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Assessing Impact of Climatic Variability on Crop Yields in Rajasthan

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Abstract: The paper analyzes yield sensitivity of major rainfed crops namely pearl millet, sorghum and maize to climatic variability in Rajasthan, the driest state of India. The yield time series data for the three selected crops were compiled for all 32 districts of Rajasthan from 1990 to 2006. For each crop only those districts where area sown under the crop was more than 5000 ha were included in the analysis. Consequently we included 14 districts for sorghum, 17 for pearl millet and 16 for maize and district wise monthly maximum temperature during crop season, wet day frequency and total precipitation as the basic climate variables. The effect of technological progress was removed by de-trending the productivity. The district-wise sensitivity estimates were grouped more homogeneously using multivariate cluster analysis. The yield of analyzed dryland crops was highly sensitive to weather variables. The increase in rainfall and number of rainy days would result in yield increment in most of the districts and *vice-versa*. Maximum temperature was found to influence the yields negatively in most of the districts. Finally we suggest research and development options for climate adaptation for different clusters of districts.

Key words: Weather sensitivity, climatic variability, dryland crops, climate impact.

Warming of climate system and its effects are likely to affect global livelihood and environmental systems in various ways (IPCC, 2007). Since climatic factors serve as direct inputs to agriculture, any change in climatic factors is bound to have a significant impact on crop yields and production. There is a considerable research focus on the impact of climate change on agriculture. Studies have shown a significant effect of change in climatic factors on average crop yield (Dinar *et al.*, 1998; Seo, and Mendelsohn, 2008; Mall *et al.*, 2006; Cline, 2007). However the impact of climatic factors on mean crop yield has not been investigated much especially in agriculture based developing economies where there is likely to be more serious repercussions in terms of food security, inequality and economic growth. Uncertainties in weather create risky environments for crop production, farming systems and food supply. The way climate change will affect agricultural productivity is expected to vary depending upon various factors including geography and technology levels. While an overall significant damage of 3.2% is expected in the global agriculture production by the 2080s under business as usual scenario, it is found that the losses may even go up to 15.9% if the carbon fertilization effect is not realized. The developing countries, predominantly located near the lower altitude, are most likely to incur a much greater loss roughly quantified at 21% (Cline, 2007). In developing countries, climate change will cause yield declines for the most important crops and South Asia will be particularly hard hit (IFPRI, 2009). Many studies in the past have shown that India is likely to witness one of the highest agricultural productivity losses in the world in accordance with the climate change pattern observed and scenarios projected. Climate change projections made up to 2100 for India indicate an overall increase in temperature by 2-4°C with no substantial change in precipitation quantity (Kavikumar, 2010). The projected agricultural productivity loss for India by 2100 is 10% to 40% after taking carbon fertilization effect into account (Agrawal, 2008). Many simulation-based crop growth models have been developed to examine the vulnerability of agriculture to climate change (Hoogenboom, 2000) particularly for situation of developed temperate countries. Many studies (Parry *et al.*, 1999; Darwin, 2004; Olesen and Bindi, 2002; Adams *et al.*, 2003; Tsvetsinskaya

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et al., 2003) find that region specific analysis is required to evaluate agronomic and economic impact of weather changes in more detail. Within agriculture, it is the dryland agriculture that will be most impacted by climate change for two reasons. First, dryland agriculture is practiced in fragile and degraded lands which are constrained by moisture deficit as well as poor soils. Second, the people dependent on rainfed agriculture are also less endowed in terms of financial, physical, human and social capital limiting their capacity to adapt to the changing climate. The following are some of the challenges that the changing climate will pose to rainfed agriculture: Temperature is an important weather parameter that will affect productivity of rainfed crops. Last three decades saw a sharp rise in all India mean annual temperature. Though most rainfed crops tolerate high temperatures, but rainfed crops grown during post-rainy season (rabi*)* are vulnerable to changes in minimum temperatures (Venkateswarlu and Ramarao, 2010). Analysis of data for the period 1901-2005 by India Meteorological Department suggests that annual mean temperature for the country as a whole has risen to 0.51°C over the period. It may be mentioned that annual mean temperature has been consistently above normal (normal based on period, 1961-1990) since 1993. This warming is primarily due to rise in maximum temperature across the country, over a larger part of the data set. Apart from direct impacts, higher temperatures also increase the water requirements of crops putting more pressure on the availability of water (CRIDA, 2007-08). The extent to which rainfall and temperature patterns and the intensity of extreme weather events will be altered by climate change remains uncertain, although there is growing evidence that future climate change is likely to increase the temporal and spatial variability of temperature and precipitation in many regions (IPCC, 2007). Therefore, the objective of this study was to understand the sensitivity of yields of major rainfed crops viz. pearl millet, sorghum and maize to climatic factors in a state which has highest proportion of its area as rainfed among the major states of India.

Data and Methodology

The yield data of the selected crops from 1990 to 2008 were obtained from Center for Monitoring Indian Economy (CMIE) database and are denoted in kilograms per hectare (kg ha^{-1}). CMIE collates the statistics on Indian agriculture from a comprehensive range of sources including government reports. The yield time series data for the three selected crops viz., pearl millet, sorghum and maize were compiled for 32 districts of Rajasthan. However to examine the weather sensitivity, for each crop only those districts where area sown under the crop was more than 5000 ha and yield data available for at least 10 years were included in the analysis. Consequently we included 14 districts for sorghum, 17 for pearl millet and 16 for maize spread throughout Rajasthan.

Data on climatic variables are downloaded from CMIE as well as from India Water Portal. The dataset available at the portal is developed using the publicly available Climate Research Unit (CRU) dataset, out of the Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK (http://indiawaterportal.org/metdata). For this study, we consider district wise monthly maximum temperature during kharif (rainy) season, wet day frequency and total precipitation as the basic climate data. Rainy season (June-October), which is the main crop season in rainfed regions in India, is called kharif. Use of district level time series climate and yield data allowed the examination of both inter-temporal variances in the data with spatial characteristics and technology trend controlled.

Analytical model

Technological progress masks the effects of climate and resource degradation. It has been well demonstrated that the adoption of appropriate technologies could well offset the adverse effect of climatic variability on crop productivity (NICRA, 2012). Hence to understand the crop yields sensitivity to climatic variability, the influence of technology on yields needs to be removed first. We thus removed the effect of technological progress by de-trending the productivity by fitting a time trend equation. To assess the technological trend, we had first tried with independent variables like area under high yielding varieties, fertilizer use, extent of irrigation, pesticide use in the model, but the model explained less variation with low value of coefficient of determination. A large numbers of technological and management variables influence the crop yields and which are not possible to include in the function on account of non-availability of data. However, the model fitted with time as independent variable was turned out to be better fit and was finally used in the analysis. The de-trended productivity was then regressed on the three weather variables. This methodology is further described here.

Step 1. Assessing technological trend: For each crop for each district included in the analysis the following regression model was fitted.

$Y=a+bt+\theta$

where, Y is yield of the crop in year t in the district under study; a is intercept; b is technological trend in the crop assessed in the district under study; t is year and θ is residual. A total of 47 time trend equations were fitted for selected districts and crops. Then, the de-trended yields for each district were derived as under

$\theta = Y - a - bt$

Step 2. Fitting de-trended yield data on to weather parameters: De-trended yields of each district were regressed on climatic variables viz. annual rainfall, wet day frequency and kharif monthly maximum temperature (June to October). More than seasonal rainfall, its distribution is more important for dryland crops grown during rainy season (Kharif). Hence, the study included the wet day frequency in the analysis. The multiple linear regressions fitted were of the form:

$$\theta = \beta_1 R + \beta_2 W + \beta_3 T + \epsilon$$

where, β_1 is the linear sensitivity of de-trended yield to rainfall *R;* β_2 is the linear sensitivity of de-trended yield to wet day frequency *W;* β_3 is the linear sensitivity of de-trended yield to monthly maximum temperature *T.*

Step 3. Multivariate cluster analysis of sensitivities of districts: In order to enable a more meaningful and easy interpretation of the findings, the districts were grouped into more homogeneous districts by subjecting the district-wise sensitivity estimates to multivariate cluster analysis. For each crop, 2-4 clusters with varying extent of sensitivity were delineated. Before subjecting the data to cluster analysis the 3 sensitivity variables were standardized using z score method ([(x-mean)/SD]). All the hierarchical clustering algorithms such as Farthest neighbor, Nearest neighbor and Ward's methods were tried with standardized data and finally Ward's method was found to be yielding the manageable number of clusters at relatively lower intra-cluster variation. The distance measure used in analysis was Squared Euclidian distance. The analysis facilitated to interpret 3 sensitivity variables together in term of variability in sensitivities. One cluster of districts with –ve sensitivities (highly sensitive) and another cluster of districts with medium sensitivity and one cluster of districts with +ve sensitivities (highly sensitive) and so on.

Results and Discussion

As part of South Asia, Indian agriculture continues to be dominated by rainfed agriculture with nearly 60% of net cultivated area not having any access to irrigation. The proportion of rainfed area in Rajasthan is 80%, which is highest among different states of India. It has been estimated that even after full irrigation potential of India is realized, half of the cultivated area will continue to be under rainfed farming (Katyal *et al.*, 1996). Thus examining factors affecting crop yield in rainfed regions becomes more important. Besides weather variables, the crop yields in rainfed areas are also influenced by technology, market and management factors. Fitting technological trend and consequently deriving de-trended yields for further functional analysis takes care of the factors other than weather variables. District wise and crop wise regression functions fitted by using de-trended yields as dependent variables and weather variables as independent, demonstrated that the weather variables like rainfall, wet day frequency and maximum temperature influenced the yields of rainfed crops. The multivariate cluster analysis resulted in classifying the sensitivity estimates for pearl millet into 4 groups and that of sorghum into 2 groups and for maize only one cluster. The numbers of clusters were more in case of pearl millet as it is grown under more diverse conditions across arid as well as semiarid agro-ecologies as compared to other two crops.

In case of pearl millet cluster wise sensitivity coefficients presented in Table 1 show that the crop yields were highly and positively influenced by wet day frequency (number

Table 1. Weather sensitivity coefficients for pearl millet productivity

Cluster	Frequency	Variables	Av. of 25th & 75th percentile of weather sensitivity coefficients	Range of coefficients		Districts in each cluster
I	19	Annual rainfall	0.14	-0.02	0.31	Sawai Madhopur, Nagaur, Jaisalmer, Barmer, Jalore, Sirohi, Pali, Ajmer
		ann_wdf	11.85	5.22	18.48	
		Kha_max_temp	-11.03	-15.37	-6.70	
II	6	Annual rainfall	0.43	0.09	0.78	Hanumangarh, Churu
		ann_wdf	26.09	15.26	36.92	
		Kha_max_temp	-40.85	-58.50	-23.20	
III	14	Annual rainfall	1.02	0.81	1.24	Bikaner, Jodhpur, Tonk
		ann_wdf	-8.00	-12.37	-5.64	
		Kha_max_temp	-1.57	-10.72	5.86	
IV	12	Annual rainfall	0.22	0.13	0.31	Jhunjhunu, Bharatpur, Jaipur
		ann_wdf	-9.62	-13.80	-5.45	
		Kha_max_temp	8.06	2.80	13.32	

Note: Kha_max_temp: Kharif maximum monthly temperature; ann_wdf: Annual wet day frequency.

of rainy days) in especially in clusters I and II. The distribution of rainfall was a major factor influencing pearl millet yield. Similarly, the pearl millet yield was quite sensitive to the amount of rainfall and was positively associated indicating that yield will increase with the increase in rainfall and vice versa in all the clusters. The sensitivity coefficient of rainfall was positive and highest in cluster III with actual annual rainfall varying from 295 to 613 mm. The observed negative relationship of yield with wet day frequency in cluster III and IV may be due to untimely rains affecting the crop. Sensitivity coefficients show that pearl millet yield was highly sensitive to kharif maximum temperature negatively in cluster I, II and III, but not in cluster IV. Since the districts falling in cluster IV like Jhunjhunu, Bharatpur, Jaipur are relatively agriculturally progressive and might have higher adoption of improved technologies including short duration variety of pearl millet like improved HHB-67. The higher productivity in these districts in the base year itself (1990) may also not be allowing the technological trend to reflect the influence of technology. In terms of comparison among clusters, the cluster I and II were more vulnerable to change in climatic factors. In these clusters the pearl millet yield was influenced by all the three factors, where the coefficient of rainfall and wet day frequency was positive indicating adverse impact on yield in case of decrease in their magnitude, and negative coefficient for kharif monthly maximum temperature indicating adverse impact on yield with its rise.

Maize is a major rainfed crop and has huge untapped potential (Dass *et al*., 2010). In the past few years it has been replacing crops like sorghum, castor, post rainy season paddy, etc., particularly in rainfed regions. Since all the districts having more than 5000 ha area under the crop selected for analysis were part of semi-arid agro ecology, the cluster analysis for maize allowed all the selected districts in one cluster. The analysis of weather sensitivity of maize productivity carried out for 16 districts of Rajasthan (Table 2) indicates that the productivity of maize was quite sensitive to change in kharif maximum temperature and wet day frequency (number of rainy days) as

Table 2. Weather sensitivity coefficients for maize productivity

Cluster	Frequency	Variables	Av. of 25th & 75th percentile of weather sensitivity coefficients	Range of coefficients		Districts in each cluster
I	16	Annual rainfall	0.20	-0.19	0.40	Rajsamand, Sirohi, Bhilwara, Jaipur, Udaipur, Alwar, Pali, Dungarpur, Chittorgarh, Bundi, Banswara, Ajmer, Baran, Kota, Jhalawar, Tonk
		ann_wdf	4.76	-1.90	12.41	
		kharif_max_temp	-0.94	-17.87	5.99	

Table 3. Weather sensitivity coefficients for sorghum productivity

Cluster	Frequency	Variables	Av. of 25th & 75th percentile of weather sensitivity coefficients	Range of coefficients		Districts in each cluster
I	13	Annual rainfall	-0.045	-0.27	0.18	Sawai Madhopur, Jaipur, Nagaur, Jodhpur, Sirohi, Pali, Ajmer, Tonk, Rajsamand, Udaipur, Kota, Baran, Jhalawar
		ann_wdf	9.955	2.14	17.77	
		Kha_max_temp	-11.745	-21.16	-2.33	
II	1	Annual rainfall	0.595	0.36	0.83	Bharatpur
		ann_wdf	-23.835	-32.43	-15.24	
		Kha_max_temp	15.885	5.91	25.86	

well as the amount of rainfall in most of the districts. It is pertinent to note that besides rise in temperature levels over the past 100 years; the frequency of extreme weather events like dry spells, extreme temperatures, high intensity rainfall, etc. during the recent decades is increasing (CRIDA, 2007-08) and thus has implications for crop like maize. The sensitivity coefficient for wet day frequency was positive indicating that any decrease in the number of rainy days will negatively affect the maize yield in these districts.

Sensitivity coefficients of rainfall were also positive indicating impact of rainfall variability on maize yield. At the same time, the coefficient was negative in the districts which are irrigated and have higher level of rainfall like Banswara, Udaipur, etc. Therefore, for better maize yield, besides rainwater harvesting and *in situ* moisture conservation practices in low rainfall regions, provision for draining out excess rainwater during high intensity rains is equally important. The sensitivity coefficients of kharif maximum temperature were negative indicating that reduction in maize yields from the currently used seeds is imminent in the respective districts as a result of increase in temperature due to future threat of climate change. It needs further investigation as to how increased temperature affects the yield whether through increased evapo-transpiration or other factors.

Similarly, weather sensitivity analysis for sorghum was carried out and the equations for the 14 districts were clustered into two groups based on similarities of sensitivity coefficients (Table 3). As sorghum is known to be tolerant to drought conditions, sensitivity coefficient of rainfall was positive indicating that the decrease in rainfall will adversely affect sorghum yield in these districts. But the coefficient of rainfall was negative mainly in districts with higher rainfall like Banswara, Udaipur, Kota, etc. The sorghum yields were highly sensitive to change in distribution of rainfall in terms of wet day frequency. The coefficients of wet day frequency were positive in cluster I for all 13 districts. The number of rainy days per annum has been decreasing all over the country during the past two decades resulting in frequent and longer dry spells. Hence, there is need for interventions to cope with moisture stress during dry spells. The cluster of districts where the magnitude of positive coefficient of wet day frequency is large is more sensitive and need appropriate adaptation and coping strategies. Similar to the other two crops of pearl millet and maize, the sensitivity coefficient of kharif maximum temperature were negative for sorghum also in cluster I covering 13 sorghum producing districts out of total 14 selected districts.

Conclusions

The debate on the extent of climate change and its impact on agricultural production are still continuing, however, it is becoming increasingly evident that the climatic variations and extreme weather events observed in the recent decades are impacting agriculture. The analysis carried out for the crops of pearl millet, maize and sorghum shows that the increase in rainfall and number of rainy days would result in yield increment in most of the districts and vice-versa. Kharif maximum temperature was found to influence the yields negatively in most of the districts. The cluster analysis has helped in categorizing the districts based on similarity in weather sensitivity. In the cluster of districts where the sensitivity coefficient of rainfall is very high and positive, the interventions on rainwater harvesting through farm ponds, percolation pond, and its use for supplemental irrigation are likely to result in considerable increase in productivity. For such districts, there is also need to strengthen weather based agro-advisories and prepare agricultural contingency plans. The seed of contingency crops/varieties may be arranged in advance through participatory approach like community seed bank with support from relevant stakeholders. Similarly, in the cluster of districts where sensitivity coefficient of wet day frequency is high and positive, the interventions to reduce moisture stress through supplemental irrigation, mulching and *in situ* moisture conservation practices like conservation furrow, ridge and furrow system of sowing, etc. are likely to result in increase of crop yield. The sensitivity coefficients of kharif maximum temperature which were negative for most of the clusters in all the three crops showing negative impact of increase in temperature on crop yields needs to be further examined. Farmers in the districts which have very high negative coefficient for kharif temperature may need to shift to suitable varieties. For all the three crops the sensitivity coefficients of rainfall were also negative for some of the districts. That may be due to high intensity or untimely rainfall affecting the crop yields. In such situation, the natural resource management (NRM) interventions like ridge and furrow system of sowing, conservation furrow, etc. will not only help in *in-situ* moisture conservation but also in draining out the excess rain water. The interventions like farm ponds, percolation ponds, water recharge structures, *in situ* moisture conservation practices as part of adaptation to climate change could be taken up under on-going rural development programmes in a big way. However such works at field level must be supervised by trained manpower in order to ensure technical soundness of NRM interventions. Enhanced understanding of crop yield sensitivity to climatic variability would help in designing appropriate adaptation strategies.

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