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Review Article

INTEGRATED ASSESSMENT OF CLIMATE CHANGE ADAPTATIONS FOR THE RESILIENT AGRICULTURAL PRODUCTION SYSTEM IN SOUTH PUNJAB, PAKISTAN

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Abstract

Agricultural production systems are multidimensional, interlinked, complex and diverse, and need special attention to cope with changing climate, technology and changes in input and output market structure. Climate change is an evident phenomenon that drastically affects the agricultural production system. The developing countries mainly rely on farming activities for the needs of food and Fiber. This study aims to find climate change impacts and economic analysis of proposed adaptations and to formulate a climate-resilient agricultural production system. The primary and secondary data were collected by conducting a well-designed South Punjab survey. The secondary data about historical crop yields, socioeconomic profiles, climate data, and crop simulation results are incorporated into the model. The TOA-MD (Tradeoff analysis multidimensional impact assessment) model was used for the economic analysis. The results showed substantial negative impacts of climate change on farm income. The adaptations regarding climatic variations are present and increase the net farm returns adopted by farming communities, which are projected in public policies. The financial inclusion of the farming community is needed in terms of farm insurance and finance.

Keywords: Climate change, Resilient Agriculture, Pakistan, Vulnerability
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1. INTRODUCTION

Bionetworks and food security are badly affected by climatic variations, and global sustainable development faces severe challenges due to these vital issues. Climatic variations, population rise, and resource degradation (Hussain et al., 2020). The developing world must formulate policies to cope with climate change challenges and increase the adaptive capacity of communities to respond to these variations (Asseng et al., 2019). Recently Pakistan's economy facing severe challenges in meeting the domestic demands for food and fiber due to flood and drought conditions the reported losses are alarming (Nhamo et al., 2019; Santos et al., 2020).

Climatic variations are evident and pose a great threat to food value chains and farming production systems (Nasir et al., 2020). The variation in rainfall patterns and changes in temperature causes major shifts in cropping patterns and farming yields. Extreme climate events like draughts and floods destroy the economies of developing countries in Asia and Africa. Climatic variants and resulting calamities hit the communities in a harsh way in terms of global food security and sustainable development (Shaffril et al., 2020). For the prompt response to changing climate, it is necessary to estimate the impacts of climatic changes on cropping patterns and formulate long-term agricultural policies in synergy with climate policy (IPCC, 2007; Janes et al., 2019).

The development framework needs the integration of various policies for real impacts on communities. To combat climate-related challenges, the biggest factor of risk and uncertainty is the lack of data availability and future production systems (Xenarios *et al*., 2020). There are planned and unplanned adaptations from farmer ends that resulted into some progressive and some economically unprogressive segments of society. It is evident that changing climatic patterns will badly affect the food system and induce shifts in farm practices (Kellogg, 2019). The earth's temperature will rise 1.5-2 degrees C^{o} by 2100 (IPCC, 2013). Pakistan is ranked 8th position in the Long-Term Climate Risk Index and 16th in CCVI (German Watch, 2019). South Asia will be severely affected by climate change; by 2050, it may lose 50% of its wheat productivity (Nasir *et al*., 2019).

Climatic variation seriously threatens global food chains and trade by drastically affecting crop yields. Sustainable development goals could only be achieved if the rising challenges of population growth and climate uncertainties are coped effectively across the globe. The disparity between high-income and low-income countries creates great challenges for emerging economies in formulating policies and allocating funds to cope with these challenges. The policy formulation has multi-tier effects regarding resource conservation, environmental sustainability, and growth of the economy (IPCC, 2014; (Nasir et al., 2020).

Global, regional, and local actions to cope with climate change need synergies between mitigation and adaptation efforts. The adaptation efforts must consider the whole value chain of farming activities to tackle the diverse issues, and the emissions and externalities must be chattered in whole value chains. The policies must also contain mitigation efforts like carbon sinks, water conservation, and pollution reduction strategies in the policy response regarding adapting to the climate (Ahmad and Afzal, 2020). The adaptation strategies must be formulated by consulting specific geographical farm locations and farming communities. Community engagement could positively impact awareness of climatic challenges in farming populations. The adaptation must consider the socioeconomic, policy, and institutional factors that can make a remarkable difference regarding the adoption of climate variations (Khan et al., 2020).

Climate change is a global issue, and it affects the whole planet's food supply by changes in temperatures and precipitation patterns that will lead to changes in crop yields, length of growing season, and droughts. Extreme events will decrease yields and cause biodiversity shifts and changes in crop varieties along with the rise of new pests and diseases. The climatic pattern changes affected the food security/food supply, trade structure, and food prices (Farhad and Wang, 2020).

This study aims at finding ways to estimate climate change's impacts and finding ways to cope with such great challenges for the next generations. The coping strategies for future generations, their economic viability, adoption rate, and impacts on farm income and poverty.

2. Materials and Methods

This study is based on the robust downscale climate scenarios generated in AgMIP phase II protocols. The study area comprises five major cotton-producing districts in the Cotton-Wheat cropping system (Major Crops), as shown in Figure 1. The main crops included in the analysis are cotton, wheat, and allied agricultural activities like livestock and fodder production. The study also includes the non-farm agricultural income to capture the dynamics of the development shift of farming community income and socioeconomic shifts. This study utilizes primary and secondary data in analysis. The primary data was collected with the help of a well-structured questionnaire, and a survey was designed to retrieve the data from the farming community. The farmers were selected using a stratified sampling method. The climate and crop model outcomes were used as secondary economic analysis data. Two RCP 4.5 and 8.5, two crop models (DSSAT and APSIM) with five GCM used in the analysis for climatic scenarios (Ahmad et al., 2021).

The TOA-MD (Trade of analysis multidimensional impacts assessment) model is used to analyze the impact of climate change on socioeconomic indicators, along with the adoption rate and adaptation benefits of proposed adaptations in the study area. The livestock activity-milking and meat production (i.e., buffalo, cow, goats, bullock raring), minor/ fodder crops (i.e., sorghum, maize, lucerne, Persian clover, and other fodder crops), cotton is a kharif crop while wheat is a rabi crop.

is multidisciplinary and runs a comprehensive data set to capture the broader picture utilizing the information on whole farm activity (Antle et al., 2015; Antle and Valdivia, 2011).

The farming system is comprised of crops (cotton, wheat, and fodder) along with livestock and non-farm income. The farm returns for all systems, subsystems and activities are defined as,

$$R_{hsg} = P_{hsg} Y_{hsg} - C_{hsg} - F_{hsg} / \Delta$$

The variances are calculated by following formulas for activity g.

$$\varphi_{hsgj} = \varphi_{hs}\, \varphi_{hsg} \varphi_{hsj} \; for\ all\ g \neq j$$

$$M_{hs} = A_s \mu_{hC} + \rho_{hF} \sigma_{hF} \sigma_{hC}$$

$$S^2{}_{hs} = A^2{}_s \sigma^2{}_{hs} + \mu_s{}^2 \sigma^2{}_{sF} + \sigma_{sF}{}^2 \sigma^2{}_{hs} + \{A_s \sigma_{hs} + \mu_s \sigma_{sF} |\rho_{hF}| + 4 A_s \mu_s \rho_{hF}\} \sigma_{hs} \sigma_{sF}$$

3. RESULTS AND DISCUSSION

The results based on the simulation and TOA-MD results projected that the CC impacts are vital on current and future agricultural production systems.) Table 1

District	Latitude	Longitude
Bahawalnagar	29.6	73.1
Bahawalpur	29.6	72.2
Lodhran	29.6	71.7
Multan	30.2	71.5
Rahim Yar Khan	28.7	70.7

Figure 1: Study area along the farm positions around met stations.

The TOA-MD model used for assessment is developed especially for climate change impacts and adaptation analysis. It is a comprehensive model that could be used for impact assessment of technology and widely used for climate and ecosystem Analysis. It takes the input of a heterogenous farm population along with simulated yields that describe the change caused by environmental factors. The model compares the two systems based on input sheets and parameters, and the outcome is in the form of vulnerability, per capita income changes, and farm Poverty after the changed system. TOA-MD model

describes the socioeconomic profile of the farms under consideration.

Cotton has a vital role in Pakistan's economy by contributing the highest share of foreign exchange earnings due to the well-functioning textile sector (Nazeer et al., 2023). Cotton also provides livelihoods for the cotton wheat cropping system as labor is utilized from sowing to picking (Ahmad et al., 2023). The share of crops in net farm returns are 54.93, 35.88, 092, 0.92, and 7.35 percent for cotton, wheat, Rabi fodder, Kharif fodder, and livestock. Livestock is also a major contributor to the net returns of farms.

Table 1: Description of socioeconomic and farm profile of study area

Socioeconomic Indicators	Units	Mean	Standard Deviation
Household head age	Years	35	8.6
Farming experience of farmer	Years	12.3	4.4
Education of respondent	Years of Schooling	8.7	2.9
Area owned	Ha	4.69	5.3
Family Size	Member	5.5	1.3
Cotton area	Ha	4.05	4.7
Wheat area	Ha	4.08	4.70
Rice area	Ha	0.21	0.80
Sugarcane area	Ha	0.08	0.4
Fodder	Ha	0.56	0.8
Non-farm Income	Rupees per season	15887.6	24145.6
Herd Size of farm	Number of animals	9	5.13
Land Holding	Ha	5.014	5.5
Rent per acre	Rupees	5187	11113.7
Area rented in	Ha	0.445	2.3

Source: Calculated from Survey Data

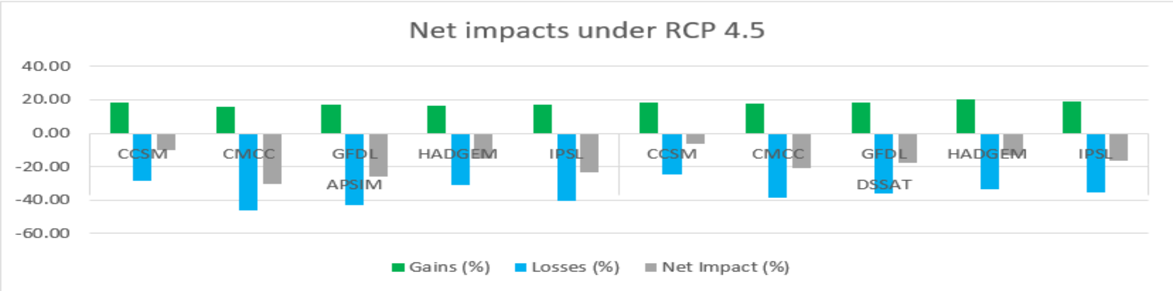
Table 2: Distribution of net farm returns in various farm activities (Rupees/farm)

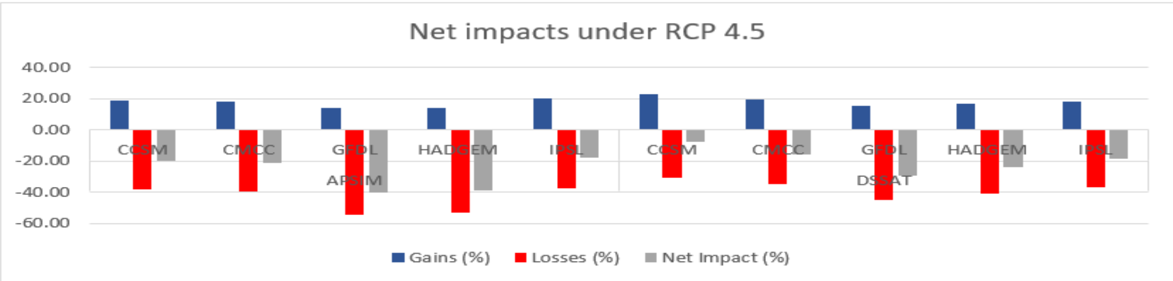
Strata	Wheat	Cotton	Rabi fodder	Kharif fodder	Livestock
Bahawalnagar	253627	398966.5	8328.558	8500.194	50878.6
Bahawalpur	248465.4	387071.4	5732.748	5730.752	52462.2
Lodhran	238884.9	389802.8	6415.859	6515.719	33709.3
Multan	271410.8	335551.9	3387.121	3495.758	5275.9
Rahim Yar Khan	229331.6	389487.6	8089.145	7039.893	42942
AVERAGE	248343.8	380176.3	6390.886	6256.663	50879.6
Percentage share in total net farm returns	**35.88**	**54.93**	**0.92**	**0.90**	**7.35**

The relative yield distribution of wheat and cotton is shown in Table 3 for modeled crops. The analytics and model outcomes projected that cotton is relatively more sensitive to climatic variations than wheat, and the decrease in cotton yield ranges from 14 to 82 percent. The cotton is highly sensitive to temperature and rainfall variations and responds to humidity at the time of harvesting. The hot scenarios showed that there is no germination of cotton crops, and complete death of plants could happen due to heat shock. humid scenarios are also not productive for cotton production. The wheat crop yield is increased in middle, cool, dry, and cool wet GCMs. The yield of wheat is reduced under a hot, dry scenario at large.

Table 3: Relative Yield Distributions for Modeled Crops

Crops	Crop Model-RCPs	GCMs				
		Middle	Hot Dry	Cool Dry	Hot Wet	Cool Wet
Cotton	APSIM_4.5	0.565	0.330	0.704	0.348	0.489
	APSIM_8.5	0.56	0.19	0.46	0.18	0.50
	DSSAT_4.5	0.691	0.599	0.869	0.672	0.614
	DSSAT_8.5	0.86	0.47	0.69	0.54	0.92
Wheat	APSIM_4.5	0.985	0.859	1.014	0.996	0.887
	APSIM_8.5	0.875	0.885	0.998	0.997	1.021
	DSSAT_4.5	1.018	0.894	0.979	0.933	1.052
	DSSAT_8.5	1.021	0.856	0.963	0.933	1.087





The resulting socioeconomic impacts due to declining yields are vital to decreasing the net farm income and increasing farm Poverty and PCI (per capita income). The net impacts of climatic variations are negative under all GCM and RCPs. The net farm returns decrease due to climatic variations under all scenarios, as shown in Figure 3.

The second objective of this research emphasizes the adaptation efforts regarding these serious climate change effects in the study area. The adaptations about biophysical, socioeconomic, and institutional variables were gathered as an adaptation package and then analyzed in an economic package considering the cost-benefit analysis.

The economic analysis for the proposed adaptations was performed for two pathways sustainable development pathways under high and low-price ranges. The results are described in Table 5. The adaptation package includes high-yielding cultivars, increasing the amount of urea, increasing plant population, and sowing density that are included in the analytics. The proposed adaptation Virtual Cultivars, sowing density increased by 10 percent, and balanced use of fertilizer are analyzed by economic model while crop diversification, input subsidy on seed and fertilizers, crop, and livestock insurance.

Table 4: Proposed Adaptive Measures for Cotton Wheat Cropping System in Punjab:

Socio-Economic	Bio-Physical Factors	Policy Variables	Other factors
Off-farm income opportunities, Crop Diversification to avoid risk, Population control measures, Participatory Management Approach, Agro-forestry, Fisheries and Livestock Farms, Optimal use of inputs,	Changes in cropping patterns, Improved cultivars, Improved Agri. Practices, (Drainage, IPM, HEIS, Precision Agriculture etc.)	Efficient markets, Increase in Govt. investments (Infrastructure, Research and Development), effective trade policies, Farm consolidation measures, GW / Surface water policies, Subsidy on critical inputs, Agricultural insurance/finance,	Agro-climatic advisory services for farmers, Establish and strengthen interaction among stakeholders, Use of IT tools (climate / market data, etc.),

Source: Based on Literature Review and Expert Opinion from stakeholder interactions

Table 5: Aggregate Climate Change Adaptation Benefits Regarding Cotton Crop on Future Agricultural Production System under APSIM and DSSAT for Low and High Prices

Climate Model	GCM	Percentage Change in Net returns	Percentage Change in Per capita income	Percentage Change in Poverty	Percentage Potential adoption rate
APSIM High prices	**CCSM**	21.37	21.84	-94.26	67.36
	CMCC	19.40	19.61	-91.84	66.26
	GFDL	22.78	22.69	-89.35	69.25
	HADGEM	17.30	17.61	-86.99	59.21
	IPSL	24.45	24.40	-104.43	73.11
DSSAT High Prices	**CCSM**	16.95	16.77	-87.59	60.17
	CMCC	18.74	18.53	-90.42	64.46
	GFDL	21.93	21.31	-91.49	68.53
	HADGEM	20.45	20.07	-91.87	66.71
	IPSL	16.75	16.72	-87.85	60.07
APSIM Low prices	**CCSM**	13.86	14.25	-26.26	41.17
	CMCC	15.38	15.23	-37.49	49.90
	GFDL	37.72	35.45	-130.08	86.70
	HADGEM	14.54	14.36	-37.36	48.37
	IPSL	18.27	17.80	-43.15	55.20
DSSAT Low prices	**CCSM**	13.59	13.13	-31.22	44.03
	CMCC	14.63	14.14	-32.54	47.38
	GFDL	17.57	16.53	-35.41	51.73
	HADGEM	16.34	15.58	-35.03	50.09
	IPSL	15.10	14.73	-46.99	52.12

The adoption rate of proposed adaptations are significant and showed in figures 4 and 5 below.

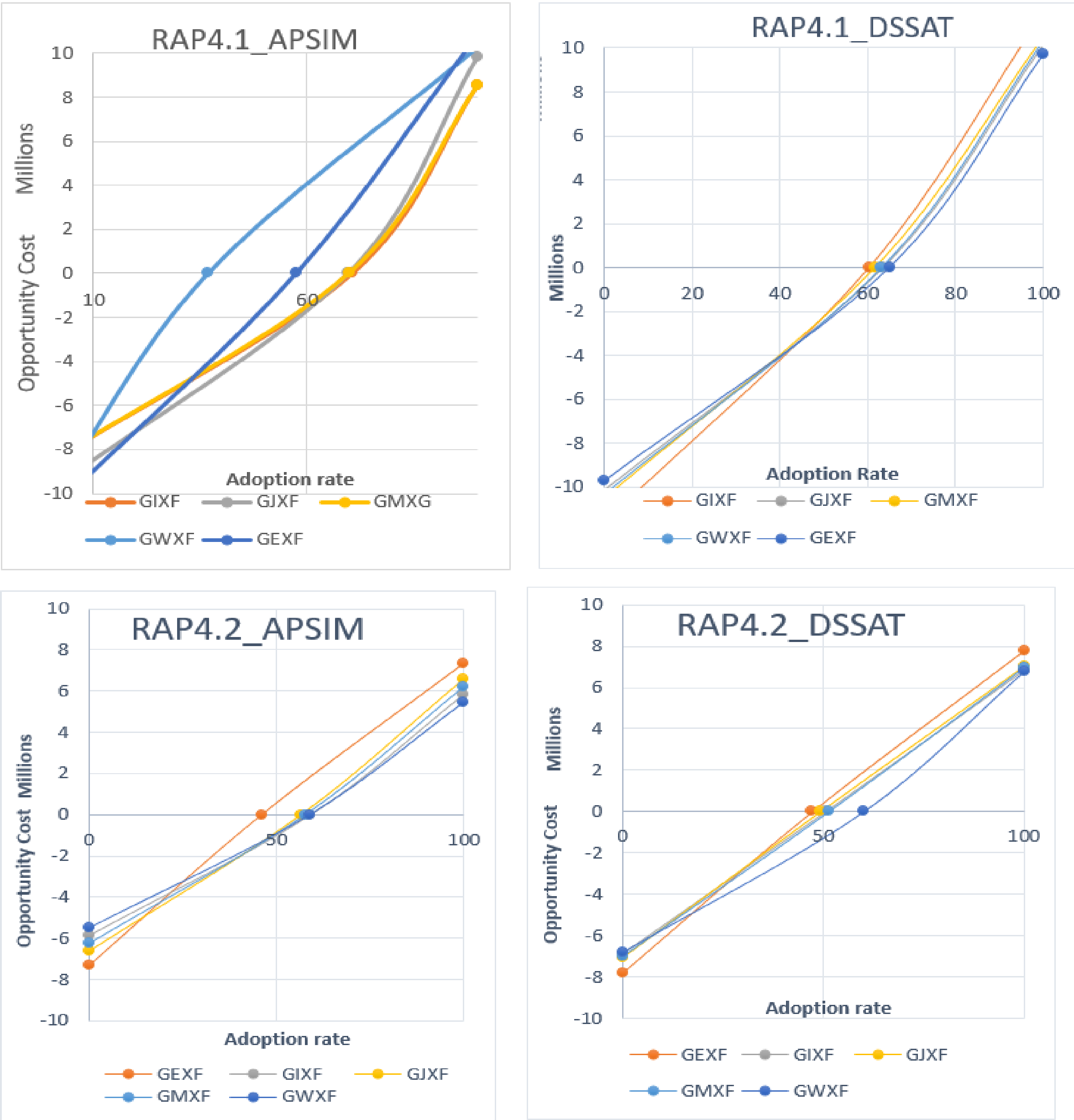


Figure 4: Percentage Adoption Rate of Adaptation regarding Climate Change for cotton crop under Sustainable Development for low and High Price Range for APSIM and DSSAT

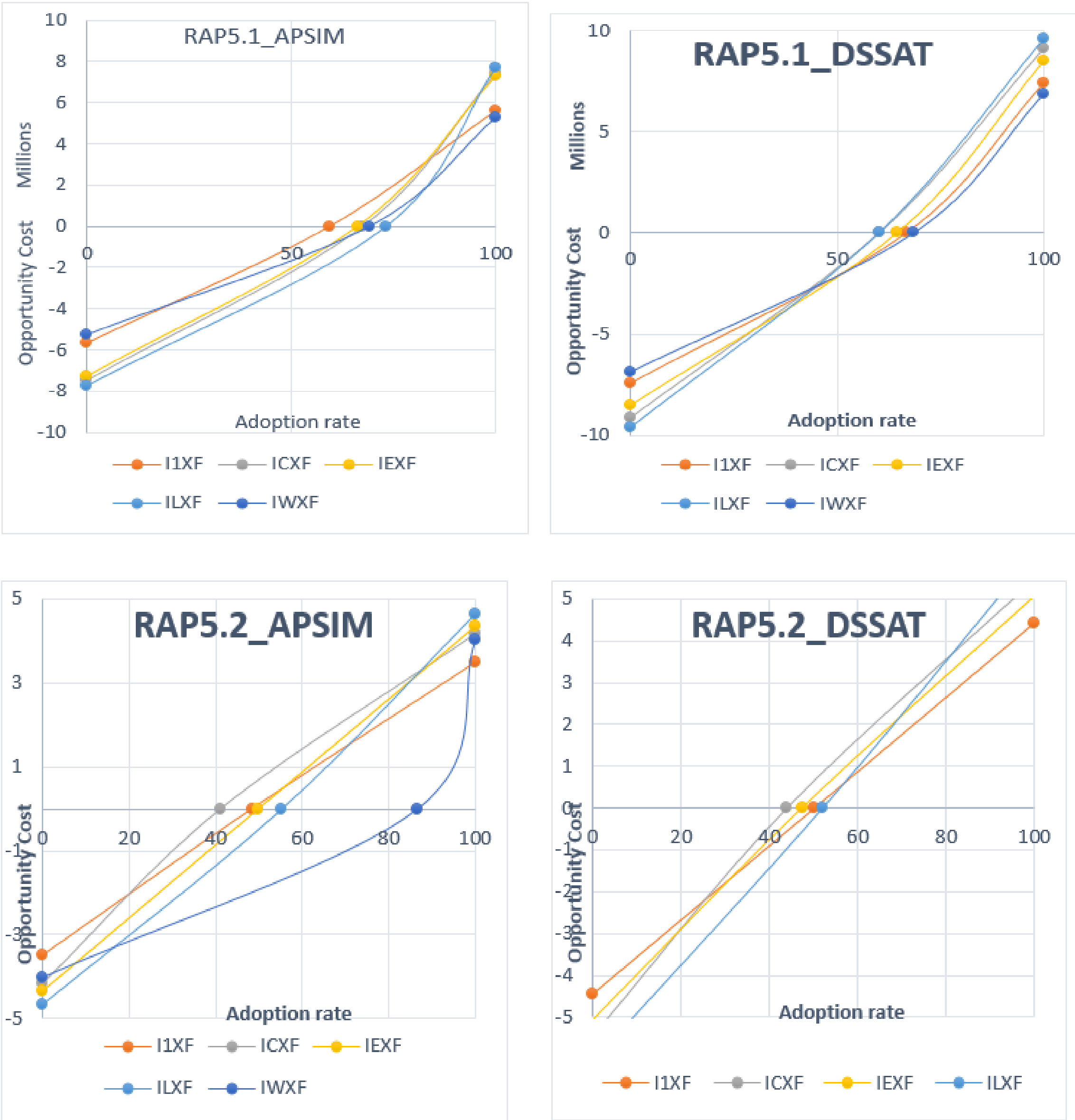


Figure 5: Percentage Adoption Rate of Adaptation regarding Climate Change for cotton crop under sustainable Development for low and High Price Range for APSIM and DSSAT

Figures 4 and 5 describe the adoption rate of the proposed adaptation in the study area based on cost-benefit analysis for the midcentury scenario. The adaptations are cost-effective and increase crop yields substantially.

4. Conclusion

The impacts of climate change under the cotton wheat cropping system are drastic; cotton crops especially face serious challenges in current and future periods. The results showed that there would be intense impacts of climate change on cotton crops and relatively mild impacts on wheat in the Punjab cotton wheat cropping system.

The reduction in the cotton crop will be 42 percent, and the wheat yield reduction is projected at 4.5 percent in mild climatic scenarios. However, the reduction of 47 percent and 2 percent under RCP 8.5 for 2040-69. The proposed adaptive measures will help farming communities to cope with climate change challenges and increase the resilience in farmers by increasing the net farm returns and per capita income. Farm poverty could be decreased in farming communities by designing rapid public policies in synergy with the climate change policies.

The development of heat and drought-tolerant cultivars/varieties and adoption of recommended sowing dates, especially early sowing of wheat, increase the crop yield significantly. Ensure plant population (Sowing density increased by 10%, increase seed rate and seed quality) and balanced fertilizer use (N: P: K and gypsum; improve the fertilizer application method). Initiatives for agricultural insurance and establishing risk and climate funds for farmers from central banks are needed. Public policy must be formulated to facilitate crop and income diversification, and agricultural policies must be formulated according to agroecological Zones.

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