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Dr. Amita Rani
Assistant Professor of Economics, Govt. College for Women, Sonipat, Haryana, India

Corresponding Author:
Dr. Amita Rani
Assistant Professor of Economics, Govt. College for Women, Sonipat, Haryana, India

Exposure of kharif crops production to climate change

Dr. Amita Rani

Abstract
Present study is an attempt to estimate and forecast the impact of moderate climate change projection on two major food crop- Maize and Rice productivity under the question of providing food security along with sustainability. The study attempted to analysis the impact of moderate rise in Kharif season climatic variables, mean maximum temperature and mean rainfall is 1.63 °C and 5 percent by 2100 AD which is more than annual climatic variables (2.02 °C and 7 percent) respectively on maize crop yield and rice crop yield across north India, northeast India and peninsular India along with impact on national crop yield using crop model. Decadal growth rate of mean maximum temperature and rainfall for Kharif season 0.2 °C & 0.63 percent respectively. The crop yields are regressed on climatic variables using panel data over 118 districts across three regions of India (North India, North-East India and Peninsular India for sixteen years (1998-2014) to estimate the impact. About 5 percent increase in kharif season mean maximum temperature is found across the period of sixteen period whereas 5 percent cumulative increase in kharif season mean rainfall for all India. This change is unevenly distributed across three regions. Projection in Kharif season maize and rice crop yield under five climatic scenarios (2020, 2040, 2060, 2080 and 2100) is estimated by applying logarithmic panel data regression crop model. The results of study found a decrease in maize crop yield across north India by 0.93percent whereas increases across north east India, peninsular India and all India by 1.3 percent, 0.16 percent and 0.53 percent respectively till the end of 21st century whereas in absolute terms highest loss of 0.172 quintals per hectare in maize crop yield is estimated across north region. Projections for Rice crop yield indicates a loss of 0.83 percent across peninsular India whereas an increase across north India, north east India and all India by 7.19 percent, 7.7 percent and 0.13 percent respectively. The study included other geophysical variables-type of soil, fertility of soil, longitude and latitude position and socio-economic variables- population density, size of holdings, use of fertilizer, farm harvest price and irrigation facilities. However, for kharif season crop availability of irrigation facilities affect much.

Keywords: Climate change, food crop yield, kharif season, food security, adaptation

Introduction

A heap of literature addressed rising temperature as one of the greatest worries for agriculture and world food security concerns. All through the 20th century earth surface temperature has increased by 0.6 °C and anticipated to increase by 1.5 °C to 3.5 °C in the next 100 years. Climatic change hinders efforts of nations for sustainable development and also determines the future food security for the world (Mor, 2016) [31]. Climate change refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods (IPCC, 2007) [24]. Climate change and global warming are result of excessive emission of Carbon Dioxide and other greenhouse gases. Climate change is a hard reality of the 21st century as rising temperatures, increased frequency of floods and droughts, fluctuations in rainy days and rainfall are occurring eventually. Agriculture is closely related to climate change and sustainability as on one hand rise in temperature and alteration in rainfall pattern effect crop productivity and on other hand increasing agriculture activity to secure food accessibility harm environment as it is responsible for tremendous emission of greenhouse gases (methane and nitrous oxide).

Food Security Challenge

Food security challenge is defined as make available physical, communal and cost-effective access to adequate, secure and healthy food to all people, at all times so that they can fulfill their dietary needs along with their food preferences for a healthy life (World Food Security Committee, IFPRI UN 2020). Food security includes food availability, food access and food utilization, stress on anyone of these aspect disturb the whole food system. Such stresses may be caused by many factors- climate change in addition to urbanization, globalization, demographic transitions, pest attacks etc. Poverty, lack of education, unemployment, food price hike, improper property rights, poor market access are most common hurdles in the path of food security system intensified by moderate climate change shocks (Gregory, P. J. *et al*, 2005) [13]. Whereas global environment change stresses food security system in four ways- change in type, frequency and magnitude of Global environment along with social, economic & institutional change bring change in food security system which in turn responsible for adoption of new mitigation and adaptation policies toward global environment change (Bohle 2001; Brklacich & Bohle 2005; Wisner *et al*. 2004, Ingram *et al*, 2005) [2, 36, 23].

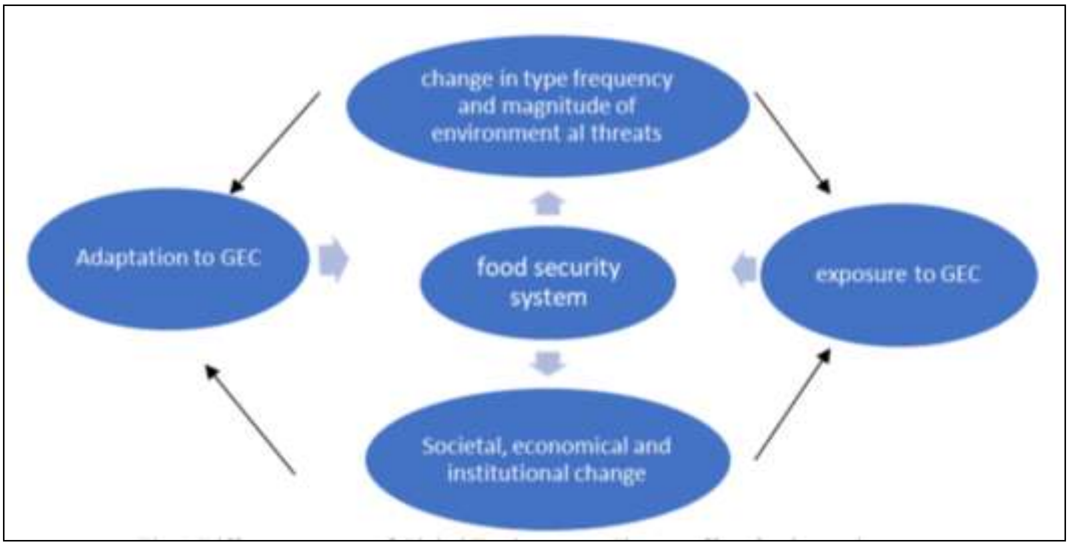

Fig 1: Different aspects of Global Environment Change effect food security system

Further studies suggested difference in regional global environment change impact on agriculture as developing nations are at greater risk than developed nations (To ensure the availability, accessibility and security of food to all with the environmental sustainability is matter of great concern nowadays. In this context present study is an attempt to access the impact of climate change on two major food crops yield -maize and rice under moderate climate change projections.

Methodology

This section deals with the fundamental of methodology-analytically tools, data and sampling description of variables and the climatic projections used in the study.

Analytical tools

Examination of literature reveals five methods to estimate impact of climate change on agriculture sector differ in terms of variables and objective of study- crop simulation model (Williams *et al*., 2003; Kang *et al.*, 2009; Porter, 2017), Production Function model/Crop Model (Kumar & Parikh, 2004; Poudel & Kotani, 2013 and Zampieri, 2017) [26, 25, 33, 32, 35], Ricardian model or hedonic model introduced by Mendelsohn and his colleagues using Ricardian theory of rent (Mendelsohn *et al*., 1994; Seo & Mendelsohn 2008; Massetti & Mendelsohn, 2011; Deschenes & Greenstone 2012; DeSalvo *et al*., 2013) [29, 35, 28, 5, 40], Economic Management Model named Positive Mathematical Programming PMP Model (Qureshi *et al*., 2013; Howitt *et al*., 2014) [34, 30] and General Econometric Model (Darwin *et al.*,1999) [4].

Present study applied production function approach to identify and forecast the basic relationship between climate and agricultural production (Adams *et al*., 1989; Rosenzweing & Parry, 1993) [1, 41] and estimating the responses of change in climate variables in the yield. The estimated variables are aggregated to show the overall impact on the nation (Olsen, 2000; Adams *et al*., 1989; Kumar & Parikh, 1998; Chang, 2002) [42, 1, 6] in spite of few drawbacks of this model as crop and site specific along with exclusion of farmer adaptation, crop switching and other management services alteration followed to cope up with changing climatic conditions.

To minimize the impact of extreme values and biased results logarithmic linear multivariable model of production function has been applied.

$$Y_{ij} = b_{ij}\text{Log } T_{ij} + c_{ij}\text{Log } P_{ij} + d_{ij}\text{Log } D_{ij} + e_{ij}\text{Log } H_{ij} + f_{ij}\text{Log } FR_{ij} + g_{ij}\text{Log } F_{j} + h_{ij}\text{Log } S_{j} + k_{ij}\text{Log } LG_{j} + l_{ij}\text{Log } LT_{j} + m_{ij}\text{Log } IR_{ij} + n_{ij}\text{Log } FH_{ij} + U_{i} \quad \text{eq-1}$$

Where

Y_i = Maize/Rice crop yield (Quintal per hectares);

i= (1, 2, 3,…., 16) years under study

j= (1, 2, 3,..….., 127) agro-climatic zones

T=Kharif season Mean maximum temperature in degree Celsius,

P= Kharif season Mean rainfall for season in mm,
D= Population density,
H=Number of farm holdings (per hectare),
FR= Fertilizer consumed per hectare,
F=Soil Fertility,
S=Soil Type,
LG=longitude,
LT= Latitude,
IR= irrigation,
FH= Farm harvest price (Rs per quintal),
U_i =composite variable

The impact of climate change is measured by the change in crop production (in quintals) resulting from the accumulated change from (baseline) to can be measured as;

$$\Delta Y = Y(C_0) - Y(C_1) \quad \text{eq-2}$$

By comparing the crop yield under different locations/ different climatic scenario the actual response of crop yield can be estimated as:

$$Y_i = F(C_i) + U_i \quad \text{eq-3}$$

Where Y is the predicted yield for crop i, is the exogenous environment variables and (U_i) is the error term. Impact on farm productivity is measured in terms of crop yield. Crop yield for each district is measured in terms of quintal per hectare which is calculated by dividing gross crop production with area under crop for the period under study.

Database and sampling

To analysis the impact of climate change on wheat crop yield, a sample of 118 districts across 127 agro-climatic zones has been selected using nonrandom purposive sampling method to take account of all geographical and climatic disparity present in the population. District level data for crop variables (Maize and Rice crop yield), climatic variables (mean maximum temperature and mean rainfall) and data on edaphic variables, spatial variables, socio economic variables have been collected for a period of sixteen years (1998-99 to 2013-14). 127 agro-climatic zones based on homogeneity of soil, temperature, precipitation and other agro-meteorological uniqueness broadly grouped into three regions-north region, north-east region and peninsular region (NARP project by Indian Council Agriculture Research, ICAR). Quantitative data for Kharif food crops-Maize and Rice are collected over five comparatively wet and arid months July to October. One district from each agro climatic zone is included in study. Out of 127, 118 agro-climatic zones are viable for agriculture production. These agro-climatic zones are further clubbed in three regions- North region (33 agro-climatic zones), North east region (33 agro-climatic zones) and peninsular region (52 agro-climatic zones).

Specification of variables used in the study

Numerous variables have been used in the study for the analysis of the impact of climate change on Rabi crop wheat in India are described as under:

Dependent Variable

- Maize and rice crop yield are calculated by dividing gross crop production with area under crop for each district, measured in quintals per hectares

Independent Variables

A. Climate variables

Cumulative mean maximum temperature and mean rainfall for Kharif season (June to September) is calculated from monthly variable values which are less correlated than seasonal averages

- **Temperature:** Temperature is measured in degree Celsius (°C). The average temperature for Kharif crop season has been used in the analysis.
- **Rainfall:** Rainfall is measured in millimeters (mm) and average rainfall in Kharif season crop has been estimated and utilized.

B. Crop variables

Other socio- economic variables density, farm harvest price and number of farm holdings per hectare are included in study as these variables reflect the level of adaptations effecting number of farmers in agriculture sector and area under cultivation.

- **Density:** Population density is included in study to check the effect of increase in population on land available for cultivation which in turn affects the crop production.
- **Farm harvest price (FHP):** Farm harvest price is the price at which crop purchased by consumer in local markets. It is measured in terms of rupees per quintal.
- **Farm holdings per hectare:** Higher the number of farm holdings per hectare means smaller the size of holdings and it effect crop yield adversely as smaller the holding size, which in turn low use of new technology to combat climate change. This in turn affects wheat productivity adversely.
- **Fertilizers:** Use of more fertilizer per hectare increases two crop yields.
- **Area under irrigation:** Area under irrigation for wheat crop has been calculated in terms of percentage of area under irrigation by dividing irrigated area under crop by total irrigated area.
- Edaphic variables (soil fertility and soil type) and spatial variables (longitude and latitude) are time invariant variables and assessed through fixed or random effect by applying *Hausman Random effect* and cross section F statistics test.

Climatic projection

In order to estimate the climate change on crop yield, five climatic projections are assumed. To simulate the impact of future climate change on maize and rice crop yield, coefficients estimated using multi-variant logarithmic regression model are used. Assumption of constant socio-economic condition, preset irrigation facilities, unchanging fertilizers consumption and constant farm harvest price are made during forecasting impact of climate change. Five seasonal climatic scenarios take up in study are calculated from monthly mean maximum temperature and mean rainfall projection projected by IPCC[1]. The forecasting occurrences for study are taken as 2020-2040, 2050-60, 2070-80 and 2090-2100. The 50th percentile value of 42 GCMs ensemble projected range under RCM 4.5(a mild emission scenario) for temperature and rainfall monthly

[1]IPCC WGI fifth assessment report AR5 (2014) used widely used multi model-Coupled Model Inter comparison project, Phase 5 (CMIP5) predicted climatic scenario RCP 4.5 with medium-low emission.

means are considered for forecasting. All India is likely to experience increase in annual mean maximum temperature 0.9 to 1.4°C by 2060 and 2.02 °C by 2100 relative to base year 1985-2010. (Table-1). This increase is not equally distributed over all season. Decadal growth rate of mean maximum temperature and rainfall for Kharif season 0.2 °C & 0.63 percent respectively.

Table 1: Projected change in mean maximum temperature (°C and rainfall (%)

Season	Climate variables	Base year (2013-14)	Scenario I 2020	Scenario II 2040	Scenario III 2060	Scenario IV 2080	Scenario V 2100
Kharif season	Mean maximum temp mean rainfall	Actual	0.12	0.78	1.16	1.56	1.63
			0.38	2	3	5	5
Annual	Mean maximum temp mean rainfall	Actual	.15	0.94	1.43	1.86	2.02
			1.09	-2	2	5	7

Source: IPCC WGI fifth assessment report (AR5) using multi model CMIP5.

Table 1 depicts the projected increase in Kharif season climatic variables, mean maximum temperature and mean rainfall is 1.63 °C and 5 percent by 2100 AD which is more than annual climatic variables (2.02 °C and 7 percent) respectively. This shows that climatic change hit kharif season less badly than annual climatic variables.

Results and Discussion

The present section deals with forecasting results for Maize and rice crop yield over five decades with moderate climate change projections.

Table 2: Projected change in Kharif season maize and rice crop yield (quintals per hectare)

	Crop	Climate scenario I 2020	Climate scenario II 2040	Climate scenario III 2060	Climate scenario IV 2080	Climate scenario V 2100
North region						
Food crop	Maize	-0.013	-0.082	-0.082	-0.162	-0.172
		(-0.07)	(-0.44)	(-0.44)	(-0.88)	(-0.93)
	Rice	0.11	0.72	0.72	1.48	1.54
		(0.51)	(3.36)	(3.36)	(6.91)	(7.19)
North East region						
Food crop	Maize	0.01	0.05	0.08	0.1	0.11
		(0.12)	(0.59)	(0.94)	(1.18)	(1.30)
	Rice	0.09	0.59	0.87	1.2	1.25
		(0.55)	(3.64)	(5.36)	(7.39)	(7.70)
Peninsular region						
Food crop	Maize	0.0012	0.006	0.009	0.021	0.02
		(0.01)	(0.05)	(0.07)	(0.17)	(0.16)
	Rice	-0.01	-0.07	-0.102	-0.121	-0.13
		(-0.06)	(-0.44)	(-0.65)	(-0.77)	(-0.82)
All India						
Food crop	Maize	0.004	0.024	0.036	0.047	0.049
		(0.04)	(0.26)	(0.39)	(0.50)	(0.53)
	Rice	0.001	0.004	0.006	0.021	0.019
		(0.01)	(0.03)	(0.04)	(0.14)	(0.13)

Source: calculated from data
Note: value in parentheses in percent

Table-2 displays the impact of climate change on kharif season major food crops-maize and rice crop yield across climatically diverse section in India are shown transversely five climatic scenarios. The average insignificant gain in the maize production and rice productivity in all India is turned out to be only 0.53 percent (0.049 quintal per hectare) and 0.13 percent (0.019 quintal per hectare) when compared to the base year (2013-14) till the turn of the century attributed to non uniform loss in productivity across different regions.

In case of maize crop yield most adverse effect of climate change is estimated for North India as crop yield reduced by 0.93 percent till end of 21st century which is responsible for overall insignificant increase in national average maize crop yield. Whereas loss of 0.82 percent in rice crop yield is found across peninsular region responsible for mitigating positive impact of climate change on national average in north region (7.19 percent) and northeast region (7.7 percent).

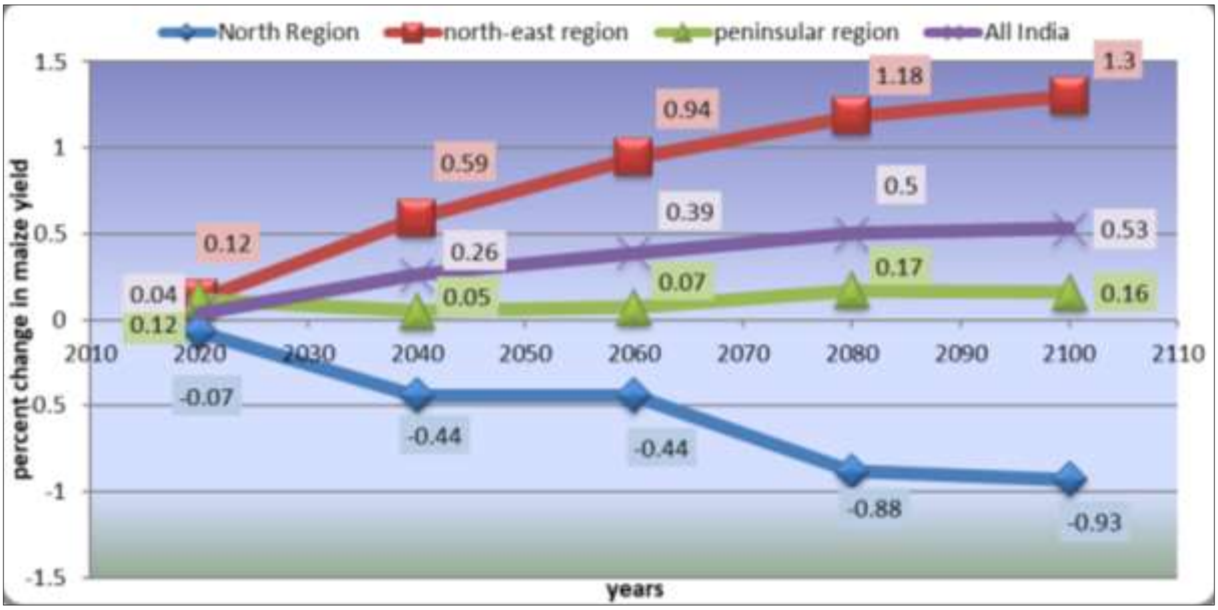

Fig 1: Percent change in maize yield

Decadal projection for impact of climate change on maize crop yield shows north region will be adversely affected. All reduction occurs during first decade (2020-2040) and third decade (2060-2080). Increase in maize crop yield in north-east region is estimated to increase at decreasing rate. From 2020 to 2040 it would increase by 0.47% and reduced to 0.12% during last decade (2080 -2100). Increase in maize crop yield in peninsular region estimate is almost negligible (0.04%) in early decades; highest increase in yield is estimated during 2060 to 2080 which decrease again during last decade.

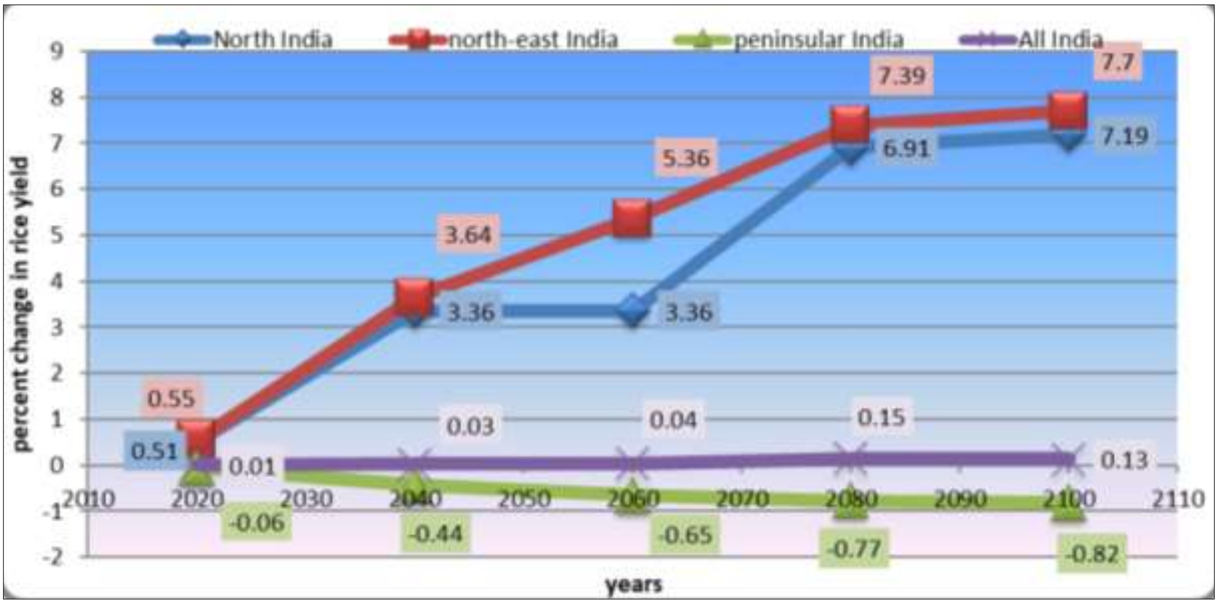

Fig 2: Percent change in rice yield

Further decadal estimation of impact on rice crop yield indicates north region will be irregularly affected. All increase in rice crop yield in north region occurs during first decade (2020-2040) and third decade (2060-2080) and almost steady during second decade (2040-2060). Increase in rice crop yield in north-east region is estimated to increase at decreasing rate. From 2020 to 2040 it would increase by 2.85% and reduced to 0.31% during last decade (2080 -2100). Decrease in rice crop yield in peninsular region estimate is almost negligible (0.76%) throughout decades. This shows that rate of loss in maize and rice crop yields are not uniform under all four decades as it slowed down during late decades of this century. Hence, the second maintained hypothesis of the study that there is no impact on the yield of maize and rice crop in the three regions of India have also been rejected.

Conclusion and suggestions

In view of world food security program, present study is an effort to analysis the future of two major food crops-Maize and rice crops in reference to moderate climate change projection. Using two major climatic variables- seasonal mean maximum temperature and rainfall along with some important socio-economic climatic variables, a logarithmic panel regression crop model is applied and impact of climate change on kharif season yield of maize and rice crops are estimated. Results of study suggested highest maize producing north Indian region in India would be badly knocked by rising temperature accompanied with increase in rainfall as maize yield is estimated to shrink by 0.173 quintals per hectare till 2100AD which is higher than insignificant increase in maize crop yield across northeast India and peninsular region. In 2018-19, India exported 226.63 thousand tones worth 427.47 cror rupees food grains. Rice is the most grown food crop in India. With 38.78 quintals per hectare rice crop yield (22.7 percent of global total production) and 30.24 quintals per hectare (2.42 percent of global production) maize crop yields India is second largest rice producer and seventh largest maize producer world widely. A slow and steady growth rate (less than one percent) over the decades of these food grains against fast growing national population (1.06 percent growth rate) and global population (one percent growth rate) is a matter of deep concern to secure food for all objective. According to agriculture statistics in India it accounts approximately 35.7percent of gross food grain production in India. To achieve the UN mission of food for all and to feed 135 million populations in India 0.73 percent growth rate of wheat crop yield is quite low.

Limitation: The study suggested further improvement in analysis as present study is limited to only two kharif season food crops maize and rice with limited number of climatic variables. Second this study excluded farm income from agriculture allied activities. Third micro level study will give more area specific estimates can be useful for micro policy formation.

Future research: Every research ended with questions need to be enquired for better understanding. Present study makes an effort to analysis impact of major climatic variables- seasonal mean maximum temperature and seasonal mean rainfall on main food crops- maize and rice. This is a partial analysis as it is limited to two climatic variables which can be extended to number of climatic (hours of sunshine, shift in season, level of carbon dioxide, length of season etc.) and socio-economic variables (farmers literacy, allied activities, availability of agriculture infrastructure, agriculture mechanization). In present paper supply side of climate change impact on agriculture sector is analyzed whereas demand side of duos correlation need to be addressed as food grain reduction would shift the demand for food grains. Other important research question to be addressed is impact of agriculture production on climate as 24.5 percent of gross GHG emission contributed by agriculture sector (FAO, 2020) [11] Cultivation of soil, burning of crop residuals, use of synthetic fertilizers, cultivation of organic soil, enteric fermentation, manure residuals in soil and manure management are sources of GHG emission from agriculture activities. On agriculture emission of carbon dioxide equivalent scale India rank first with 650000 ggms carbon dioxide emission. Ironically, 9.9 percent of total agriculture GHG emission comes from rice-a major food crop of food security system, which is a big threat to sustainability.

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