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Yield Vulnerability of Sorghum and Pearl Millet to Climate Change in India

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ABSTRACT

Climate change is emerging as an important threat to agriculture, food security and livelihoods. The impacts are likely to be more in rainfed agriculture. In this paper, we have examined the yield vulnerability of sorghum and pearl millet to climate change through panel data regression using the district level data for 1971-2004 and climate projections based on the regional climate model PRECIS. The yield was regressed on monthly rainfall and average temperature and the variability therein. Both levels and variability in monthly temperature affected crop yield significantly. Unlike many studies, this paper included variability in climate within a month as one of the regressors. The yield vulnerability is higher towards the period 2071-98 compared to 2021-50. The average yield impact is about 218 kg/ha for sorghum and 274 kg/ha for pearl millet. The analysis indicated no significant yield vulnerability for the mid-century period. However, the yield vulnerability showed considerable variability across districts. Efforts are therefore to be focused in the districts where steep yield reductions are projected. Further, technological change was found to neutralise considerable climate change impact underscoring the need to provide support to agricultural research in terms of resource allocation to agricultural research in general and climate change research in particular.

Keywords: Climate change, Crop yield, PRECIS, India, Sorghum, Pearl millet.

JEL: Q10, Q18, Q54, R58

I

INTRODUCTION

Agriculture continues to be the largest provider of employment in India with more than 50 per cent of workforce engaged in agriculture, though the share of this sector to gross domestic product is less than 20 per cent. The performance of agriculture also affects the performance of other sectors of the economy. The sector is facing challenges such as resource degradation, rising input costs, volatile output prices, etc. as well as the structural limitations mainly in the form of small farm size. The problem of climate change is further adding the dimensions of complexity and urgency to deal with all other problems making the task of moving towards more sustainable agriculture, food security and livelihoods more daunting. Though climate change is considered to be a global phenomenon, its impacts are more widely felt in the developing countries, due to their greater vulnerabilities and lesser ability to

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mitigate the effects of climate change. Agriculture being a natural resource dependent sector is directly affected by and more vulnerable to climate change (Ali *et al*., 2017).

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) stated that the atmospheric levels of carbon dioxide and nitrous oxide 'substantially exceeded' the highest levels known during the last 800000 years (IPCC, 2013). Each of the last three decades has been warmer than any preceding decade since the year 1850. Global mean temperature rose by 0.85 degrees Celsius (°C) between 1850 and 2012. While global warming is not spatially uniform across the globe, there is almost no region in the world that has not experienced some rise in the average temperature (Jayaraman and Murari, 2014). Noticeable increases in temperature, rise in sea level and incidence of extreme events such as drought and flood are projected with relatively higher levels of confidence. Rainfall patterns are also projected to change with most models showing some increase in rainfall though with 'less' level of confidence.

Rising temperature and carbon dioxide levels coupled with varying rainfall patterns affect the productivity of crops. Understanding and quantifying such yield vulnerability and consequent implications to food security has attracted the attention of several researchers. Two broad approaches of studying climate change impacts on or vulnerability of crop yields are evident from the literature: crop simulation modeling and econometric modeling. There were studies on the impacts and vulnerability of climate change on yield of wheat (Naresh Kumar *et al*., 2014), rice (Pathak and Wassmann, 2009, Subba Rao *et al*., 2015), sorghum (Srivasatava *et al*., 2010), mustard (Boomiraj *et al*., 2010). Such models are basically mechanistic in nature and are based on physiological understanding of crop growth and development and are generally done for selected locations. Jayaraman (2011) lists some of the simulation-based productivity impacts for different crops. Not all adaptation options and technological changes can be incorporated into such models. Also, they are more data intensive as models need to be calibrated and validated. Econometric models consisting of Ricardian and panel data approaches, on the other hand, can usefully complement the simulation based models and are relatively less intensive in data needs. Examples of such studies include Kumar and Parikh (2001), Birthal *et al*., (2014a,b). Panel data approach is relatively recent and is being used for the purpose following Deschenes and Greenstone (2007). Birthal *et al*., (2014a,b) mention the advantages of panel data regression approach.

Further, historically more attention was given to the relationship between foodgrain production and negative deviations in rainfall. However, the rising temperature and the variability therein are now emerging as important threats to productivity of crops (Jayaraman and Murari, 2014).

With this background, this paper attempts to examine the yield vulnerability of two major rainfed crops, viz., sorghum and pearl millet, to climate change in India. These two crops are chosen as they are largely grown under rainfed conditions during *kharif* (rainy season) and are not much impacted by the carbon fertilisation effect of climate change being C4 crops. We also included variability in temperature and rainfall in the analysis unlike many of the earlier studies.

II

METHODOLOGY AND DATA

The methodology comprised two step procedure: First, derive the relationship between climate variables and yield by applying panel data regression to the historical yield and climate data. Climate variables included monthly temperature, rainfall in terms of average and variability and number of rainy days by month. The months during which these crops are generally grown are considered (June to October). Second, apply the coefficients so derived to the projected changes in future climate variables. The following fixed effect model for climate impacts is specified:

$$Y_{it} = \alpha_o + \sum \alpha_i D_i + \sum \beta_j P_{jit} + \sum \gamma_j Q_{jit} + \sum \delta_j R_{jit} + \sum \eta_j (CV\_P)_{jit} + \sum \theta_j (CV\_Q)_{jit} + \Psi t + U_{it}$$

where
Y_{it} = Yield of i-th district in year t
D_i= Dummy variable for i-th cross- sectional unit (district) (i=1 to (k-1))
P_{jit}= Average temperature during j-th month for i-th district in t-th year
Q_{jit}= Rainfall during j-th month for i-th district in t-th year
R_{jit}= No. of rainy days during j-th month for i-th district in t-th year
CV = Coefficient of variation
k = number of cross sectional units (districts)
j = June, July, August, September, October
U_{it} = error term iid ~N (0, 1)
$\alpha, \beta, \gamma, \eta, \theta, \Psi$ are regression coefficients.

The time variable (t) was included in the model to capture the technological trend (Ψ) which captures the sum of effects of technological changes and other responses that happen over years. The district-specific dummy variables capture the effect of time invariant district specific resources like soil, irrigation available to the crop and crop management on the yield. The regression coefficients were estimated by LSDV method**.**

Data

The historical data on crop yields for different districts for the years 1971-2004 were obtained from the Department of Agriculture, Co-operation and Farmers' Welfare, Government of India and various state governments. All the districts having an area of at least 5000 ha[1] under the crop were included in the analysis. In case of climate, the grid level data provided by the India Meteorological Department was used to derive the district level data on average temperature and rainfall for the same period.

Two time periods were considered for future climate: mid-century period (2021-50) and end-century period (2071-98). The future climate was obtained by using the projections from PRECIS[2] regional climate model for SRES A1B[3] scenario in line with the India's Second National Communication (Government of India, 2012) to United Nations Framework Convention on Climate Change (UNFCCC). The yield impacts were reported for mid-points of the mid- and end-century periods.

III

RESULTS AND DISCUSSION

Climate Change in the Crop Growing Districts

Tables 1 and 2 summarise the change in climate variables during the mid-century (2021-50) and end-century (2071-98) periods compared to the baseline 1971-2004. In the sorghum growing districts, the average June temperature increased by about 2.73°C during mid-century and by 4.74°C during the end-century compared to 1971-2004. Along with the mean temperature, there was also a conspicuous increase in variability. Though the rise in temperature during the other months is relatively small, variability is more. The change in rainfall ranged from -19 to 68 mm during mid-century and from -14 to 86 mm during end-century in different months (Table 1).

TABLE 1. CLIMATE CHANGE IN SORGHUM GROWING DISTRICTS (172)

Climate variable		Change in mid-century				Change end-century			
		Min	Max	Mean	CV (per cent)	Min	Max	Mean	CV (per cent)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Average temperature (°C)	June	-3.16	7.56	2.73	55	-1.89	9.59	4.74	31
	July	-4.54	3.74	-0.07	-1778	-3.17	6.44	1.94	72
	August	-3.81	3.26	0.47	202	-2.53	5.85	2.24	57
	September	-4.28	3.85	0.37	299	-2.27	7.88	2.73	45
	October	-2.99	3.74	0.59	219	-0.30	7.72	4.20	22
Rainfall (mm)	June	-90	311	23	249	-149	242	17	425
	July	-77	626	68	145	-84	573	86	118
	August	-191	460	6	1282	-125	518	49	184
	September	-211	208	10	535	-206	246	21	259
	October	-158	40	-19	-205	-133	25	-14	-212
Rainy days (No.)	June	-6.15	10.81	1.19	329	-8.75	11.43	0.41	1239
	July	-4.51	16.47	6.73	52	-3.08	16.27	6.18	59
	August	-1.19	15.73	6.42	51	-2.62	15.76	6.83	51
	September	-6.66	11.81	3.57	119	-5.50	11.49	4.12	98
	October	-5.74	2.30	-0.57	-314	-4.18	4.72	0.20	753

In case of districts growing pearl millet, the likely increase in average temperature is higher for June (3.5°C) for mid-century and 5.41°C for end-century as compared to other months. The projected change in rainfall ranged between -18 to 56 mm in mid-century and from -136 to 324 mm during end-century. Even the variability in all the three climate variables is high. Thus, in both cases climate change is more conspicuous during end-century compared to mid-century (Table 2).

TABLE 2. CLIMATE CHANGE IN PEARL MILLET GROWING DISTRICTS (132)

Climate variable		Change in mid-century				Change in end-century			
		Min	Max	Mean	CV (per cent)	Min	Max	Mean	CV (per cent)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Average temperature (ºC)	June	-0.48	9.36	3.50	52	1.28	11.66	5.41	33
	July	-2.81	5.23	0.46	311	-0.80	7.51	2.51	60
	August	-1.88	4.44	0.71	147	-0.81	7.26	2.67	52
	September	-1.55	4.73	0.79	156	0.29	8.27	3.26	43
	October	-1.75	3.85	0.78	175	2.12	7.66	4.37	23
Rainfall (mm)	June	-89	131	2	1890	-150	-103	-136	-183
	July	-86	317	56	142	147	303	324	29
	August	-174	186	23	227	4	68	54	-14
	September	-166	103	-3	-1900	68	86	69	34
	October	-211	39	-18	-244	1849	126	129	-242
Rainy days (No.)	June	-6.15	9.70	1.08	368	-8.75	-4.82	-3.11	-6
	July	-5.80	16.99	7.12	59	9.95	16.82	15.80	5
	August	-0.74	16.09	7.24	48	0.76	6.46	7.28	0
	September	-10.17	11.75	3.03	147	5.16	4.38	3.74	2
	October	-6.62	2.55	-0.51	-389	678.43	67.84	51.37	898

Sorghum

Both levels and variability in climate variables affect growth and productivity of any crop. The panel data regression results for sorghum are presented in Table 3. The average temperature during June and July were found to have significantly positive effect on sorghum yields whereas average temperature during September and October were found to have negative effect as these two months coincide with reproductive and maturity stages of the crop. With respect to rainfall, June and August rainfall were found to have positive and negative effects, respectively. Sorghum is generally sown during June with the onset of the monsoon rains and any delay in sowing is known to be associated with decline in yields. At the same time, high rainfall when the crop approaches reproductive stage will lead to higher incidence of pest and diseases. Further, variability in temperature during July was found to have deleterious effect on yield. The technological trend was found to be significant with 9.5 kg/ha. This indicates yield growth on account of technological change, changes in input use, etc. over time.

Using these regression coefficients, yield of sorghum was estimated assuming no climate change and with climate change as obtained through PRECIS A1B projections. In both the cases, the current rate of technological trend was assumed to continue into future. The results revealed that sorghum yields would increase to 1060 and 1528 kg/ha by mid- and end-century periods in the absence of climate change. However, if the climate projections hold true, sorghum yields are likely to decrease by about 219 kg/ha by end century period compared to a no-climate change situation.

There was no considerable impact of climate change for the mid-century period (Figure 1).

TABLE 3. PANEL DATA REGRESSION COEFFICIENTS FOR SORGHUM YIELD

Variable (1)	Coefficient (2)	Standard error (3)
Time trend	9.53***	0.47
June T	19.62***	6.31
July T	19.82**	8.85
August T	-16.70	10.96
September T	-29.93***	8.53
October T	-35.25***	7.53
CV-June T	33.96	28.35
CV-July T	-152.34***	36.38
CV-August T	-7.72	54.58
CV-September T	-37.21	55.11
CV-October T	9.22	35.39
June RF	0.35***	0.09
July RF	-0.01	0.06
August RF	-0.08	0.06
September RF	-0.17**	0.08
October RF	-0.01	0.12
June RD	-2.20	2.20
July RD	3.10*	1.74
August RD	1.51	1.62
September RD	4.08**	1.87
October RD	1.02	2.40
CV-June RF	0.13	0.10
CV-July RF	0.19	0.14
CV-August RF	-0.21	0.13
CV-September RF	-0.04	0.10
CV-October RF	0.04	0.06
R-square	0.58	

***, ** and * indicate significance level at 1, 5 and 10 per cent, respectively. District dummies were found significant indicating the presence of time-invariant factors. T: Average temperature RF: Rainfall; RD: Number of rainy days; CV; Coefficient of variation (CV).

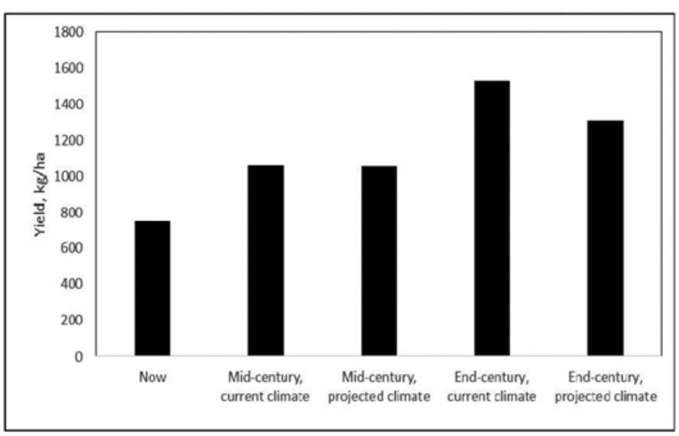

Figure 1. Sorghum Yield Projections with and without Climate Change.

However, there can be inter-district variations in the impact of climate change as climate is a spatial phenomenon. The distribution of districts based on the yield impacts is presented in Table 4. As is evident from the Table, during the mid-century, climate change will not have any adverse yield impact in a majority of the districts and in fact yield is projected to increase. However, the 57 of 172 districts are found to be vulnerable with respect to sorghum yield. The list of districts is provided in Annexures I and II.

TABLE 4. DISTRIBUTION OF DISTRICTS ACCORDING TO YIELD IMPACTS OF CLIMATE CHANGE

	Yield impact (kg/ha)														
	>-400		-400 to -301		-300 to -201		-200 to -101		-100 to -1		0 to 100		>100		Total no.
Crop	MC	EC	MC	EC	MC	EC	MC	EC	MC	EC	MC	EC	MC	EC	of districts
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Sorghum				13		55	12	74	45	30	49		66		172
Pearl millet		9		20	5	44	21	45	40	14	28		38		132

EC: End-century; MC: Mid-century.

Pearl Millet

The regression results using the data on 132 pearl millet growing districts are presented in Table 5. The yield was found to increase by about 17 kg per year. The yield was found to be significantly affected by both level and variability in monthly temperature. However, the effects are significantly negative for temperature during August, September and October and variability in temperature during July and August. Rainfall variability during August had a negative effect on yield. The model accounted for 69 per cent variation in yield.

TABLE 5. PANEL DATA REGRESSION COEFFICIENTS FOR PEARL MILLET YIELD

Variable	Coefficient	Standard Error
(1)	(2)	(3)
Time trend	16.98***	0.48
June T	13.89**	6.32
July T	31.19***	8.30
August T	- 40.76***	11.16
September T	- 34.77***	8.75
October T	- 36.91***	7.33
CV-June T	26.27	30.44
CV-July T	- 244.91***	36.14
CV-August T	- 160.56***	59.17
CV-September T	14.07	49.28
CV-October T	2.85	34.65
June RF	0.15	0.11
July RF	0.03	0.07
August RF	0.00	0.07
September RF	- 0.16	0.09
October RF	- 0.08	0.13
June RD	1.44	2.35

Contd.

TABLE 5. CONCLD.

Variable (1)	Coefficient (2)	Standard Error (3)
July RD	1.19	1.86
August RD	3.32**	1.73
September RD	5.04**	1.95
October RD	1.63	2.49
CV-June RF	0.04	0.09
CV-July RF	- 0.09	0.13
CV-August RF	- 0.39***	0.11
CV-September RF	- 0.03	0.09
CV-October RF	0.06	0.06
R-square	0.69	

*** and ** indicate significance level at 1 and 5 per cent, respectively. All district dummies were found significant indicating the presence of time-invariant factors. T: Average temperature RF: Rainfall; RD: Number of rainy days; CV; Coefficient of variation (CV).

As in the case of sorghum, the aggregate yield at the country level is likely to decrease by 274 kg/ha because of climate change by end-century (1954 kg/ha) compared to a no-climate change situation (2228 kg/ha) (Figure 2). But the yield impact of climate change for mid-century period was found to be 25 kg/ha only. Thus, the climate change vulnerability deepens in the long run in the absence of sustained and strong technological progress.

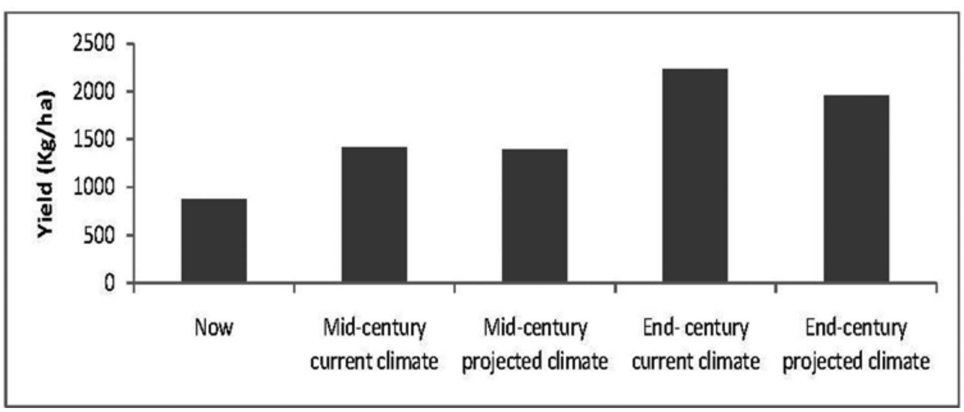

Figure 2. Pearl Millet Yield Projections with and without Climate Change

The impacts however varied among the districts owing to the difference in the climate (Table 4). The yield is projected to decline in 66 and all 132 districts by mid- and end-century periods respectively. In four districts, the yield vulnerability is high and ranged between 500 to 600 kg/ha. Thus, the yield vulnerability is wider and deeper during the end-century period. The list of districts with varying degree of vulnerability are provided in Annexures III and IV for mid- and end-century periods, respectively. These two crops are grown in regions with less rainfall. Higher impacts towards the end-century is probably due to higher rise temperature outweighing the positive influence of increase in rainfall. Thus, the effects of temperature stress on crop growth and how to migitate such effects forms an important part of the research agenda.

Climate change largely comprises two related aspects: a gradual change in mean climate variables and sudden and extreme events. IPCC (2007) conceptualises vulnerability as a residual impact of climate change after accounting for adaptation. Thus, the extent of yield decline with climate change compared to no climate change situation after accounting for unplanned or autonomous adaptation, which in this case is captured through technological trend, can be considered as yield vulnerability. Agricultural research process that involves generation of technologies in the form of better crop varieties and other management technologies happens in the evolving climate change and hence the technologies are subjected to slowly changing climate. It may not be inappropriate to infer that the technologies carry (unplanned/ autonomous) adaptation as they are evaluated for their performance in evolving climate before being 'delivered' for adoption by the farmers. Farmers also observe, learn and respond to evolving climate by adjusting various farm operations. This is probably why crop yields show a rising trend in the long run despite climate change and variability. The technological trend in the regression model captures such responses. However, it is important to ensure that the technological trend does not decelerate so that the climate change induced negative impacts are more than neutralised by technology effects. Further, there is a need to address the issue of sudden and extreme events more explicitly in terms of research and policies for adaptation.

IV

CONCLUSIONS

In this paper, we have examined the yield vulnerability of sorghum and pearl millet to climate change through panel data regression using the district level data for 1971-2004 and climate projections based on the regional climate model PRECIS. The yield was regressed on monthly rainfall and average temperature and the variability therein. Both levels and variability in monthly temperature affected crop yield significantly. The yield vulnerability is higher towards the period 2071-98 compared to 2021-50. The average yield impact is about 218 kg/ha for sorghum and 274 kg/ha for pearl millet. The analysis further indicated no significant yield vulnerability for the mid-century period. However, the yield vulnerability showed considerable variability across districts. Efforts are therefore needed to be focused in the districts where steep yield reductions are projected. Further, technological change was found to neutralise considerable climate change impact underscoring the need to provide support to agricultural research in terms of resource allocation to agricultural research in general and climate change research in particular.

NOTES

1) Districts with certain minimum area under the crop concerned are selected to ensure representativeness of crop growing conditions. Districts with negligible area under any crop may not reflect the true growing conditions of the crop. Similar procedure was adopted in Kumar *et al*. (2011).

2) We are thankful to the Indian Institute of Tropical Meteorology, Pune for providing the PRECIS data set. For more details on PRECIS climate projections for India, see Krishna Kumar *et al*. (2011).

3) This scenario assumes a future characterised by rapid economic growth, low population growth and introduction of new and more efficient technology.

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ANNEXURE I

DISTRIBUTION OF DISTRICTS BASED ON YIELD IMPACT FOR MID-CENTURY FOR SORGHUM

Yield change – 200 to -101 kg/ha (12)
Mandya, Madurai, Coimbatore, Ramanathapuram, Cuddapah, Kurnool, Anantapur, Raichur, Kutch, Mysore, Jodhpur, Vellore
Yield change – 100 to -0 kg/ha (45)
Ganganagar, Tumkur, Guntur, Salem, Cuddalore, Pali, Prakasam, Mahabubnagar, Nalgonda, Kolar, Nellore, Banaskantha, West Godavari, Chittoor, Hassan, Bijapur, Gulbarga, Bellary, Chitradurga, Parbhani, Ahmedabad, Solapur, Warangal, East Godavari, Mehsana, Surendranagar, Bhavanagar,Karimnagar, Nagaur, Pune, Chikmagalur, Ahmednagar, Beed, Shimoga, Krishna, Rajkot, Jamnagar,Bharuch, Dhule, Nanded, Jalgaon, Tirunelveli, Jungadh, Amreli, Hyderabad
Yield change 1 to 100 kg/ha (49)
Nizamabad, Osmanabad, Bidar, Satara, Chittorgarh, Surat, West Nimar, Valasad, Aurangabad (Mah), Nagpur, Medak, Srikakulam, Sabarkanta, Adilabad, Yavatmal, Akola, Dhar, Bhandara, Panchmahal,Wardha, Khammam, Indore, Vadodara, Belgaum, Kheda, Kota, Nasik, Mandsaur, Visakhapatnam, Buldhana, Sangli, Ajmer, Sirohi, Jhalawar, Chandrapur, East Nimar, Bhilwara, Ratlam, Bundi, Dharwad, Dewas, Amravati, Jhabua, Tonk, Shajapur, Ujjain, Seoni, Rajgarh, Hoshangabad
Yield change 101 to 200 kg/ha (64)
Kolhapur, Vidisha, Narsinghpur, Raisen, Sagar, Bhopal, Jaipur, Hissar, Kalahandi, Chhindwara, Bareilly, Rampur, Sawai Madhopur, Allahabad, Guna, Betul, Hamirpur, Ghazipur, Banda, Pratapgarh, Jaunpur,Tikamgarh, Fatehpur, Varanasi, Morena, Alwar, Damoh, Shivpuri, Mirzapur, Sultanpur, Moradabad, Jhansi, Mahendragarh, Bharatpur, Faizabad, Shahjahanpur, Gwalior, Mathura, Datia, Bara Banki, Jalaun, Etawah, Sitapur, Rewa, Etah, Bhind, Jabalpur, Badaun, Sarguja, Karnal, Sidhi, Rae Bareli, Udaipur, Gurgaon, Satna, Shahdol, Lucknow, Rohtak, Jind, Chhatarpur, Hardoi, Panna, Bulandshahr, Mainpuri
Yield change 201 to 300kg/ha (2)
Unnao, Farrukhabad

ANNEXURE II

DISTRIBUTION OF DISTRICTS BASED ON YIELD IMPACT FOR END-CENTURY FOR SORGHUM

Yield change – 400 to -301 kg/ha (13)
Ganganagar, Mandya, Jodhpur, Pali, Coimbatore, Raichur, Kurnool, Madurai, Anantapur, Nalgonda, Mahabubnagar, Cuddapah, Nagaur
Yield change – 300 to - 201 kg/ha (55)
Guntur, Parbhani, Banaskantha, Tumkur, Gulbarga, Mysore, Kutch, Bijapur, Prakasam, Nanded, Warangal, Ramanathapuram, Salem, Yavatmal, Karimnagar, Beed, Kolar, Hyderabad, Solapur, Wardha, West Godavari, Vellore, Ahmedabad, Nagpur, Akola, Mehsana, Bellary, Nizamabad, Nellore, Ajmer, Chandrapur, Chitradurga, Surendranagar, Bhandara, Kota, Cuddalore, Medak, Jalgaon, Hassan, Bidar, Bundi, Osmanabad, Chittorgarh, Bhilwara, Ahmednagar, Jhalawar, Tonk, Bhavanagar, Krishna, Adilabad, Mandsaur, Dhule, West Nimar, East Godavari, Hissar
Yield change – 200 to - 101 kg/ha (74)
Shimoga, Amravati, Sabarkanta, East Nimar, Chikmagalur, Kheda, Dhar, Valasad, Indore, Sirohi, Ratlam, Khammam, Bharuch, Jaipur, Jungadh, Amreli, Panchmahal, Shajapur, Jamnagar, Dewas, Surat, Vadodara, Sawai Madhopur, Mahendragarh, Satara, Rajgarh, Ujjain, Alwar, Vidisha, Morena, Hoshangabad, Seoni, Srikakulam, Hamirpur, Nasik, Bharatpur, Jind, Tikamgarh, Raisen, Sagar, Gwalior, Narsinghpur, Belgaum, Mathura, Rohtak, Tirunelveli, Fatehpur, Bhopal, Banda, Shivpuri, Sangli, Datia, Dharwad, Etawah, Guna, Allahabad, Bhind, Gurgaon, Jalaun, Pratapgarh, Jhabua, Bareilly, Jhansi, Karnal, Betul, Chhindwara, Jaunpur, Etah, Varanasi
Yield change – 100 to 0 kg/ha (30)
Ghazipur, Shahjahanpur, Visakhapatnam, Rampur, Sultanpur, Badaun, Moradabad, Mirzapur, Damoh, Bulandshahr, Faizabad, Kalahandi, Mainpuri, Rae Bareli, Bara Banki, Lucknow, Rewa, Chhatarpur, Hardoi, Sitapur, Jabalpur, Unnao, Satna, Farrukhabad, Kolhapur, Panna, Sidhi, Shahdol, Sarguja, Udaipur

ANNEXURE III

DISTRIBUTION OF DISTRICTS BASED ON YIELD IMPACT FOR MID-CENTURY FOR PEARL MILLET

Yield change – 300 to -201 kg/ha (5)
Jaisalmer, Coimbatore, Madurai, Barmer, Jalore
Yield change – 200 to - 101 kg/ha (21)
Bikaner, Guntur, Jodhpur, Cuddapah, Pali, Raichur, Ganganagar, Firozpur, Anantapur, Nalgonda, Kurnnol, Vellore, Kutch, Prakasam, Kolar, Banaskantha, Mahabubnagar, Warangal, Parbhani, Ramanathapuram, Kanchipuram
Yield change –100 to 0 kg/ha (40)
Ahmedabad, Gulbarga,Bijapur,East Godavari, Nellore, Beed, Jalgaon, Salem, Surendranagar, Cuddalore, Dhule, Solapur, Mehsana, Ahmednagar, Srikakulam, Chittoor, Nagaur, West Nimar, Akola, Bhavanagar, Yavatmal, Medak, Tiruvannamalai, Bellary, Rajkot, Kota, Hyderabad, Dhar, Churu, Bathinda, Aurangabad (Mah), Bharuch, Osmanabad, Bidar, Chitradurga, Amravati, Pune, Khammam, Jamnagar, Amreli
Yield change 1 to 100 kg/ha (28)
Saharanpur, Buldhana, Nizamabad, Kheda, Sabarkanta, Visakhapatnam, Ratlam, Vadodara, Ajmer, Panchmahal, Amritsar, Tirunelveli, Sirohi, Jungadh, Satara, Sangrur, Ballia, Tonk, Nasik, Jhabua, Sangli, Meerut, Belgaum, Kalahandi, Allahabad, Bareilly, Moradabad, Pratapgarh
Yield change 101 to 200 kg/ha (35)
Jhunjunu, Fatehpur, Varanasi, Shahjahanpur, Mirzapur, Hissar, Jaipur, Ambala, Jaunpur, Banda, Sawai Madhopur, Sikar, Agra, Mahendragarh, Shivpuri, Morena, Badaun, Bharatpur, Alwar, Aligarh, Jalaun, Karnal, Rae Bareli, Lucknow, Etawah, Bulandshahr, Hardoi, Sitapur, Gurgaon, Bhind, Mathura, Rohtak, Mainpuri, Ghaziabad, Jind
Yield change 201 to 300 kg/ha (3)
Etah, Unnao, Farrukhabad

ANNEXURE IV
DISTRIBUTION OF DISTRICTS BASED ON YIELD IMPACT FOR END-CENTURY FOR PEARL MILLET

Yield change – 600 to -501 kg/ha (4)
Firozpur, Ganganagar, Jaisalmer, Bikaner
Yield change – 500 to - 401 kg/ha (5)
Barmer, Jodhpur, Jalore,Coimbatore, Pali
Yield change –400 to 301 kg/ha (20)
Bathinda, Madurai, Guntur, Nagaur, Churu, Nalgonda,Anantapur, Banaskantha, Raichur, Parbhani, Cuddapah, Mahabubnagar, Kurnool, Warangal, Kolar, Kutch, Kota, Beed, Prakasam, Amritsar
Yield change -300 to -201 kg/ha (44)
Ahmedabad, Yavatmal, Sangrur, Gulbarga, Akola, Vellore, Bijapur, Mehsana, Surendranagar, Medak, Jalgaon, Solapur, Salem, Ajmer, Saharanpur, Hyderabad, West Nimar, Nellore, Kanchipuram, East Godavari, Tonk, Bellary, Amravati, Ramanathapuram, Osmanabad, Dhule, Ahmednagar, Bidar, Dhar, Aurangabad (Mah), Kheda, Bhavanagar, Hissar, Srikakulam, Chitradurga, Cuddalore, Meerut, Nizamabad, Buldhana, Jhunjunu, Tiruvannamalai, Rajkot, Ratlam, Khammam
Yield change -201 to -100 kg/ha (45)
Sabarkanta, Sirohi, Ballia, Jaipur, Bharuch, Fatehpur, Allahabad, Sikar, Pratapgarh, Panchmahal, Mahendragarh, Chittoor, Pune, Sawai Madhopur, Bareilly, Vadodara, Agra, Banda, Varanasi, Shahjahanpur, Morena, Jalaun, Moradabad, Jamnagar, Alwar, Bharatpur, Amreli, Mirzapur, Shivpuri, Jaunpur, Karnal, Aligarh, Etawah, Ambala, Badaun, Jind, Bhind, Visakhapatnam, Jhabua, Rohtak, Gurgaon, Rae Bareli, Bulandshahr, Mathura, Lucknow
Yield change -100 to 0 kg/ha (14)
Mainpuri, Jungadh, Kalahandi, Satara, Hardoi, Tirunelveli, Ghaziabad, Sangli, Nasik, Etah, Sitapur, Belgaum, Unnao, Farrukhabad