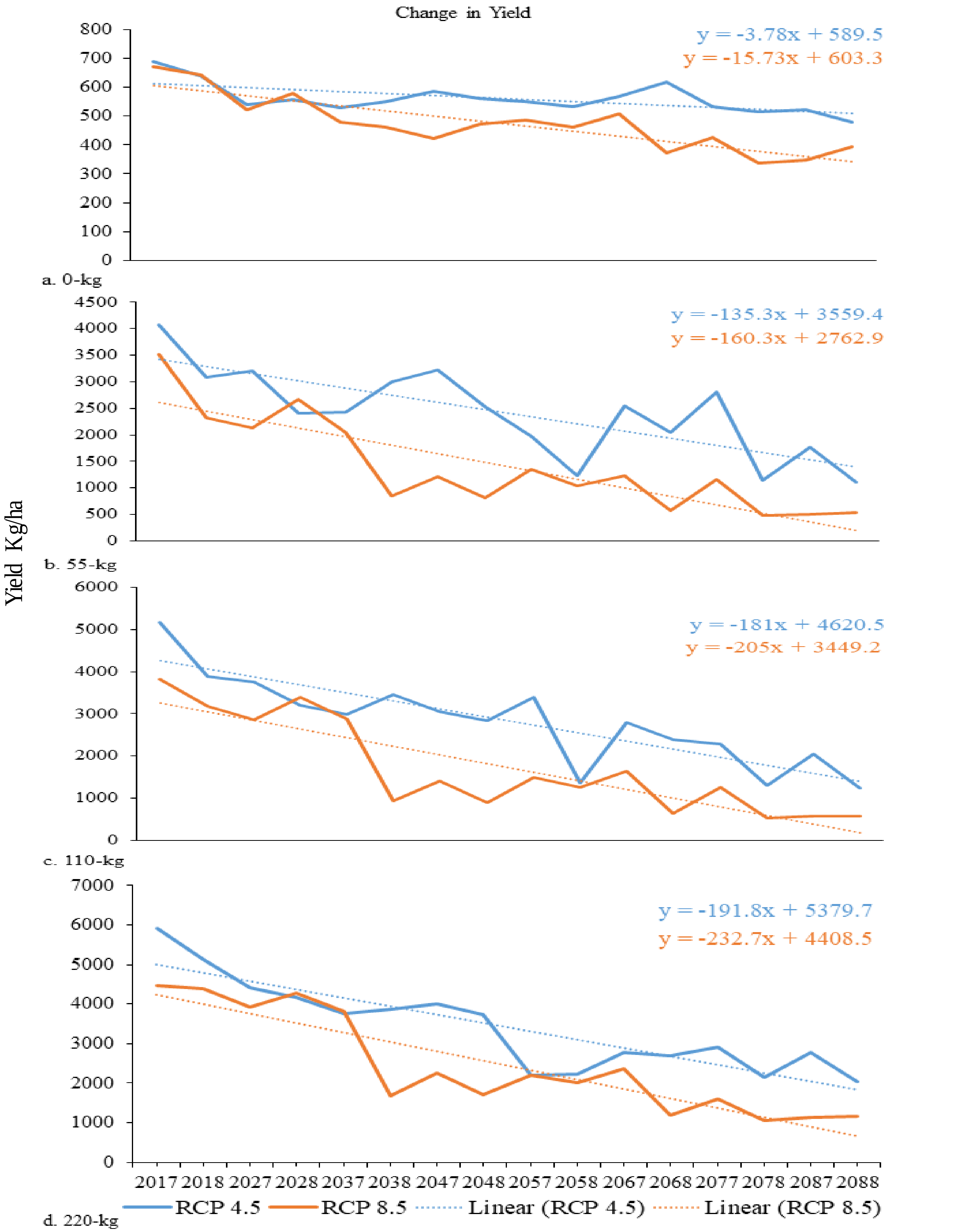

Figure 9. long term future (2006-2088) change in Yield (Sehar-2006) with different nitrogen level (0, 55, 110, 220 Kg) under future climate change scenarios RCP4.5 and 8.5.

4.5 Change in Crop Water Productivity

The variation in agricultural water production is associated with the relationship of yield and total evapotranspiration at the end the crop growing season. It is the amount of unit water consumed by the crop to produce a kg of yield of the crop in study. As temperature and precipitation had a considerable amount of impact on the yield of wheat crop in the long term. The climate change projection CORDEX-SA RCM data was used to find out the crop water productivity and it was observed that under both RCP4.5 and8.5 the crop water productivity dropped as due to high temperature and less precipitation received in the crop growing season evapotranspiration was high and due to back shift of anthesis and maturity days it became apparent that shortening of crop growing period affects the development of wheat yield therefore resulting in decline in yield and consequently crop water productivity.

In addition to this, four level of nitrogen level (0-kg, 55-kg, 110-kg and 220-kg) field were setup to observe the development of wheat crop and it is observed that in neither of the experiment crop water productivity and yield was sustainable in long term future climate projections as Figure 10 depicts the state of decline in CWP. Therefore, declining CWP is a clear sign that with current irrigation practices crop production will be decreased during 2030s, 2060s and 2090s as in both RCPs (RCP4.5: CWP decreased by 18% (2.78 kg/m^3 to 2.27kg/m^3) in 0kg Nitrogen from 2017 to 2088 whereas in 55kg Nitrogen 69%(13.26 kg/m^3 to 4.1 kg/m^3)) decreased in CWP moreover, in RCP8.5: CWP decreased by 33% in 0kg nitrogen and 80% decline was observed in 55kg treatment from 11.8 kg/m^3 to 2.3 kg/m^3 under future scenarios as observed in Figure 10.

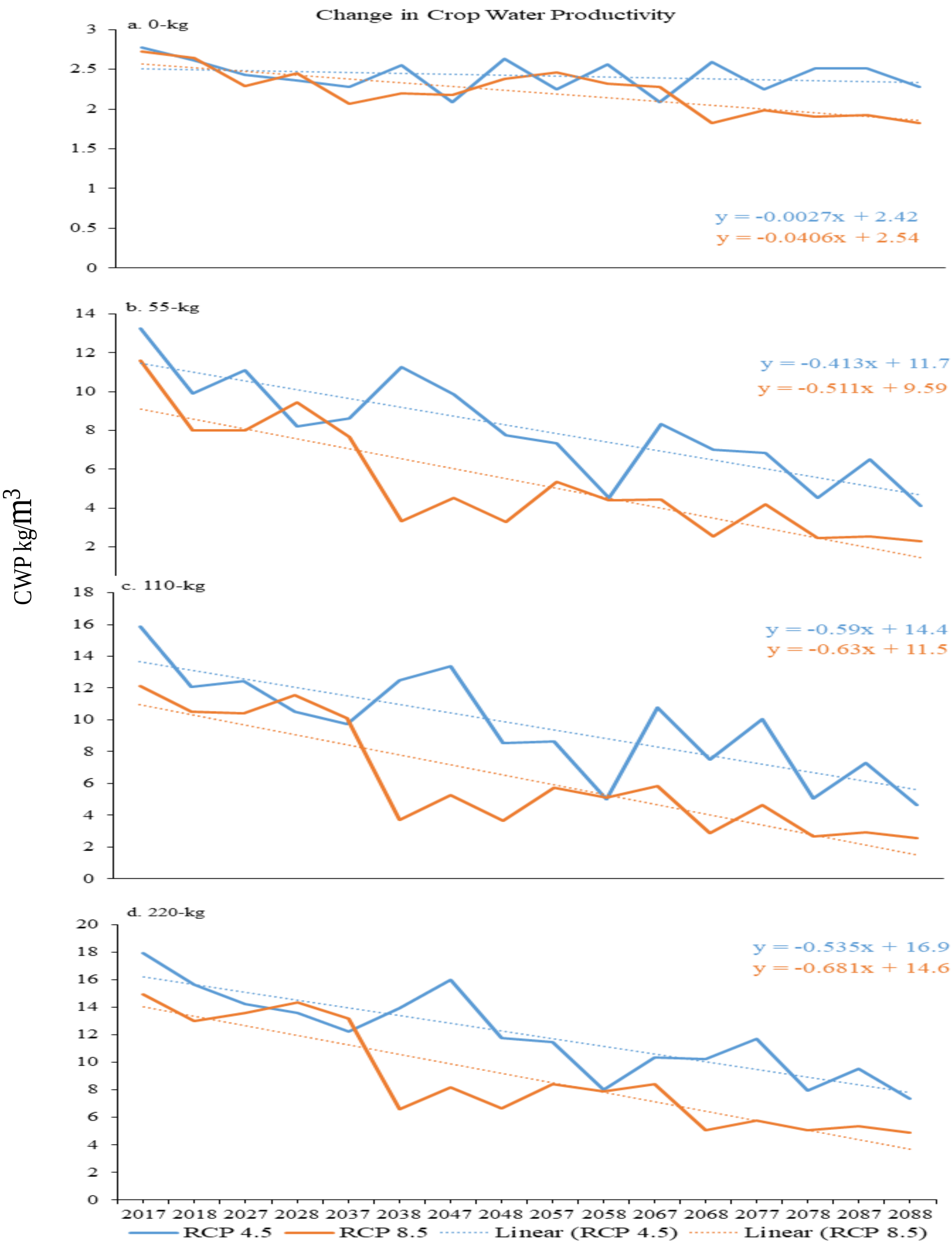

Figure 10. Change in crop water productivity for cultivar Faisalabad-2008 with different nitrogen level (a, b, c, d) for future (2017-2088) under climate change scenarios RCP4.5 and 8.5.

Table 13. Change in Mean Temperature°C, Average Growing Degree Days, anthesis day and maturity day under future climate change scenario for Both the RCP4.5 and 8.5.

a. RCP 4.5				
Variables	**Base Period**	**2030s**	**2060s**	**2090s**
Mean Temperature (°C)	16	19	20	22
Avg GDD (°C)	1735	2283	2478	2702
Anthesis day	107	107	103	96
Maturity day	137	137	131	124
b. RCP 8.5				
Variables	**Base Period**	**2030s**	**2060s**	**2090s**
Mean Temperature (°C)	16	21	24	26
Avg GDD (°C)	1735	2612	3095	3399
Anthesis Day	107	101	89	82
Maturity day	137	127	116	108

CHAPTER 5

Conclusion

The changing climate and unpredictable pattern of precipitation will have an adverse impact on the crop production as this research observed. Moreover, utilizing inputs from CORDEX-SA-RCMs and incorporating the DSSAT crop model on the Faisalabad area, this study examined the effects of climate change on wheat crop phenology, including Anthesis day, Maturity day, and increasing degree days, biomass, and yield over projected climate change scenarios. Moreover, crop water productivity was also calculated using DSSAT model for every nitrogen treatment under future projections. The following conclusions were drawn for the relevant study:

The DSSAT wheat model's calibration and validation revealed that it can accurately reproduce plant physiological phases, biomass, and yield in accordance with experiment conducted data acquired for Faisalabad regions for different level of nitrogen (0-kg, 55-kg, 110-kg and 220-kg) applied to the plant developmental phases at various stages. Further, wheat crop phenology and yield revealed negative effects of climate change using the DSSAT crop model under future climate change simulations in RCPs 4.5 and 8.5. In both the scenarios climate had significant impact of Crop water production, crop output, and development but overall in RCP 8.5 significant decline in yield and crop water productivity was observed due to decline in precipitation and rise in temperature.

Nevertheless, the study of change in precipitation is also associated with yield loss, causing water deficit in the region and in addition to this rise in temperature show that there is a significant rise of temperature and it was observed that due to rise on temperature there was decline in crop yield. The increase from baseline (16℃) to 19℃, 20℃ and 22℃ for 2030s, 2060s and 2090s period for RCP 4.5 and correspondingly under Representative concentration pathways 8.5 increase in temperature stood 21℃, 24℃ and 26℃ for 2030, 2060 and 2090 period. Therefore, the above mentioned facts and change in crop phenology and alteration in temperature and precipitation and growing degree days had drastic impact on crop yield.

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