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Crops Response to Climate Variables in Eastern India : An Assessment of Yield

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ABSTRACT

The effects of climate variables on the yield of major crops in Eastern India had been assessed by using a panel data regression model. District-wise analysis of secondary data from 1990 to 2017 time period had been carried out. The climate variables had a significant effect on the yields for major crops of the region. The rainfall pattern decreased agricultural yields for wheat, mustard, and sesame, while induced beneficial effects to increase yields for rice and chickpea. The minimum temperature expressed a negative impact on all crop yields more over the rice being an exception. Fertilizer use emerged as an important factor among non-weather factors that influenced all crop production positively. The policymakers should focus on integrated adaptation measures to mitigate ill effects of the deteriorating climate variables on the agriculture production to sustain agriculture.

Keywords Crop yield, Panel data, Climate, Eastern India, PCSE.

INTRODUCTION

Agriculture has been affected badly owing to the vulnerability to climate change (Wing *et al*. 2021). The production of crops is substantially impacted by variations in climatic events like temperature and rainfall (Aryal *et al*. 2019). The failure of crops to harvest the anticipated yield owing to excessive temperatures, changes in precipitation, and declines in animal production have been observed as signs of the detrimental effects of climatic variability on agricultural production (Ahsan *et al*. 2020, Markou *et al*. 2020). Crop production is biophysically impacted by changes in climatic variables such as rising temperatures, changing rainfall patterns, and rising atmospheric carbon dioxide levels (Agovino *et al*. 2019). The effect of changing precipitation patterns, rising temperatures, and CO_2 levels differ depending on the crop, the area and the degree of parameter change (Dubey and Sharma 2018). Number of recent studies

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have revealed that average agriculture production and profitability of this sector are significantly hampered by climate change (Leng and Hall 2019, Singh and Dhadse 2020, Kumar *et al*. 2021, Wing *et al*. 2021). The last several decades showed increased human activities had changed the composition of the earth's atmosphere as carbon dioxide increased from 22.15 billion metric tonnes in 1990 to 36.14 billion in 2014 (Abeydeera *et al*. 2019). Without a significant reduction in emissions, the average global temperature will exceed 1.5°C over pre-industrial levels in the next 20 years (by 2040) and 2°C by the middle of the century. A 1.09°C increase in global surface temperature was seen in 2011-2020 from 1850 to 1900 (IPCC 2021). As many studies endeavoured to analyse the effect of carbon dioxide emission, temperature experimentally, and rainfall on agriculture production, the discussions on the impact of climate change on agricultural production became a subject of interest.

In India, the southwest monsoon, responsible for over 80% of the country's total rainfall between June and September, is primarily responsible for agriculture (Bagla 2012). A large amount of the country's cultivated area is rainfed and highly dependent on monsoon unpredictability due to the country's net irrigated area being just 68.3 million hectares out of a total net cultivated area of 140.1 million hectares (Gupta *et al*. 2014). Climate variability and change are projected to have a significant negative impact on Indian agriculture. According to the National Action Plan on Climate Change, crop yields are anticipated to be reduced by 10–40% by 2100 (Dubey and Sharma 2018, Singh and Dhadse 2020).

MATERIALS AND METHODS

Important seven states of the eastern India, namely Assam, Bihar, Chhattisgarh, Jharkhand, Odisha, West Bengal, and eastern Uttar Pradesh, which composed 34% of the country's population and held around 21.85% of its total geographical area. This region's cropping intensity is 150%, greater than the national average of 141%. The average annual rainfall in varies from 1091 to 2477 millimeters, with a regional average of 1526 millimeters sufficient to support various crop growth. The irrigated area is lower (39%) than the national average (45%) (Bhatt *et al*. 2016). The data set for the present study was taken from 45 districts in Eastern India. The district-wise yield of major crops for the period 1990-2017 was collected from the Directorate of Economics and Statistics, Government of India. District wise monthly rainfall, maximum and minimum temperature data for the period 1990-2017 were collected from the online web services of 'NASA POWER - Data access viewer.' Crop-wise irrigated area and season-wise fertilizer consumption data were collected from the ICRISAT district level dataset for India (Lobell *et al*. 2007, Carew *et al*. 2009, Bhatt *et al*. 2016).

A panel data regression model with a fixed effect was used to assess the variability in yield as to change in climate variables (Deschênes and Greenstone 2007). In this method, the weather parameters are determined from the district-specific variations in response to the district averages after adjusting for common shocks in all districts. There are two models to handle large datasets and problems with heteroscedasticity, serial correlation, and cross sectional dependence. These include the panel corrected standard errors (PCSE) approach and the feasible generalized least square (FGLS) method. There is a criterion for choosing one approach between FGLS and PCSE. The FGLS model is a superior choice if the time period (t) exceeds the number of cross sections (i) otherwise, the PCSE technique is favored (Reed and Ye 2011, Kumar *et al*. 2021). PCSE is the superior accessible option in the present study because the time period (t=28) is shorter than the number of cross-sections (i=45) (Reed and Ye 2011). In the empirical estimation, crop yield is the dependent variable, while weather factors are the independent variables. The model is formulated as follows:

$$\ln Y_{it} = \alpha_i + \gamma_t + \beta W_{it} + \sum \text{€} * f(X_{it}) + \mu_{it}$$

Where 'i' denotes district, and 't' denotes times

$\ln Y_{it}$ = The log values of district wise yield of major crop

α_i = The district-level fixed effects, which are quite useful in capturing unobserved heterogeneity across districts

γ_t = The year-specific dummies which control for annual differences in yield, common to all the districts

W_{it} = The district and year-specific agricultural variables

X_i = Climate parameters

μ_{it} = Error term

RESULTS AND DISCUSSION

The results for all crops show that the district fixed effects have been found to be significant for all crops, showing that it is crucial to include fixed spatial effects in climate models for controlling time-invariant location-specific characteristics that might be correlated with the climate variables. Kumar *et al*. (2021) indicated that the production of cereal crops in lower middle-income countries is significantly affected by climate change. The increase in temperature has an adverse effect on cereal production. Contrarily, the production of cereal crops is positively influenced by precipitation and CO_2 emissions. In addition, it has been discovered that cultivated land is crucial to the production of cereal crops. For all the crops, the fertilizer co-efficient has been found to be positive and significant, indicating its importance as a factor that partially mitigates the adverse effects of climate change on these crops.

Rice cereal crop

Table 1 gave the regression estimation results for rice, taking the temperature variable as the 12-month average of the monthly average temperatures and defining the rainfall variable as the total annual rainfall. Study reveals that rainfall has a significantly positive effect on rice yields. Higher rainfall leads to a higher yield of rice as reported by Gupta *et al*. (2014). While the coefficient on the quadratic term for rainfall is negative, higher rainfall has a decreasing beneficial effect. Maximum temperature has a negative effect, while minimum temperature has a positive effect, but both are insignificant as also Tokunga *et al*. (2015) reported that rice production decreased as a result of rising temperatures.

Wheat cereal crop

Table 2 indicated wheat yield has an opposite relationship by increasing maximum and minimum temperature, positive and negative effect, respectively. However, quadratic terms of both indicate that both temperatures have a non-linear effect on the crop yields. Again rise in rainfall during the growing season negatively affect the crop yields. Whereas the coefficient on the quadratic term for rainfall is positive, higher rainfall has a smaller harmful effect. Similar type of observation reported by Thapa and Joshi (2010) based on Ricardian approach to measure climate's change effect on agriculture.

Chickpea pulse crop

Table 3 revealed a similar impact of temperature on chickpea yields as in the case of wheat. An increase in maximum temperature has a positive effect, while an

Table 1. Estimated co-efficient of PCSE for the rice crop.
No. of observation : 1225 R squared value : 0.7902
Wald Chi^2 (8) : 64.23 Prob>Chi^2 : 0.000

Ln yield	Coefficient	Panel corrected std. errors	z	P>|z|
Intercept	2.562644***	0.395818	6.47	0.000
Irrigation	0.000219	0.00026	0.84	0.399
Fertilizer	0.00063***	0.000164	3.85	0.000
Log (Rainfall)	0.2115207***	0.0200441	4.64	0.000
Log $(Rainfall)^2$	-0.2977***	0.070202	-4.24	0.000
T_{Max}	-0.21826	0.227804	-0.96	0.338
T_{Max}^2	0.003429	0.003699	0.93	0.354
T_M	0.142959	0.205715	0.69	0.487
T_{Min}^2	-0.00302	0.004839	-0.62	0.533

Note: *, **and *** indicates significance at 10%, 5%, and 1% level.

Table 2. Estimated co-efficient of PCSE for the wheat crop.
No. of observation : 1172 R squared value : 0.7979
Wald Chi^2 (8) : 54.04 Prob>Chi^2 : 0.000

Ln yield	Coefficient	Panel corrected std. errors	z	P>|z|
Intercept	2.963868***	0.159506	18.58	0.000
Irrigation	0.000252	0.000226	1.11	0.265
Fertilizer	0.000811***	0.000165	4.92	0.000
Log (Rainfall)	-0.02772**	0.01251	-2.22	0.027
Log $(Rainfall)^2$	0.00718	0.005113	1.40	0.160
T_{Max}	0.300609**	0.129327	2.32	0.020
T_{Max}^2	-0.00534**	0.002386	-2.24	0.025
T_M	-0.13233*	0.075339	-1.76	0.079
T_{Min}^2	0.004156	0.002623	1.58	0.113

Table 3. Estimated co-efficient of PCSE for the chickpea crop.
No. of observation : 1022 R squared value : 0.8573
Wald Chi^2 (8) : 22.39 Prob>Chi^2 : 0.000

Ln yield	Coefficient	Panel corrected std. errors	z	P>|z|
Intercept	2.673774***	0.265987	10.05	0.000
Irrigation	-0.00027	0.000292	-0.94	0.347
Fertilizer	0.001001**	0.000461	2.17	0.030
Log (Rainfall)	0.001325	0.020857	0.06	0.949
Log (Rainfall)^2	0.004488	0.00809	0.55	0.579
T_{Max}	0.504953**	0.228552	2.21	0.027
T_{Max}^2	-0.00907**	0.004343	-2.09	0.037
T_M	-0.22722***	0.067011	-3.39	0.001
T_{Min}^2	0.007057***	0.002111	3.34	0.001

increase in minimum temperature has a negative effect. Here also, the relationship is non-linear. Rainfall has an insignificant effect on crop yields. Srivastava *et al*. (2010) demonstrated reduction in monsoon rainfall with climate change would affect production more in 2050 and 2080 projected scenarios.

Rapeseed and mustard oilseed crops

An increasing minimum temperature had a negative effect on the oil seeds crop yields (Table 4). At the same time, quadratic terms indicate that a higher minimum temperature has a lower harmful effect on the crop yields. Further, the insignificant effect of maximum temperature and rainfall indicates that this crop has minimal climatic effects. Singh and Dhadse (2020) reported yields would be reduced by 10–40% by the year 2100.

Table 4. Estimated co-efficient of PCSE for the rapeseed and mustard crop.
No. of observation : 1153 R squared value : 0.7810
Wald Chi^2 (8) : 67.54 Prob>Chi^2 : 0.000

Ln yield	Coefficient	Panel corrected std. errors	z	P>|z|
Intercept	2.9178***	0.206411	14.14	0.000
Irrigation	0.00028	0.00044	0.64	0.523
Fertilizer	0.00148***	0.000274	5.41	0.000
Log (Rainfall)	-0.01794	0.018249	-0.98	0.326
Log (Rainfall)^2	0.010403	0.00752	1.38	0.167
T_{Max}	0.010501	0.009029	1.16	0.245
T_{Max}^2	-0.00236	0.002592	-0.91	0.362
T_M	-0.0338***	0.008796	-3.84	0.000
T_{Min}^2	0.00058	0.002896	0.02	0.984

Note: *, **, and *** indicates significance at 10%, 5%, and 1% level.

Table 5. Estimated co-efficient of PCSE for the sesame crop.
No. of Observation : 1209 **R squared value** : 0.8583
Wald Chi^2 (8) : 42.07 **Prob>Chi^2** : 0.000

Ln yield	Coefficient	Panel corrected std. errors	z	P>|z|
Intercept	4.992542*	3.002463	1.66	0.096
Irrigation	-0.00075*	0.000442	-1.69	0.091
Fertilizer	0.00124***	0.000271	4.57	0.000
Log(Rainfall)	-0.08388	0.087788	-0.96	0.339
Log(Rainfall)^2	0.023195	0.019325	1.20	0.230
T_{Max}	-0.06657	0.294812	-0.23	0.821
T_{Max}^2	0.001593	0.004727	0.34	0.736
T_M	-0.030052***	0.010793	-2.78	0.005
T_{Min}^2	0.004414	0.004904	0.90	0.368

Note: *, **, and *** indicates significance at 10%, 5%, and 1% level.

Sesame crop

Somewhat similar impact of minimum temperature on sesame yields as in the case of rapeseed and mustard (Table 5). An increase in minimum temperature leads to reduce yields, but the quadratic terms indicate that a higher minimum temperature has a lower harmful effect on the crop yields.

CONCLUSION

Though the overall trend for rainfall in India and the frequency of severe droughts and floods have not changed significantly over the past century, various regional anomalies have been reported. Present study investigated variability I yield of major crops in response to climatic factors during time period 1990 to 2017 for the eastern part of the country. Using the PCSE model, the study addressed the problems of serial correlation, panel group wise heteroscedasticity, cross-sectional dependency, and heterogeneity. The changes in maximum and minimum temperature and rainfall pattern had utilized to measure climate vulnerability. The increase in the minimum temperature has a negative effect on all crops except rice. Rainfall positively affected rice and chickpea productivity, while other crops influenced negatively. The findings would guide the policymakers to orient the agriculture production by mitigating the ill effects of climatic factors and develop practical plans to improve farmers' ability to withstand the yield for major crops in the Eastern part of country.

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