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Review article

Could agricultural system be adapted to climate change? A Review

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Abstract

Agriculture sector is the most sensitive sector depicted considerable impact of climatic variability and poses threat of food security in future. The present review focuses on the factors mainly responsible for climate change and their adaptation and mitigation options using conventional and modern approaches. Since productive and sustainable agriculture sector might help to reduce poverty in the context of climate change because of dependence of maximum population on it. Therefore, to mitigate ill effects of climate change and to increase and maintain crop productivity, holistic approach needs to be selected by agriculture researcher. This includes development of stress tolerant genotypes together with sustainable crop and natural resources management with implementation of all these efforts by sound policies. Meanwhile increased temperature (2–4°C by 2100), rise in CO_2, droughts and floods might be frequent events of future therefore, emphasis needs to be on climate smart agriculture with the aim of reduction of greenhouse gas emissions (GHGE) enhanced resilience and reduced wastes with the increase in the productivity of small and large scale farmers. The use of empirical, modeling and Niche-based approaches to design a decision support tools will be helpful. Meanwhile, development of resistance genotypes to biotic/abiotic stresses, choice of crops, change in the cropping patterns, rotation, time of planting and avoidance, nutrient use efficiency (NUE) and modern approaches like wide crosses, transgenesis or mutagenesis will be very helpful to achieve the goal of yield sustainability. Similarly, induction of C4 metabolism in C3 crops and increasing the specificity of RuBisco toward CO_2 will be another achievement. The techniques like introgression, amphiploids, induced genetic variation and bioinformatics (modeling and GIS) could be helpful to minimize the impact of climate change on agriculture system. Furthermore, simulation modeling technique was confirmed by considering case study of use of Agricultural Production System Simulator (APSIM) on management of agriculture system in rainfed area of world. The review would be useful for researcher, students and teachers working in the field of climate change and crop productions to recognize the use of modern approaches in the improvement of agricultural sector.

Keywords: Food security; climate smart agriculture; nutrient use efficiency; bioinformatics; APSIM.
Abbreviations: APSIM_Agricultural Production System Simulator; FAO_Food and Agriculture Organisation; UNCSD_United Nations Conference on Sustainable Development; IPCC_ Intergovernmental Panel on Climate Change; QTL_Quantitative trait loci; RuBisco _Ribulosebisphospahte carboxylase.

Introduction

The economic development of countries depends upon climate sensitive sector (CSS) that is agriculture which is the backbone of most of the developing countries like Pakistan. Similarly, agriculture is the main sector which might help to reduce poverty since it was earlier reported that proportion of people living less than $1.25 /day had dropped (FAO, 2012). Therefore, to eradicate hunger and poverty it is imperative to focus concentration toward agriculture sector especially in context of climate change. World population is increasing with high pace and it will be 8 Billion in 2025 (UN, 2012) therefore, understanding of the impacts of climate variability on agriculture needs more attention to feed billion of population. According to UN (United Nations) estimates, around 60% of the world population lived in Asia during 2011-12 and population is increasing with double pace i.e. 1 % per year. World is ecologically more fragile due to multiple climate stresses and there effects are more on nature dependent sector i.e. agriculture therefore, need of mitigation and adaptation is necessary for this sector (Acosta-Michlik and Espaldon, 2008). This sector have direct link with poorest peoples thus, their vulnerability to future climatic extremes would be more open (Nanda, 2009). Though at present, the Asia is most populous continent around the globe yet future scenario would shift towards Africa (United Nations, 2012). However, to feed more than 9 billion people by 2050 such measures like best adapted crop varieties, selection of suitable sowing time, re-designing of cropping systems, choice of best crop and land management practices needs to be taken using simulation approaches.

The developing countries agriculture including Pakistan would be affected by severe desertification, floods, drought, rising temperature and extreme events as reported by Intergovernmental Panel on Climate Change (IPCC, 2009). Therefore, climate change and population growth may threaten food security which would necessitate coordinated efforts to ensure food security on long term basis. Long term analysis of data revealed that change in weather patterns and global warming may lead to civil wars in Europe, Asia and Africa (Zhang et al., 2007; Burke et al., 2009). Therefore, to mitigate ill effects of climate change and to increase and maintain crop productivity, holistic approach needs to be selected by agriculture researchers. This includes development of stress tolerant genotypes together with sustainable crop and natural resources management with implementation of all these efforts by consistent sound policies. In most of the developing countries particularly in Pakistan due to lack of vibrant and consistent policies research outputs most of the time end nowhere. The effect of climate change are being anticipated to be more severe in the developing world as more than 50% of the population in the developing world is involved in agriculture (FAO, 2012) and maximum world population lives in this region (United Nations Population Division; DoEaSA, 2012).

Impact of climate change

The effects of climate change was apparent from several decades and it is evident from raised simulation of temperature, increases or decrease in rainfall, increases in sea level and cloud cover (IPCC, Fourth Assessment Report, 2007). Similarly extremes events may prevail more often like increase in the intensity of rainfall, increased risk of duration of drought and cyclones. The models outcomes depicted increasing temperature (likely to be in the range of 2–4°C to 2100) and change in rainfall around the globe some regions might have drought while other side have floods. However, forecasting of rainfall is complex compared to temperature about which models have more certainty. Similarly, climate modelers have depicted certainty of extreme climatic events like droughts, floods, hot days and high intensity rainfall events. The impacts of all these extreme events on crop productivity are negative yet moderate rise in temperature would increase productivity while beyond 1^{o}C the effect becomes negative. However, the rise in CO_2 has significant positive effect on the productivity of crops. Therefore, it's essential to maintain sustainability in the productivity of crops by using models on regional scales which can forecast impact of extreme events on crops. This will help in the designing of decision support tool on regional scale. United Nations Conference on Sustainable Development (Rio+20, UNCSD, 2012**)** concluded that agriculture and food systems are basis of food security and to meet the challenges of climate change both need to be designed. Since agriculture impacts more on the world compared to anything else therefore, transformation in agriculture is essential to ensure yield sustainability, to reduce impacts of climate extremes and to build a resilience system according to the changing climate. This resilient system will ultimately reduce the impact of climate change on agriculture. Meanwhile, promotion of climate smart agriculture with the aim to reduce GHGE (Greenhouse Gas Emissions), enhanced resilience and reduced wastes with the increase in the productivity of small and large scale farmers might be beneficial.

Climate change, vulnerability and adaptation

Agriculture depends upon calamities of nature if climate is favourable it would lead to good crop yield thus ensuring food security. However, in the context of climate change the issue of food security will be more highlighted because of dependency of maximum population on agriculture. Since climate change is affecting the agriculture sector maximum therefore, adaptation approaches needs to be considered for survival of agriculture sector. These approaches includes empirical (use of past data to study the impact of climate change), Mechanistic crop modeling approaches (use of crop models like APSIM, DSSAT, EPIC etc. to build climate scenarios (Temperature, rainfall and CO_2 and different crops response under these climatic factors) and Niche-based approaches or agroecological zoning approaches (use of global models like GCM to study climatic parameters of climatic adaptations). Based on the outcomes of these approaches previous studies concluded that climate change will impact on grain production potentials which might be severe in developing countries (Fischer et al., 2005). Similarly, shifts in the patterns of pests/diseases and life cycles of weeds due to global climate change might also impact on agriculture (Estay et al., 2009). Therefore, systematic studies of different crop responses to climatic parameters and pest/disease will help to monitor the impact of climate change on crops. The world food economy will be affected by change in climate and it depends upon three factors i.e. nature of climate change (Temperature and rainfall trend), cropping system response and response of food economy to changs in the cropping system. The biotic factors which are the main cause of yield reduction include different kinds of plant diseases (Fusarium head blights, leaf/stem rust and spot blotch etc.) and insects/pests. Since by the year 2100 the temperature might rise between 0.9 to 3.5^{o}C resulting to frequent hot days/nights, variation in the intensity, frequency and timing of rainfall leading to change in the impacts of biotic factors (Dukes et al., 2009). Therefore, the quality and quantity of agricultural products will be severely affected due to change in the frequency and severity of biotic factors (Mestre-Sanchis and Feijoo-Bello, 2009). However, it is possible that with climate change some diseases may increase while others decreases thus producing neutral impact (Coakley et al., 1999). Now it is necessary to understand the drivers of change and design such strategies which can minimize the impact of climate change. Strategies like improving plant resistance to biotic stresses, agricultural practices (Choice of crops, change in the cropping patterns, rotation, time of planting and avoidance), chemical control and forecasting models might be used to minimize the virulence of biotic factors. Modeling, the early warning tool might be used to study biotic factors dynamics, their impacts and strategies to minimize and control them. The use of different modeling approaches like regression model of leaf wetness and temperature (Bourgeois et al., 2004), IpmPIPE (Integrated Pest Management Pest Information Platform for Extension and Education) (USDA, 2009), Rustmapper (Hodson et al., 2009) and DLIS (Desert Locust Information Service) (FAO, 2009) had proved benefits of modeling and GIS (Geographical Information Systems). Crops responses like accelerated life cycle, skipping of phenological stages, reduced leaf area and duration, inhibition of metabolism (photosynthesis and respiration) and impaired reproductive growth might be seen under different kinds of climatic stresses. However, increased CO_2 have beneficial effect on C3 crops like wheat, barley and rice (Leakey et al., 2006).

Table 1. Biotechnological development to coup climatic extremes.

Climate Change Problems	Biotechnological development	Advantages
Extreme Conditions	Gene sequences to identify flowering time	Matches crop phenology with available resources and minimum exposure to climatic extremes
Water stress or drought	Omic analyses and functional genomics	Understanding of mechanisms (regulatory networks) in plants under water stress to engineer drought tolerant genotypes
Extreme temperature	Phenotypic or Molecular markers	Understanding of physiological and genetic bases of heat tolerance to engineer heat tolerant genotypes
Salinity, inundation and reduced rainfall	Gene sequences and QTL mapping	Cell specific Na^+ excluding crops engineering
GHG due to fertilizer	Gene sequences	Crops with high nutrient use efficiency (NUE)
Diseases and pests	Simulation modelling/Bioinformatics	Disease/pest resistance

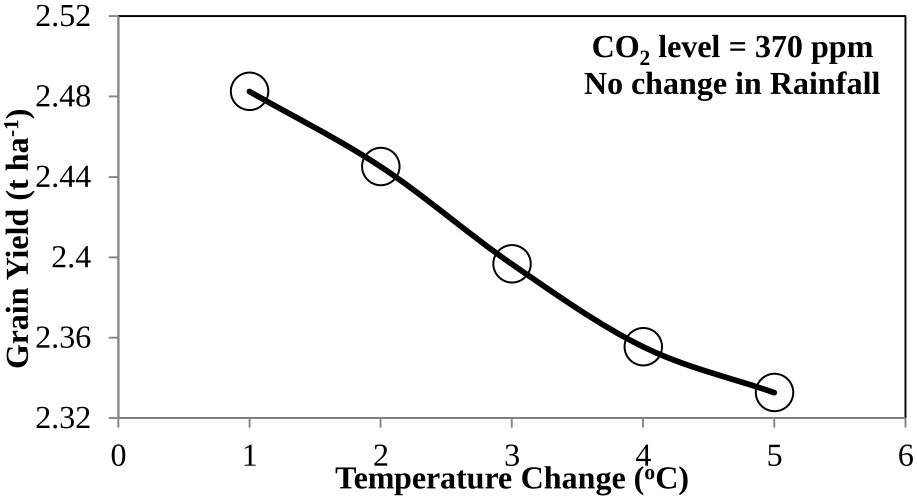

Fig 1. Impact of increased Temperature on grain yield of wheat simulated by APSIM/

The design of new adaptive genotypes in response to these climatic stresses might include study of QTL (Quantitative trait loci) traits and physiological and genetic options. Multilocations testing approaches using empirical models could be used to study the response of genotypes under contrasting environments (Genotypes x Environments Interactions) which could be helpful for breeders and researchers. The dissection of yield into its physiological components and understanding of stress adaptive traits (Deeper roots, Canopy cooling, Transpiration efficiency and Delayed senescence) may be the best options to adapt under changing climate (Ahmed et al., 2012). Therefore, the traits which will be demanding under rainfed agriculture as illustrated by Passioura, (1977) included photoprotection, transpiration efficiency, partitioning and water uptake. However, under irrigated environments with high temperature desirable traits might include photoprotection, efficient metabolism, partitioning, light interception and water uptake. To utilize all these traits, agronomic, environment and genetic strategies might be used to ameliorate the negative impacts of climatic stresses. Similarly, characterization of target ecosystem using models in context of future scenarios could be helpful to design an adaptation plans for all crops. Rainfed farming system in South Asia comprises of different management options depended upon rainfall as well as supplemental irrigation. Therefore, development of irrigation systems for rainfed area could improve grain yield by providing supplemental irrigation. This supplemental irrigation for rainfed agriculture could coup dry spells and eliminates or minimise the drought effect. The variability in the farming systems in the South Asian region may be due to climatic and soil factors. However, main rainfed areas of Pakistan, India and Afghanistan are dependent upon wheat based cropping system while eastern areas of South Asia, peoples mainly rely on rice.

Salinity and climate change

Salinity is common feature in arid areas (Ghassemi et al., 1995). Salinity, waterlogging and inundation affect crop production all around the globe and it might increases in future due to climatic extremes. However, its impacts increase due to waterlogging and inundation (Barrett-Lennard, 2003). For better planning, magnitude and extent of salinity are important to understand. Salinity could be divided into primary (linked with waterways, lakes and flood plains) and secondary (anthropomorphic origin linked with excessive rainfall more than crop delta resulting to capillary movement of water and salt to top soil layer). The crop growth and metabolism have been severely affected due to excessive accumulation of sodium and chloride ions in water resultantly decline of water potential in soil and lesser uptake by the roots. Therefore, desirable traits which will be demanding under saline stress may include sodium and chloride ions exclusion by the root, Sodium/Potassium ion discrimination, removal of ion from xylem, ions tolerance in crop tissues, osmotic adjustment, accumulation of ions in older leaves and seed viability and early maturing genotypes. These traits need to be considered in the breeding of future genotypes. The

Table 2. List of Models used as a Decision support tools.

Models	Details	References
ALMANAC	Agricultural Land Management Alternatives with Numerical Assessment Criteria	Kiniry et al., 2008
APEX	Agricultural Policy/Environmental extender model	Williams and Izaurralde, 2005
AUSCANE	Sugarcane, potential & water stress conditions, erosion	Jones et al., 1989
AQUACROP	Crop net irrigation, soil evaporation and crop response to different climatic variables simulation	FAO, 2012
Agro-BGC	enzyme-driven C4 photosynthesis, Generic PFT, dynamic, individual live and dead leaf, stem, and root carbon and nitrogen pools	Di Vittorio et al., 2010
Agro-IBIS	Atmosphere & Biosphere Models, Generic PFT, dynamic	Kucharik, 2003
Biome-BGC	Biogeochemical Cycles, ecosystem model,C4 photosynthesis	Ueyama et al., 2009
CANEGRO	Sugarcane, potential & water stress conditions	Inman-Bamber, 1991
CliCrop	a Crop Water-Stress and Irrigation Demand Model for an Integrated Global Assessment Modeling Approach	Fant et al., 2012
COTTAM	cotton plant model, timing irrigation application of field grown cotton with limited water supply	Jackson et al., 1990
CROPWAT	Crop water and irrigation requirement	FAO, 2012
CropSyst	Cropping system simulation model	Claudio et al., 2003
CERES family of models	Crop Environment Resource Synthesis	
CERES-Rice	Rice growth, water, nutrients dynamics	Timsin and Humphreys, 2006
CERES-Wheat	Wheat growth, water and nutrients dynamics	Timsin and Humphreys, 2006
CERES-MAIZE	Predictive, deterministic model designed to simulate corn growth, soil, water and temperature and soil nitrogen dynamics at a field scale for one growing season	Adams et al., 1990
CERES-barley	Barley growth, water and nutrients dynamics	Hoogenboom et al., 1992
CERES-sorghum	Sorghum growth, water and nutrients dynamics	Hoogenboom et al., 1992
CERES-millet	Millet growth, water and nutrients dynamics	Hoogenboom et al., 1992
CROPGRO series of models for legumes		
BEANGRO	Beans growth, water and nutrients dynamics	Hoogenboom et al., 1992
SOYGRO	Soyabean growth, water and nutrients dynamics	Adams et al., 1990
PNUTGRO	Peanut growth, water and nutrients dynamics	Hoogenboom et al., 1992
CROPSIM model series for root crops		
CROPSIM-cassava	Cassava growth, water and nutrients dynamics	Hoogenboom et al., 1992
SUBSTOR-potato	Potato growth, water and nutrients dynamics	Hoogenboom et al., 1992
DAFOSYM	DAIRY FORAGE SYSTEM MODEL	Jonghan et al., 2012
DSSAT	Decision support system for agrotechnology transfer framework of models includes all CERES, CROPGRO, BEANGRO and CROPSIM family	Bidogeza et al., 2012
DNDC	Denitrification and Decomposition	Changsheng et al., 2012
EPIC	Erosion Productivity Impact Calculator	Rinaldi and De Luca, 2012
FAO-MOSAICC	Modelling System for Agricultural Impacts of Climate Change	FAO, 2012
GCMs	General Circulation Models describe the global climate system, representing the complex dynamics of the atmosphere, oceans, and land with mathematical equations that balance mass and energy	Chen et al., 2012; Vanuytrecht et al., 2012
GWM	General weed model in row crops	Wiles et al., 1996
GOSSYM-COMAX	Cotton	Liang et al., 2012
GRAZPLAN	Pasture, water, lamb	King et al., 2012
IFSM	Integrated Farm System Model	Belflower et al., 2012
LUPINMOD	Lupin	Cheeroo-Nayamuth, 1999
LPJmL	Lund-Potsdam-Jena managed Land, Dynamic global vegetation and water balance model	Lapola et al., 2009
LINTUL	Light Interception and Utilization simulator	Jing et al., 2012
MERES	Methane Emissions from rice eco system	Aulakh et al., 2001
MISCANMOD	Crop specific	Clifton-Brown et al., 2000
MISCANFOR	Crop genotype specific	Hastings et al., 2009
MODVEX	Model development and validation system	Cheeroo-Nayamuth, 1999

Continued NDICEA	Nitrogen planner presents an integrated assessment on the question of nitrogen availability for your crops	Kanellopoulos et al., 2012
NTKenaf	Kenaf, potential growth, water stress	Muchow and Carberry, 1993
SLAM II	Forage harvesting operation	Buck et al., 1998
SWAT	Soil and Water assessment Tool	Santhi et al., 2007
SIMWASER	applicable tool to demonstrate and study plant – soil – water relationships as well as influence of land use, especially on ground water recharge.	Stastna abd Stenitzer 2005
SWIM	Soil and Water Integrated Model	Gottschalk et al., 2012
WOFOST	Wheat & maize, Water and nutrient	Tripathy et al., 2013

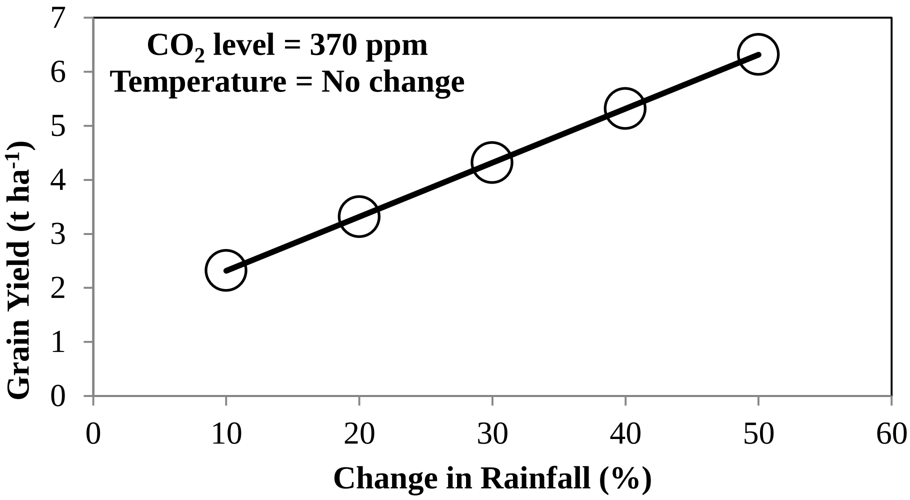

Fig 2. Impact of increased Rainfall on grain yield of wheat simulated by APSIM.

hypoxic conditions which develop due to excessive water in soils lead to unavailability of oxygen to the roots and anaerobic respiration. The growth of roots will be severely affected due to hypoxia resulting decreased root/shoot ratio and declined yield (Robertson et al., 2009). Therefore, genotypes those can adapt under hypoxia need to be used to maintain sustainability of crop yield. The adaptive genotypes have physiological traits like increased porosity in the aerenchyma (McDonald et al., 2002) and having barrier in the root which hinders loss of radial oxygen (Colmer, 2003). Climate change would increase all these phenomena's therefore, it is necessary to consider domestication of halophytes for protection of dryland areas of the world. Similarly, assessment of crops and land using modern tools like modeling and remote sensing will be very beneficial.

Water, GHG and Climate Change

The supply of water needed for crop production and food for growing population will be major problem under changing climate. The staple grain crops like wheat, maize and rice will be under major threats because of lesser availability of water. These major staples food crops occupy 40% of the global crop area of 1.4 billion ha (FAOSTAT, 2012) and provide 37% of all protein and 44% of all calories. Wheat is the most widely grown crop with average yield of 3 t/ha and it is grown over an area of 220 mha. Under changing climate the wheat varieties having enhanced tolerance to heat and drought, high nutrient and water use efficiency, resistance to diseases and ability to cope with climatic extremes will be best adapted. Therefore, it's necessary to use such procedures like multi-location testing which might quantify the impact of different climatic conditions around the globe on wheat crop yield. However, this is impossible on field scale therefore models (APSIM and DSSAT) could be used to elaborate the impact of multi environments (ME) on crop yield and its establishment. The big contributors to the climate change are greenhouse gases those poses major threats to crop production. These gases are released due to extensive use of fertilizers and cultural operation therefore, it is recommended that crops with high nutrient use efficiency (NUE) and potential to grow under limited conditions needs to be considered. The use of drought resistant rice is a step forward in this regard (Farooq et al., 2009). Doubling and even trebling of CO_2 in coming decades will pose a major threat to climate (IPCC, 2009). However, CO_2 is very important reactant of photosynthesis reaction in plants resulting to the production of phtoassimilates. Therefore, it also has fertilization effect on crops especially for C3 crops. Its increased concentration resulted to more affinity to Rubisco (Ribulose bisphospahte carboxylase) and declined photorespiration (30% of phtoassimilates loss due this process) (Aliyev, 2012). However, under resource limited conditions the response of crops for yield was very low as predicted by models (Long et al., 2006 a and b) which may be due to delayed reproductive phase (Castro et al., 2009). Similarly, temperature and water are the limiting factors for crop production hence productivity of crops are not up to the mark due to rise in temperature and uncertainty in rainfall. The spatial and temporal variability in rainfall and temperature may be beneficial for some areas (e.g. Siberia and northern America) where there is no or limited crop production but problems for suitable crop growing areas. The earlier research confirmed this observation as reported by simulation studies in south-east Australia where wheat yield was projected to reduce by 29% (Anwar et al., 2007), rice yield may drop to 10% due to 1°C rise in temperature (Peng et al., 2004). The skipping of phenological stages and earlier maturity of crop due to rise in temperature resulted to decline crop productivity (Asseng et al., 2004). The increased temperature speeded up the photorespiration and strong affinity toward oxygen due to its high solubility compared to CO_2 (Parry et al., 2003 a and b). Therefore, variability in temperature during crop growing cycle resulted to decline yield (Cassman, 2007) as every crop requires specific critical temperature for grain development. The critical temperature reported for rice (Matsui et al., 1997) and wheat (Saini and Aspinall, 1982) are 34 and 30^{o}C respectively. However, there are some crop traits those could be used to mitigate the effects of rise in temperature and CO_2. The rise in temperature created high evapotranspiration losses, but elevated carbon dioxide decreased stomatal conductance and evapotranspiration losses, thus balanced the equilibrium. The availability of water is more critical as under deficient moisture wheat crop yield decreased to 1-2 t ha^{-1}(Foulkes et al., 2002). The unavailability of water might lead to crop failure and declined in crop production.

Climate Change and Modern approaches

The issue of climate change could be couped by using new modern approaches like wide crosses, transgenesis or mutagenesis. The use of techniques to produce and regenerate maximum amount of RuBisco in leaves are very helpful in this regard, as this enzyme has more affinity toward oxygen and low catalytic rate (K_{cat}). Therefore, by increasing the concentration of RuBisco in leaves the photosynthetic rate could be increased. This will ultimately solve the issue of sustainability in the crop productivity and fertilizer use efficiency by controlling the deficiency of RuBisco. The modified mechanism might increase nitrogen use efficiency in C3 and C4 (Ghannoum et al., 2005) crops while 100% increase in the photosynthesis of C3 crops (Parry et al., 2007). Chloroplast transformation might increase the specificity factor (Zhu et al., 2004) in crops for RuBisco toward CO_2 while induction of C4 metabolism into C3 crops might be beneficial (Hibberd et al., 2008). Therefore, 30% photo-assimilates loss due to photorespiration might be decreased by using procedures like metabolic engineering (Kebeish et al., 2007). Similarly, the gap between potential and actual yield could be overcome by decreasing emissions of greenhouse gases (GHG). Drought stress is another important target which has high correlation with crop yield. The yield of crop which is complex multigenic trait might be broken into crop architecture, development and phenology. However, modern techniques of biotechnology could be used to introduce new genes which increases water use efficiency (WUE) by minimizing water loss and without dropping CO_2 assimilation (Yu et al., 2008). Similarly crop survival and sustainability in the yield under drought is possible by induction of drought responsive genes (Parry et al., 2005). However, genotypes selection programme must be under different climatic scenario so that influence of climate change on genotypes might be incorporated. Crop varieties having modified development rates, decreased sensitivity to increased temperature will be required in future thus crop ideotypes selection under changing climate may be secure option.

Nutrients use efficiency and Climate Change

Nutrients use efficiency under changing climate need to be addressed, being major macronutrients, study of N dynamics could help to bring sustainability in the crop yield. Nitrogen use efficiency (NUE) is therefore an important trait, a product of two subtraits that is NUpE (N uptake efficiency) and NUtE (nitrogen utilization efficiency). Mathematically, NUE= NUpE x NUtE. NUpE is the trait linked with root architecture and activity of transporter. However, NUtE is feature related to canopy architecture like height, leaf area, angle and its orientation. The root growth as reported by Wojciechowski et al., (2009) is an important trait which might bring green revolution (Lynch, 2007) in future. Therefore, crop ideotypes which have high root proliferation and C allocation to below ground material might improve water and nitrogen use efficiency. Similarly, use of fertilizers and other inputs for crop production contributes to the release of CH_4 (20 times more than CO_2 as a GHG) (Yan et al., 2003), oxides of nitrogen (NOX) and ammonia. The use of inputs and cultural operations to meet the demand of food for ever increasing world population might increase the emissions of all these gasses resulting to extreme climate change. Use of crop improvement procedures might increase the efficiency of resources (CO_2, water and nitrogen) and reduce the emissions of GHG. These improvement plans includes intrinsic increase in yield potential to combat abiotic (Takeda and Matsuoka, 2008) and biotic (Brown, 2002) stresses. Similarly, use of transgenic biotechnological approaches to improve RuBisco function (Parry et al., 2007), induction of C4 mechanism in C3 grain crops (Hibberd et al., 2008) and improvement in root architecture might help to combat climate change. The main drivers of increased demand of food in future will be economic growth and population. The increase food production might come from the intensive management of agricultural systems which were big contributor of GHG. According to Foley et al. (2005) almost 40% of the land was used for crop production. The staple crops like rice, wheat and maize were dominatingly grown in the main cropping systems of the world. The major cropping systems included rice-wheat, maize-wheat and fallow-wheat. The total area used for the production of rice and maize were greater than 155 mha (FAOSTAT, 2012). The widely grown crop all around the globe was wheat and it covered an area of more than 215 mha while its area in Asia was more than 50% (FAOSTAT, 2012). The largest number of people in the world depends upon rice who gave more importance to this crop than any other crop. The 90% of the rice was grown and consumed in Asia while maize grown dominantly in America followed by Asia and Africa. However, maize being also used as an animal feed and production of biofuel. The trend of yield of these three major crops all around the world and especially in Pakistan are shown in Fig. 8 depicting the importance of these crops. According to IPCC, (2006) agriculture contributed 10-12% (5.1-6.1 Gigatonnes of carbon dioxide equivalents, $GtCO_2$-eq) of GHG while it released almost 60% of NOX. The use of improved agricultural management like conservation agriculture, C sequestration, improved crop and land management, degraded land restoration and improved rice and livestock management could mitigate the problem of GHG emissions from agriculture sector (Barker et al., 2007). Therefore, adoption of resource conservation agriculture could buffer the

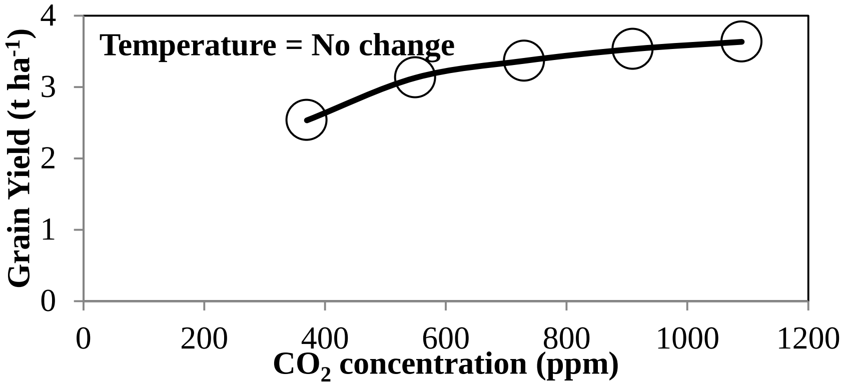

Fig 3. Impact of increased atmospheric CO_2 concentration on grain yield ofwheat simulated by APSIM.

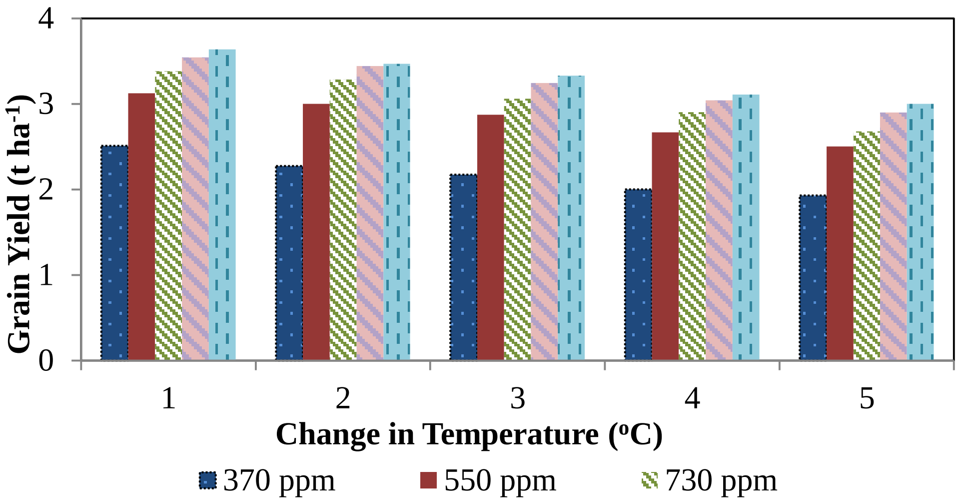

Fig 4. Impact of CO_2 concentration at five Temperature levels on grain yield of wheat simulated by APSIM.

major cropping system against the impact of climate change. The triangle of conservation agriculture that is minimum soil disturbance, crop rotations and ground cover could be considered as resilient system under changing climate (Hobbs et al., 2008). Soil borne diseases, distribution and severity might changes due to climate change and it might affect the sustainability of major cropping system. Therefore, use of different microbial strains in the rhizosphere (soil amendments), use of specific genotypes (Mazzola et al. 2004), crop rotation (Kirkegaard et al. 2008), pyrosequencing and metagenomics (Van Elsas et al., 2008) for evaluation of microbes might control the soil borne diseases. This may reduce the spread of soil borne diseases as well as mitigate the impact of climate change by reduction of further spread of different diseases.

Biotechnology and Climate Change

Biotechnology, the modern day tool is use of living organism for the improvement of agriculture. A 1°C rise in temperature may threaten rainfed cereal, however, rise in temperature beyond 3 °C the losses would become to the level of total devastation (Easterling et al., 2007). The use of biotechnology could mitigate the major crops from different insect/pest attacks and diseases reduce dependence on fertilizer and good yield stability (Table I). The procedure use to build variation in genotypes includes Introgression (genes are added by continuous backcrossing now boosted by markers), amphiploids (addition of complete genomes) and Induced genetic variation (Mutagenesis, In vitro culture and Insertional mutagenesis). Similarly, biotechnology helped in the identification and quantification of genetic variation as well as qualitative and quantitative traits. The understanding of crop response to different mechanism against complex stresses like drought to build stress resistant genotypes is now possible by the use of biotechnology. Similarly, use of modeling approaches linked with phenotypic, molecular and physiological knowledge could help to bring sustainability in the crop yield and mitigation tools against climate change.

Bioinformatics and Climate Change

Predictions/Simulations of crop response to climate change are the best ways to design a decision support system. The use of crop models (DSSAT, AQUACrop, APSIM etc.) (Ahmed, 2012; Ahmed et al, 2013) and GIS are modern innovative powerful tools used now days to mitigate the impact of climate change on crop production and environment. However, there are some statistical models used by researcher to study the impact of different variables on crop production. Similarly, models have proved to be valuable tools in agricultural crops production under changing climate (Ahmed, 2011) by considering the interactions of soil, climate and crop genotypic coefficients. Modeling efficiency has been visualized in future with several opportunities including scientific inspection or analysis, decision making by yield manager and a key role in understanding and advancing the genetic regulation of plant

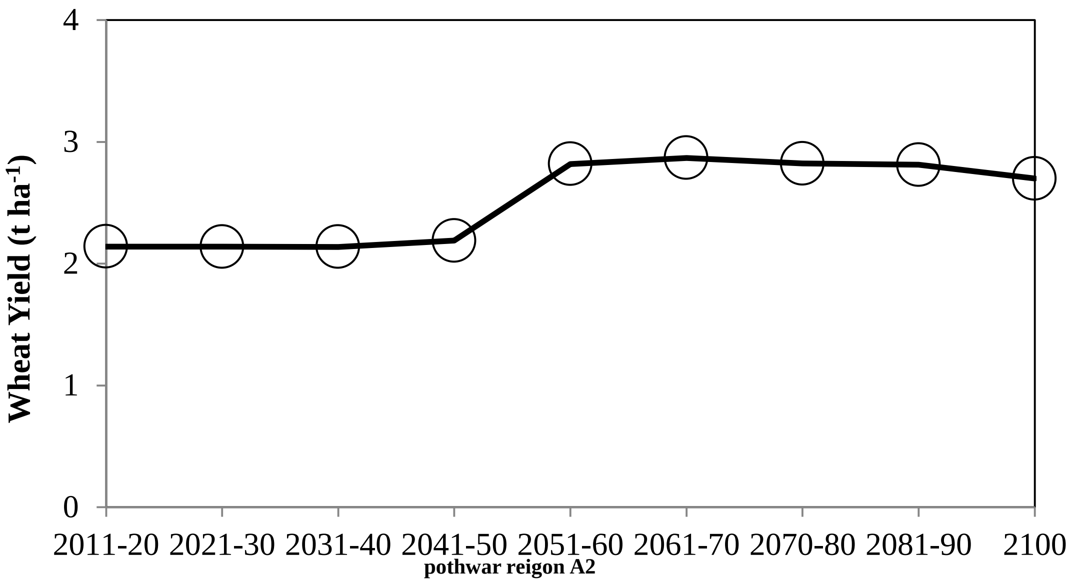

Fig 5. Impact of climate change on wheat yield in Pothwar region (Islamabad) of Pakistan under A2 scenarios.

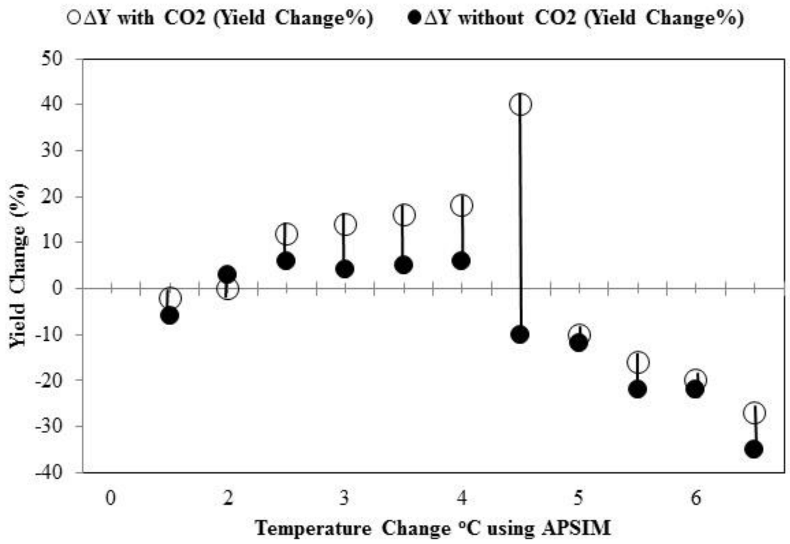

Fig 6. APSIM model estimates of wheat yield changes for different levels of temperature for (a) Pakistan under A2 scenarios of IPCC.

improvement and plant performance (Ahmed and Hassan, 2011). The models ability to simulate crops responses to different management and climatic conditions made them powerful tools for predictive analysis. The use of GIS and models in the development of fourth IPCC assessment report proved their importance (Easterling et al., 2007). The potential changes occurring on spatial scale might be depicted by using GIS and its major framework used to study the impact of climate change on agriculture (Parry et al., 2005). The outputs of GCMs in data formats suitable for GIS-based systems are available. The crop performance under variable climatic conditions might be simulated by integrating the information of agroclimatology, crop ecology, physiology and soil chemistry into crop models. However, to study the impact of climate change on crop production models were coupled with global or regional climate change models and simulation was performed under range of scenarios. APSIM and CERES have showed their suitability and gave been coupled with different GCMs (Hadley Centre's HadCM3 or CSIRO's MK3) (Defra, 2012). The use of crop models with good accuracy in making of third and fourth assessment report of IPCC proved their success. Meanwhile, accurate yield simulation of wheat under wide range of climatic conditions with 1-3^{o}C rise in temperature might be helpful for future decision making processes for selection of wheat genotypes, its sowing time and suitable growing area (Ahmed, 2011). However, there might be some uncertainties like CO_2 fertilization impacts which need to be addressed (Tubiello et al., 2007). The use of GIS as a modern tool proved its success and it can be defined as computer technology uses geographical information system as an analytic framework for managing and assimilating data, problem solving and understanding past present and future. Most of the crop models were parameterized and validate on local scale but models like APSIM (Ahmed, 2011; Ahmed et al, 2013), CropSyst (Stockle et al., 2003), DSSAT (Hoogenboom et al., 2004) and EPIC (Meinardus et al., 1998) might work on global level because of their robustness. The simple model uses intercepted solar radiation as a conversion factor to dry matter on daily scale while complex models simulate growth on minute's timescale considering different biochemical reactions in crops. In general, the decisions related to crop establishment, conservation of genetic resources and establishments of crop in the scenario of future climate change tools like GIS and crop models could be used with good success (Table II).

Simulation Modeling: Case Study of Use of APSIM in Crop Production under Rainfed Areas of Pakistan (Islamabad)

APSIM field crop model was used under rainfed region to study the impact of different climatic variables on wheat crop yield. Since crop simulation models are meaningful tools to understand the impact of soil, climate and management (Ahmed, 2012; Ahmed et al, 2013), therefore, APSIM was used to analyse the impact of climatic variability using A2 scenarios given by IPCC. The scenarios were increased temperature by one degree from the base line temperature of fifty two years average and increased carbon dioxide concentration (550, 730, 910 and 1090 ppm from the base line 370 ppm) while rainfall changed from 10-50%. The APSIM simulation of wheat grain yield for different temperature level at ambient carbon dioxide concentration (Fig. 1) revealed that increased temperature decreased yield significantly. The reduction in yield was almost linear with increased temperature. Similar results were reported by Asseng et al, (2004) with the conclusion that increased temperature hastens crop maturity, resulted reduced drymatter and limited the yield. However, increased rainfall depicted positive effects on wheat grain yield when simulated for five different levels of rainfall at ambient CO_2 concentration (Fig. 2). Therefore, it may be concluded that in future wheat crop yield would increase provided there is no change in temperature and rainfall increases significantly from the baseline rainfall. Similarly, with increased CO_2 concentration wheat yield may increase provided no change in temperature occurs. The increase in yield may range from 2.53 to 3.13 t ha^{-1} if CO_2 increases from 370ppm to 550 ppm while it goes to maximum at maximum concentration of CO_2 (Fig. 3). Therefore, it may be concluded that increased carbon dioxide or carbon dioxide fertilization boosted grain yield. Similar results were reported by Leakey et al., (2009) who concluded that increased CO_2 affected crops by photosynthesis and transpiration. The impact of increased CO_2 on photosynthesis was higher for C3 crops compared to C4 (Leakey et al., 2006). Similarly, higher CO_2 increased mobilization of assimilates and limited the attack of pathogen while Drake et al., (1997) reported positive impact of CO_2 on growth of plants. The CO_2 level may doubled in 2050, thus, yield of C3 crops would be improved through the increased diffusion of CO_2 in stomata. However, to capture the CO_2 more effectively research is going on to transfer Kranz anatomy genes in C3 crops so that its fixation might occur at great pace (Hibberd et al., 2008). The increased CO_2 decreased stomatal conductance which could help to mitigate the evapotranspiration losses under high temperature. Similarly, Springer and Ward (2007) reported that higher CO_2 has impact on crop development and allocation of C to underground plant parts is best strategy to increase WUE. The combined simulation of increased temperature and CO_2 on grain yield revealed that at lowered temperature and higher CO_2 it remained at maximum (Fig. 4). Similarly earlier research confirmed that with increased temperature reduced yield but this effect might be compensated by elevated CO_2 concentration (Anwar et al., 2007). APSIM simulation of crop yield requires minimum data set (MDS) which includes climatic data on daily scale. Therefore, long-term projection was developed by historic climatic data records worked by Pakistan Meteorological department using ECHAM5 Global Climate Model (GCM) output. The increased in temperature for Pothwar area of Pakistan under A2 scenario is 0.01, 0.03 and 0.05 ^oC while change in rainfall is 6.1, 8.1 and 9.5 mm to the late 21^{th} century (IPCC, 2009). The A2 scenario depicted lowest economic growth in future due to climate change and population growth. The long term simulation of wheat yield revealed a significant increase which might be due to rainfall and rise in CO_2 (Fig. 5). Similarly, change in the yield due to change in the temperature and CO_2 simulated by APSIM depicted significant impact by climate change (Fig. 6). Similar results were reported by Leaky et al., (2009) who reported that in future increased crop yield might be due to fertilization effect of raising CO_2. Meinke, (1996) stated that model simulation was dependent upon triangle of climate, soil and plant genetic features.

Conclusions

The climate change is affecting agriculture with high pace. Therefore, application of crop and land management practices including reduction in GHG emissions from cropping systems, crop breeding for harsh environments, cultivars adaptations, models validation and parameterizations, use of remote sensing, enhancing resource use efficiency and modeling and controlling epidemic diseases may be used to maintain sustainability of crop yield. Moreover, use of GCMs and RCMs to improve the rainfall forecasts might bridge the gap between actual and potential yield which will ultimately reduce the catastrophic effect of climate change. The issue of food security especially in Africa and South Asia could be solved by adopting crops most adaptable to those regions. Similarly, the approach of ICM (Integrated crop management) is base for sustainable and precision agriculture which might include simulation modeling and remote sensing. Meanwhile multi-disciplinary breeding with emphasis on warmer and drier environments needs to be opted as a front line approach. This will ultimately bring sustainability in crop productivity and enhances resources use efficiencies. The integration of conventional and biotechnological approaches might be considered to minimize GHG, reduces the use of energy intensive inputs and increases the efficiency of productions. In general the mitigation approaches which have synergic relationship with crop productivity and climate change need to be opted to save future.

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