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Impact of Climate Change on Average Yields and their Variability of the Principal Crops in Assam

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ABSTRACT

This paper examines the impact of climate change on mean yield and its variability of five principal crops of Assam using a district level panel data set for a period of 1991-2013. The feasible generalised least square estimates of a stochastic yield function indicate that daily average mean temperature during the growing season has beneficial impacts on the average yields of the crops while excessive temperature, which is expected in future, can have harmful impacts on the average yields of summer rice and mustard. Similarly, daily average mean temperature has non-linear impact on yield variability of summer rice, winter rice and potato. These results have implications for the agricultural sector of Assam which has witnessed an increase in mean temperature, and decline in annual and seasonal rainfall.

Keywords: Climate change, Temperature, Rainfall, Crop yield, Yield variability.

JEL: Q10, Q15, Q54

I

INTRODUCTION

There is no disagreement now about the phenomenon of global climate change as there is ample striking evidence of changes in temperature, and rainfall magnitudes and patterns along with more frequent extreme weather events. According to a special report by the IPCC, the anthropogenic global warming reached approximately 1º C above than the pre-industrial level in 2017, the increase being at the rate of 0.2º C per decade (Allen *et al.*, 2018). There is growing consensus and concerns among scientists and policy makers about the ongoing and future potential impacts of climate change on various socio-economic aspects around the globe. Agriculture, because of being directly dependent on the climatic factors such as temperature and rainfall, is going to be worst hit by climate change. These impacts are going to be exacerbated in the developing countries because of excessive dependence on rainfall, a relatively higher existing average temperature and limited adaptive capacity of their farmers who are mostly poor. In fact the developing countries are predicted to suffer an average of 10 to 25 per cent decline in agricultural productivity by 2080s (Mahato, 2014). The loss in crop yield may be even larger in some regions of the developing countries due to their existing relatively higher temperature, lack of adequate infrastructure like irrigation, farm loan, farm insurance etc. There are a number of

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empirical studies on the impacts of climate change on agriculture from around the world. The available studies in this regard have by and large focused on the developed countries (Mendelsohn *et al*., 1994; Lewandrowski and Schimmelpfennig, 1999; Bryant *et al*. 2000) though relatively a few studies on developing countries have become available by now (Guiteras, 2009; Sarker *et al*., 2012; Poudel and Kotani, 2013; Burney and Ramanathan 2014; Singh *et al*., 2017; Nath and Mandal 2018).

Assam, a core state of northeast India, is situated in the foothills of the Eastern Himalayas where agriculture occupies an important place. According to Mandal and Bezbaruah (2013), the state is more agrarian than the country in terms of a higher share of workforce engaged and its contribution to state domestic product than the country average.[1] There are some distinct changes in the climatic parameters in Assam as evident from the declining annual and seasonal rainfall, and increasing average daily mean temperature (Singha, 2019). Such changes in the climatic parameters are likely to affect the agricultural sector of the state in profound ways because of the fact that agriculture in the state is mainly rain-fed and the farmers, majority of who are poor, have very limited adaptive capacity against any adverse impact (Mandal and Singha, 2019). While declining rainfall in the absence of adequate access to irrigation can have adverse impact on crop yields, the impact of rising temperature on the same may be both positive and negative depending on the sensitivities of different crops to temperature (Mandal and Nath, 2018). Against this backdrop the study of climate change impact on agriculture in Assam has special significance from policy point of view.

This paper seeks to study the impact of climate change on mean yields and their variability of five principal crops of Assam. The novelty of the paper is that the very limited number of previous studies in the context of Assam has examined climate change impact on average yield of rice only. To the best of our knowledge there is only one study in this regard by Nath and Mandal (2018) where they study climate change impact on average yield of rice. Moreover, climate change affects not only average yield of crops but it may also render farming more risky by making crop yields more variable. However, there is no study that examines the climate change impact on variability of crop yields in Assam. Thus this paper is first of its kind as far as the impact of climate change on mean and variability of principal crops of Assam is concerned.

The study uses a stochastic production function approach as suggested by Just and Pope (1978) that captures the impact on both mean yield and its variability. On the basis of a district level panel data set for a period of 1991-2013 the feasible generalised least square estimates show that climatic variables have varied impacts on mean yield and its variability of the principal crops in Assam. Daily average temperature is found to be contributing to mean yield of all the principal crops under study, but excessive temperature which is likely to be the case in future is harmful for yield of summer rice and mustard. Likewise, temperature reduces yield variability of summer rice and potato initially but excessive temperature makes their yields more variable. On the other hand, temperature has the same non-linear but opposite kind of impact on the yield variability of winter rice.

The rest of the paper is organised as follows. Section II covers data and methodology used. Section III discusses regression results whereas Section IV makes conclusion along with implications.

II

DATA AND METHODOLOGY

II.1 *Data*

This study is based on secondary data covering 23 districts of Assam for a period of 1991-92 to 2012-13. These districts are – Barpeta, Bongaigaon, Cachar, Darrang, Dhemaji, Dhubri, Dibrugarh, Goalpara, Golaghat, Hailakandi, Jorhat, Kamrup, Karbi Anglong, Karimganj, Kokrajhar, Lakhimpur, Morigaon, Nagaon, Nalbari, Dima Hasao, Sibsagar, Sonitpur and Tinsukia. It may be noted that the districts of Assam have gone through several boundary changes over time. Until 1981 there were 10 districts. During 1981 to 1991, eight of them were split to create 13 new districts, bringing the total number to 23. Thereafter during 2003-04, three new districts namely, Baksa, Chirang and Udalguri were carved out from Barpeta, Nalbari, Kamrup, Kokrajhar, Bongaigaon, Darrang and Sonitpur. However, since data on these new districts are not available for the previous years, we have subsumed them to their parent districts.[2]

This study focuses on five principal crops of Assam, namely, autumn rice, summer rice, winter rice, mustard and potato.[3] Data on average yields of these crops are compiled from various official sources such as Directorate of Agriculture, Government of Assam; Directorate of Economics and Statistics, Government of Assam and Government of India, and Ministry of Agriculture, Government of India.

As regards the climatic data the study uses high-resolution (1º latitude × 1º longitude) daily gridded temperature and rainfall data published by the National Climate Centre of India Meteorological Department (IMD). Such high resolution daily weather data are extremely valuable because of the fact that day-to-day variations in weather conditions such as temperature during growing season is a crucial factor that affects crop growth and yield. Following Nath and Mandal (2018) we obtain district level daily temperature and rainfall data from this high-resolution gridded data by using a modified Shepard's inverse weighting interpolation method. First, we take the geographical centre of a district in terms of latitude and longitude, and identify the grid points (i.e., latitude × longitude) that fall within 100 kilometers from this centre. Then we calculate the district-level temperature and rainfall figures as a weighted average of their respective recorded values at the identified grid points. The inverse square roots of the distances of these grid points from the district centre are used as the corresponding weights. This ensures that further the grids are from the district centre lesser would be the influence of their recorded temperature and rainfall values on the district figures. The district level daily weather data thus obtained are then used to construct various climatic variables relevant for this study as mentioned below.

II.2 *Methodology:*

The available studies on climate change impacts on agriculture have used varied methodologies.[4] Our main objective is to investigate the impact of the climatic variables, namely, rainfall and temperature, on mean yields and their variability of the principal crops in Assam. Hence, we have used a stochastic production function approach as suggested by Just and Pope (1978). This production function is, in fact, a combination of two components one of which relates to output and the other variability of output. Hence, estimation of this production function helps to find out the impact on output and its variability simultaneously. This approach has been used by researchers like Chen *et al.* (2004), Isik and Devadoss (2006), McCarl *et al.* (2008), Cabas *et al.* (2010), Poudel and Kotani (2013), and Guntukula and Goyari (2020).

The yield function in the present empirical context following Just-Pope (1978) approach can be written as:

$$y = f(X,\beta) + \mu = f(X,\beta) + h(X,\alpha)\varepsilon \quad ....(1)$$

In equation (1), y represents the average yield of a crop and X is a vector of the explanatory variables (including the climatic variables). The first part of the function, i.e., $f(.)$ is the deterministic component of yield and is called the mean function as it relates the explanatory variables (Xs) to average yield with β as the associated vector of the parameters. The estimates of the parameters of $f(.)$ give the average effect of the explanatory variables on yield. On the other hand, μ is the heteroscedastic disturbance term with mean zero. The second part of equation (1), i.e., $h(.)$ is the stochastic component of yield which is called the variance function. It relates the explanatory variables (Xs) to standard deviation of yields with α as the associated parameters to be estimated, and ε is a random error term with zero mean and variance σ^2. Under the assumption of the error term ε being distributed with mean zero and unitary variance, $h^2(.)$ is the yield variance (McCarl *et al*., 2008). The Just–Pope function does not impose a priori restriction on the risk effects of inputs and therefore it accommodates both increasing and decreasing risk effects of inputs on output. More specifically, a positive (or negative) and statistically significant value of α in equation (1) implies that yield variance increases (decreases) with the corresponding covariate. Thus, estimation of α captures risk of crop yields with respect to the covariates.

The explanatory variables used in the above model as shown by equation (1) include climatic variables and some control variables. The climatic variables used in the present context are rainfall (in mm) – *Rain* ; square of rainfall – *Rain*^{2}; mean temperature (average of daily mean temperature in degree Celsius) – *Temp*; square of mean temperature – *Temp*^{2}; standard deviation of rainfall – *SD_Rain*; and standard deviation of temperature – *SD_Temp*.[5] The climatic variables are defined over the growing period of crops details of which are shown in Table 1.[6] On the other hand, the control variables used are: time trend – *Trend*; and a set of dummy variables specific to various agro-climatic zones.[7] Taking Lower Brahmaputra Valley Zone (LBVZ) as the reference category five dummies for the agro-climatic zones are used. They are *CBVZ* (=1 for districts belonging to Central Brahmaputra Valley Zone, 0 otherwise); *NBPZ* (=1 for districts of North Bank Plain Zone, 0 otherwise); *UBVZ* (=1 for districts belonging to Upper Brahmaputra Valley Zone, 0 otherwise); *HZ* (=1 for districts of Hills Zone, 0 otherwise); and *BVZ* (=1 for districts belonging to Barak Valley Zone, 0 otherwise).

TABLE 1. PRINCIPAL CROPS IN ASSAM AND THEIR SEASONS OF CULTIVATION

Crops (1)	Sowing period (2)	Harvesting period (3)	Period of growth# (4)	Source (5)
Winter rice	June - August	November - December	July to November	Directorate of Rice Development (DRD), India
Summer rice	December - February	May - June	January to May	Directorate of Rice Development (DRD), India
Autumn rice	Mid February - April	June - July	April to June	Directorate of Rice Development (DRD), India
Rapeseed and Mustard	November - December	February - March	December to February	ICAR (Crop Science Division)
Potato	October - November	January	November to December	Package of practices for Horticultural crops, Assam

Note: #Following Nath and Mandal (2018) period of growth is taken as the period from middle of sowing to middle of harvesting period.

Thus, the empirical model can be written as follows:

$$y_{it} = \beta_0 + \beta_1 Rain_{it} + \beta_2 Rain_{it}^2 + \beta_3 Temp_{it} + \beta_4 Temp_{it}^2 + \beta_5 SD\_Rain_{it} + \beta_6 SD\_Temp_{it} + \beta_7 Trend_{it} + \beta_8 CBVZ_{it} + \beta_9 NBPZ_{it} + \beta_{10} UBVZ_{it} + \beta_{11} HZ_{it} + \beta_{12} BVZ_{it} + h(X_{it}, \alpha)\varepsilon \quad ....(2)$$

Here, i and t are district and year identifiers respectively, and y represents average yield of a particular crop. Following Cabas *et al*. (2010) and McCarl *et al.* (2008) we have estimated equation (2) using feasible generalized least squares (FGLS). The FGLS estimation involves three steps. In the first step, we regress yield on the explanatory variables and obtain the least squares residuals $\hat{\mu}$ (where, $\hat{\mu} = y - f(X, \hat{\beta})$) as a consistent estimator of μ. In the second step logarithm of the squared residuals is regressed on $h(.)$ and we obtain the predicted values of the residuals, which are calculated as antilogarithm of predictions from second step. The second step regression gives the 'yield variability' results. In the final step, we estimate the original model of step one by weighted least square (WLS) where the square root of variance prediction of step two is used as weights. The results so obtained in the final step show the 'mean yield' regression results. It may be noted that pooled OLS is used for estimation purpose because it is more appropriate for the three-step estimation of the Just-Pope production function type yield function used in the present study.

III

RESULTS AND DISCUSSION

This section discusses the regression results of the impact of climate change on mean yield and its variability of the principal crops in Assam. Before estimating the regression model (equation 2) at first panel unit root test is conducted to check potential non-stationarity for all variables using Fisher's test with null hypothesis of existence of unit root followed by alternative hypothesis of existence of no unit root. The reason for using Fisher's test of panel unit root is that it is suitable for unbalanced panel data set (Maddala and Wu, 1999; Baltagi, 2005).[8] Moreover, we have considered Phillips-Perron (PP)-Fisher Chi square test over the Augmented Dickey-Fuller (ADF) - Fisher Chi square test because of three reasons. The first advantage of considering PP- Fisher Chi square test is that it has greater power than the (ADF) - Fisher Chi square test (Banerjee *et al*., 1993). Secondly, the PP- Fisher Chi square tests are robust to general forms of heteroskedasticity in the error term (Phillips and Perron, 1988). And lastly unlike ADF test, we need not have to specify the lag length in case of PP-test (Debnath and Roy, 2012). The unit root test results for trend stationarity are shown in Table 2 from which it is found that all the variables under consideration are stationary.

TABLE 2. RESULTS OF UNIT ROOT TEST OF VARIABLES (PHILLIPS-PERRON-FISHER TEST)

	Chi Squares				
Variables (1)	Autumn Rice (2)	Winter Rice (3)	Summer Rice (4)	Mustard (5)	Potato (6)
Yield	185.12***	94.57***	65.59***	204.79***	55.75***
Rain	284.33***	201.20***	234.41***	159.22***	244.37***
SD_Rain	264.90***	372.85***	270.20***	187.76***	390.22***
Temp	209.10***	159.19***	264.38***	345.79***	92.46***
SD_Temp	203.98***	211.92***	507.98***	65.35***	397.96***

Source: Researchers' own calculation.
Note: *** significant at 1per cent.

The regression results of the impact of climate change on average yield and its variability of the three seasonal varieties of rice are given in Table 3 and likewise the results of mustard and potato are worked out in Table 4.

III.1.1 *Impacts on Mean Yields of Rice*

The regression results of mean yields of the three seasonal varieties of rice are shown in Table 3 (columns 2, 4 and 6). As seen from Table 3 the coefficient of *Temp* is found to be positive and statistically significant for all three seasonal varieties of rice. This implies that daily average temperature has positive impact on mean yield of rice in Assam which is contrary to the general perception about impact of global warming on crop yields. The beneficial impact on yields may be because of the fact that rice, like every other crop, requires an optimum temperature range for its optimal growth, and daily average temperature in the state might be within this range as a result of which increase in temperature helps in higher average yield of rice. The positive impact of temperature on crop yields has also been noted by some other studies (Rao *et al.*, 2019; Rosenzweig and Hillel, 1995; Parry *et al*., 2004; Magrin *et al*., 2005). Another finding of interest as seen from Table 3 is that the coefficient of *Temp*^{2} has turned out to be negative for all but significant for summer rice. Thus, the beneficial impact of temperature on yield of summer rice gets reversed when it crosses a particular range. More precisely, any increase in daily mean temperature beyond 13.76°C tends to reduce average yield of summer rice because this excessive temperature may lead to higher respiration rates, speeding up of seed formation, and consequently, lower biomass production (Adams *et al*., 1998, Cline, 2008).

TABLE 3. REGRESSION RESULTS OF MEAN AND VARIABILITY OF RICE YIELDS

	Yield of Autumn Rice				Yield of Summer Rice				Yield of Winter Rice			
	Mean		Variability		Mean		Variability		Mean		Variability	
Variables	Coef.	T	Coef.	T	Coef.	T	Coef.	T	Coef.	T	Coef.	T
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Rain	-.280	-.18	.00005	0.06	.085	0.24	-.00007	-0.05	-.138	-0.92	.0008	0.68
Rain^2	.00007	1.41	-1.63e-0	-0.36	-.0001	-0.73	8.39e-07	0.80	5.20e-0	0.01	-1.68e-07	-0.38
Temp	59.12**	2.12	-5.43	-0.61	218.98***	3.75	-10.41*	-1.93	66.73**	2.49	12.21*	1.76
Temp^2	-.63	-0.57	.1085	0.63	-7.96***	-3.14	.251**	1.99	-.623	-0.64	-.237*	-1.78
SD_Temp	42.84	0.74	.281	0.98	77.82	1.04	.431	1.28	-39.0	-1.08	.126	0.36
SD_Rain	.245	1.38	.0006	0.47	-.092	-0.11	-.005*	-1.80	.288	0.82	-.0004	-0.15
Trend	10.24***	3.55	.017	1.05	42.23***	12.83	.004	0.29	7.34*	1.72	.059***	3.31
CBVZ	321.99	1.08	1.47***	3.81	399.18***	2.72	-1.03***	-2.79	22.85	0.35	.683	1.63
NBPZ	-40.92	-0.70	-.317	-0.86	-289.43***	-3.44	-.02	-0.06	-60.29	-1.08	.496	1.15
UBVZ	482.14***	4.50	.533	1.29	125.81	0.65	-1.61***	-4.67	269.22***	3.06	1.08**	2.30
HZ	272.09**	2.38	-1.008***	-2.55	-245.00*	-1.91	.385	1.02	115.8	0.88	1.62***	3.89
BVZ	1018.05***	6.34	.968***	3.11	-250.48*	-1.93	-.904***	-2.89	424.26***	6.54	.848**	2.51
Constant	-1.98	-1.00	77.04	0.68	.238	0.23	117.43**	2.05	2.01**	2.30	-149.15*	-1.65
R^2	72.04 per cent F(12,492) =105.62***		10.63 er cent F(12,492) = 4.88***		77.32 per cent F(12,488)= 138.67***		10.82 per cent F(12,488) = 4.93***		61.34 per cent F(12,492) = 65.04***		8.50 per cent F(12,492) = 3.81***	

Note: ***, ** and * imply statistically significant at 1, 5 and 10 per cent levels of significance respectively.

Finally positive and significant coefficients of *Trend* for all the three seasonal varieties of rice imply that their average yield has a tendency to increase over the years. As far as the agro-climatic zones are concerned the average yields of autumn and winter rice are higher in the Upper Brahmaputra Valley Zone (UBVZ) and Barak Valley Zone (BVZ) than the reference category Lower Brahmaputra Valley Zone (LBVZ). Similarly, mean yields of autumn rice and summer rice are higher in Hills Zone (HZ) and Central Brahmaputra Valley Zone (CBVZ) respectively than LBVZ. On the other hand, mean yields of summer rice are lower in North Bank Plain Zone (NBPZ), HZ and BVZ compared to LBVZ.

III.1.2 *Impacts on Yield Variability of Rice*

The regression results of variability of average yields of the three seasonal varieties of rice are shown in Table 3 (columns 3, 5 and 7).[9] As far as the impacts of climatic factors on variability of rice yields are concerned it can be observed that the coefficients of *Temp* and $Temp^2$ turned out to be statistically significant for summer rice and winter rice. The signs of their respective coefficients imply that variability (or risk) in yield of summer rice decreases with increase in daily average temperature within a particular range beyond which further rise in the temperature increases its yield variability. More precisely, yield variability of summer rice decreases with increase in daily average temperature up to 20.74ºC beyond which the impact gets reversed. This indicates that excessive temperature during the growing season of summer rice can make its cultivation more risky by increasing its yield variability. However, temperature has exactly the reverse kind of impact on the yield variability of winter rice. Moreover, standard deviation of rainfall is found to reduce variability of mean yield of summer rice.

The coefficients of *Trend* for all three seasonal rice varieties are found to be positive which implies that variability of rice yields has increased over the years. But these results have turned out to be statistically significant only in case of winter rice. Finally compared to LBVZ variability of autumn rice yield is higher in CBVZ and BVZ, and lower in HZ. Similarly, in relation to LBVZ variability of winter rice is higher in UBVZ, HZ and BVZ. On the other hand, summer rice yield variability is lower in CBVZ, UBVZ and BVZ than LBVZ.

III.2.1. *Impacts on Mean Yields of Mustard and Potato*

The regression results of mean yields of mustard and potato are indicated in Table 4 (columns 2 and 4). As seen from the table daily average temperature (*Temp*) has positive impact on mean yield of mustard and potato. This result is similar to the findings about impact of temperature on average yield of all three seasonal varieties of rice in Assam mentioned earlier (Table 3). However, a negative and statistically significant coefficient of $Temp^2$ in case of mustard implies that its yield decreases when temperature rises beyond a certain range. The intuition behind this is that excessive temperature during the growing period leads to higher respiration rates, speeding up of seed formation, and consequently to lower biomass production resulting in lower yields (Adams *et al.*, 1998). As far as the agro-climatic zones are concerned the average yield of potato is found to be lower in all but HZ as compared to LBVZ.

III.2.2 *Impacts on Variability of Yields of Mustard and Potato*

As far as the impact of climatic factors on the variability of yield is concerned it can be seen from Table 4 (columns 3 and 5) that the coefficients of *Temp* and $Temp^2$

have turned out to be statistically significant for potato. Their respective signs imply that daily average temperature reduces variability of potato yields initially but when the temperature crosses a particular range it makes potato yields more variable. Thus, the risk reducing effects of temperature for potato yield gets reversed when it crosses a particular range. On the other hand, standard deviation of temperature is found to increase variability of mustard yield. Among the control variables, variability of mustard yield is found to be higher in UBVZ, HZ and BVZ compared to LBVZ. On the other hand, potato yield variability is found to be lower in BVZ than LBVZ.

TABLE 4. REGRESSION RESULTS OF MUSTARD AND POTATO YIELDS

	Yield of Mustard				Yield of Potato			
	Mean		Variability		Mean		Variability	
Variables	Coef.	T	Coef.	t	Coef.	t	Coef.	t
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Rain	.277	0.77	-.001	-0.30	-4.07	-0.32	.005	0.37
$Rain^2$	-.0008	-0.80	4.17e-06	0.23	-.083	-0.93	-7.94e-06	-0.08
Temp	58.48***	2.81	-1.28	-0.36	756.91***	2.95	-13.47**	-2.53
$Temp^2$	-1.93*	-1.78	.030	0.30	-16.53	-1.48	.344**	2.49
SD_Temp	51.82	0.82	.773**	1.98	-389.70	-1.42	-.241	-0.74
SD_Rain	-.53	-0.79	-.0006	-0.06	15.19	1.10	-.008	-0.56
Trend	1.77	1.19	-.012	-0.64	-13.30	-0.79	-.007	-0.42
CBVZ	-38.00	-0.84	.596	1.51	-2325.488***	-5.43	.182	0.42
NBPZ	-44.21	-1.08	.543	1.48	-2297.89***	-6.55	-.177	-0.47
UBVZ	61.50	0.45	1.605***	4.26	-1684.55***	-4.71	-.128	-0.33
HZ	-102.75	-1.48	.894**	2.25	-234.59	-0.54	-.686	-1.58
BVZ	-22.73	-0.22	1.23***	3.54	-3581.59***	-7.99	-.936**	-2.42
Constant	-.318	-0.11	19.45	0.63	1.46	1.61	146.06***	2.84
R^2	58.50 per cent		6.12 per cent		35.18 per cent		4.93 per cent	
	F(12,492) =57.80***		F(12,492)= 2.67***		F(12,492)= 22.25***		F(12,492)= 2.13**	

Note: *** , ** and * imply statistically significant at 1, 5 and 10 per cent levels of significance respectively.

IV

CONCLUSION AND IMPLICATIONS

The paper examines the impact of climate change on average yield and its variability of the principal crops in Assam. Here variability of yield is captured in terms variance of yield of a particular crop. A Just-Pope stochastic production function type yield function is used which facilitates estimation of the impacts on average yield and its variability simultaneously. The analysis of results shows that daily average mean temperature during the growing season has positive impact on mean yield of all the five principal crops of Assam included in the study, viz., autumn rice, winter rice, summer rice, mustard and potato. However, these beneficial impacts tend to get reversed when temperature crosses a particular range in case of summer rice and mustard. Rainfall is, however, not found to have statistically significant impact on average yields of the principal crops in Assam.

As far as the climate change impacts on the variability of crop yields are concerned it is found that daily average mean temperature has beneficial effects in reducing variability of yields of summer rice and potato initially up to a particular point beyond which further rise in temperature increases their yield variability, thereby increasing risk for the farmers.

The results mentioned above have important implications for the agriculture sector of Assam where most of the farmers because of being poor have limited capacity to cope with the adverse impacts of ongoing and future climate change. Though daily average temperature is found to be beneficial for mean yield of all the principal crops under study, excessive temperature which is expected to be the case in future can be harmful for them. Moreover, excessive temperature can pose greater risk for the farmers by increasing yield variability of crops. It has been observed that the daily average mean temperature across the state is increasing while the annual and seasonal rainfall has been declining over the years (Singha, 2019). Such changes in the climatic pattern of the state can have serious consequences for the crop growing sector because of the fact that agriculture in the state is mainly rain-fed in nature. A declining rainfall coupled with increasing mean temperature can put added thermal stress on crop growth, and thus the non-linear negative impact of temperature on crop yield might start much earlier than expected. This calls for expansion and optimum utilisation of irrigation facilities throughout the state.[10]

Since the climatic factors like rainfall and temperature are exogenous to the farmers they need to take appropriate adaptation measures to mitigate the adverse impacts of climate change. For this the farmers need to be made aware about the changes in the climatic patterns in the state, its potential adverse impacts and the possible adaptation measures they can take to cope with the adverse impact of climate change on crop yields. The adaptation measures that can be useful in this regard include changing cropping patterns, crop diversification, farm insurance, changing farming practices and farm loans (Duong *et al.*, 2019; Ruiz *et al.*, 2015).

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NOTES

1. Agriculture supports more than 75 per cent of population and provides employment to more than 53 per cent of the workforce in Assam (Government of Assam, 2011).

2. Moreover, during 2015-16 six more districts were created taking the total number of districts to 33. The newly created districts are Biswanath, Charaideo, Hojai, South Salmara, West Karbi Anglong and Majuli. However, since our study period is until 2012-13 we have not taken them into account.

3. During 2009-10 and 2013-14 the average percentage shares in total cropped area of autumn rice, winter rice, summer rice, rapeseed and mustard, and potato were 6.78 per cent, 45 per cent, 9.6 per cent, 6.31 per cent and 2.23 per cent respectively.

4. See Mandal and Nath (2018) for a review of the methodologies.

5. This study makes use of daily gridded rainfall and temperature data of the India Meteorological Department (IMD) because previous studies (Mearns *et al*, 1996; Schlenker and Roberts, 2009) show that day-to-day variations in temperature and rainfall during the growing season have crucial effects on the growth and yield of crops. However, most studies on climatic impact on agricultural yield in India have used monthly weather data primarily due to a lack of high resolution daily weather data until recently.

6. The growing period of a crop has been defined as the period between mid-point of sowing and harvesting periods.

7. It may be noted that data on agricultural inputs such as fertilizer, irrigation and area under high-yielding variety seeds (for rice) are available in aggregate, and not separately for individual crops. Hence they could not be included in the model.

8. This study is based on an unbalanced panel dataset of 23 districts of which all have 22 time points except Bongaigaon which has one time point less.

9. Here variability of yield is captured in terms variance of yield of a particular principal crop under study.

10. The declining trend of annual and seasonal rainfall in the state may adversely affect replenishment of ground water in future. Therefore, shallow tube well based ground water irrigation system, which is very popular among the farmers in the state, need to be complemented by expansion and proper utilisation of surface water irrigation schemes.

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