Perception, Yield Sensitivity and Adaptation Strategies to Climate Change: Insights from Wheat Production in India

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Abstract:

Climate change is a serious threat to Indian agriculture affecting crop production and livelihood. The study documents the perception of 500 farmers on climate change as well as awareness and extent of adaptation strategies followed at wheat farms captured by survey (2016-17) apart from tracking yield sensitivity by employing two-stage step-wise regression. Findings indicated that perception matched with the climatology. Investigation alerted that a majority (56.6%) have not changed wheat varieties despite climate change belief barring Haryana wherein, 54% seed replacement exists. Yield has increased over time with no significant change in straw yield, grain and straw quality. Mapping of sensitive stages in crop growth indicated that minimum temperature, relative humidity and rainfall were affecting yield at early stage, whereas, maximum temperature influence yield at maturity stage. The survey explicitly alarms that barring a few strategies like application of organic manures, new varieties, crop insurance and irrigation management, the awareness on rest of the adaptation practices is very low among the wheat producers. Further, every technology is embedded with socio-economic constraints in adoption. The study advocates for implementation of region-specific participatory climate-smart farming practices and/or adaptation strategies through targeted extension programs to manage the yield sensitivity against climate change.

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JEL Codes: Q54, R11

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Abstract

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Keywords : Climate change adaptation, Climate-smart farming, Yield sensitivity, perception
JEL : C22, C83, Q15, Q54, R11

Introduction

Global warming is unequivocal and the consequent climate change is expected to increase the incidence and intensity flood, drought and cyclone (IPCC, 2007). Extreme weather events disrupt agricultural activities and encourage growth of crop competitors' *viz.,* pests, disease and weeds. Reams of literature report that climate change likely to impact adversely on the livelihood of rural people especially in vulnerable regions, potentially undermining their food security and socio-economic development if no relevant actions or adaptation strategies are implemented (Abeygunawardena et al., 2003; Adger et al., 2007; Gbetibouo et al., 2009; Ringler et al., 2011; Sendhil et al., 2017). Climate change reduces the crop yield resulting in overall decline of agricultural production and enforces threat on human security and livelihood opportunities particularly in arid and tropical regions of Asia owing to their high exposure to extreme events (IPCC, 2013).

India being an agrarian nation, the impact of climate change is expected to be severe where agriculture is the main source of livelihood for almost 57 per cent of the country's population. Climate change and agriculture are inter-connected (Parry et al., 2007) to alter the productivity levels based on the changes in climate resulting in crop yield sensitivity (Mall et al., 2006; Mendelsohn 2006; Sendhil et al., 2016). The mean annual temperature for India is expected to increase ranging from 0.5 to 1.2^{0}C by 2020, 0.88 to 3.16^{0}C by 2050 and 1.56 to 5.44^{0}C by 2080 (IPCC, 2007). Further, it is anticipated to increase between 3^{0}C and 5^{0}C by the end of 21st century and the maximum rise in mean temperature is expected to occur in Northern part of India especially in the *Rabi* (November to April) season (Aggarwal et al. 2009). Wheat, a cold loving plant grown during the *Rabi* is highly sensitive to the climate change. It is the 'critical staff of life' for millions and an integral part of nutrition security as well as economic development with 53-85 per cent marketed surplus across regions (Horo et al., 2016; Ramdas et al., 2012). Under the projected scenario for India, a 2.5–4.9^{0}C increase in the mean annual temperature, wheat yields will fall by 41–52 per cent leading to the GDP reduction estimated at 1.8–3.4 per cent (GOI, 2011; Shankar et al., 2013), and 3–7 per cent reduction in yield amounting to 4-6 million tonnes for every one degree rise in the annual mean temperature (Aggarwal et al., 2009). In addition, rainfed wheat will incur a yield and profit loss ranging between 9 and 25 per cent for a temperature increase from 2 to 3.5^{o}C.

Wheat yield sensitivity is an emerging problem in the milieu of climate-smart farming and sustainable production (Sendhil et al., 2017) apart from several challenges posed by climate change (Sharma et al., 2013b). It affects the income and welfare of farmers' especially small holders having poor adaptive capacity. Climate change also aggravates the existing stress on productive farm resources. Adaptation practices to the adverse effect of climate change will be crucial to protect the livelihoods of farmers. Literature reports that perception of farmers on climate change is a pre-requisite for adaptation. It gives a clue to determine the type and stage of adoption of strategies. Farmers' appreciation of the veracity of climate change, degree of worry about impact, and opinion on the personal and wider responsibilities for addressing the climate change shocks are imperative for influencing action. Hence, the knowledge about climate change and climate-smart farming practices assumes significance. Farmers' perception should be well-integrated with adaptation strategies at their choice so as to improve the adaptive capacity. In general, farmers response to the perceived climate change orient more towards recent climate events against the long-term changes (Smit et al., 1997; Thomas et al., 2007; Bryan et al., 2009). Further, local knowledge becomes an influential parameter in decision making (Roncoli et al., 2001; Vogel and O'Brien, 2006; Thomas et al., 2007). In the context, an attempt has been made in the present study through intensive reconnaissance field survey to document the perception of wheat producers on climate change as well as capture the awareness and extent of adoption of adaptation strategies. Further, wheat yield sensitivity to climate variables was tracked for suggesting relevant adaptation measures and/or climate-smart farming practices.

Data and Methodology

The present study has been carried out with the help of primary as well as secondary data. Primary data was collected with the aid of pre-tested structured interview schedule from 500 wheat producers across five major wheat growing zones of India *viz.,* North Western Plains Zone (MWPZ), Central Zone (CZ), North Eastern Plains Zone (NEPZ), Northern Hills Zone (NHZ) and Peninsular Zone (PZ). Southern Hills Zone (SHZ) was ignored owing to its negligible area under wheat. One state which falls completely in each zone was purposively selected from each major wheat growing zone.

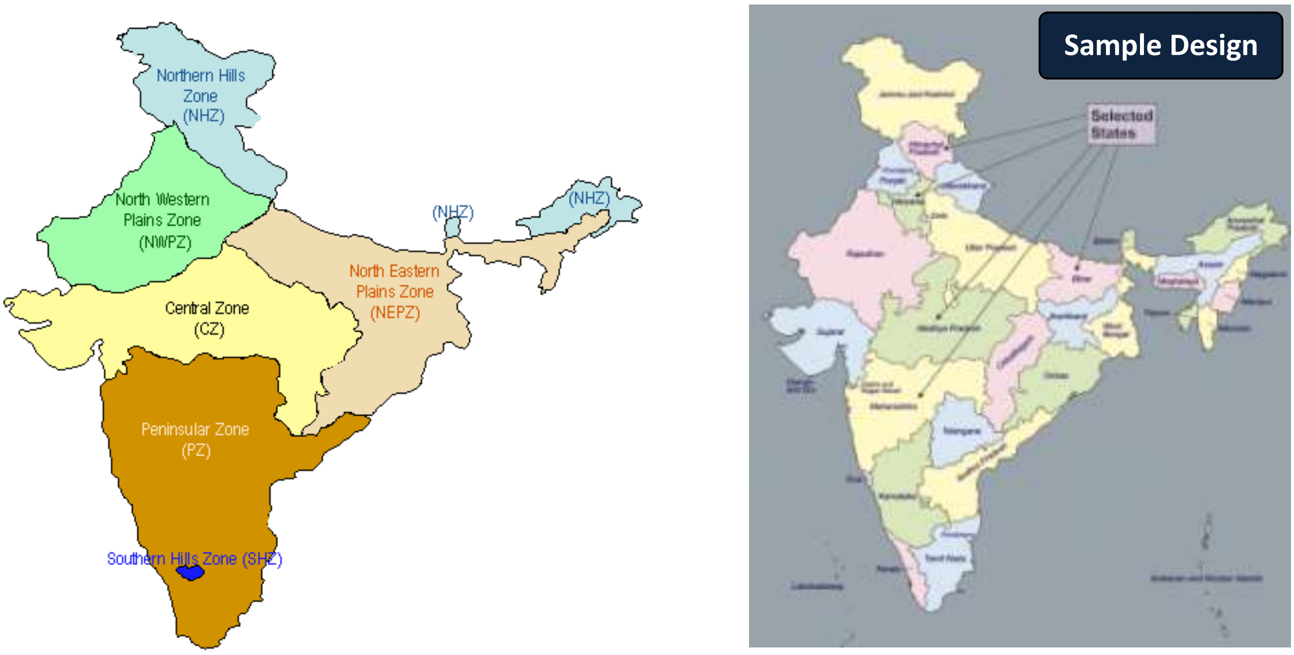


Figure 1: Map showing the sampling design

Data on socio-economic profile, production, perception and effect of climate change, adaptation strategies, and constraints in adoption were collected from 500 randomly selected farmers cultivating wheat for the crop season 2015-16 across five selected states (100 respondents from two selected districts of each state) *viz*., Haryana, Madhya Pradesh, Bihar, Himachal Pradesh and Maharashtra, each falling under one pre-classified wheat production zones (Figure 1). The selected districts were Purbi Champaran and Rohtas from Bihar, Hisar and Sirsa from Haryana, Kangra and Mandi from Himachal Pradesh, Ujjain and Vidhisha from Madhya Pradesh, and Ahmednagar and Solapur from Maharashtra. The selection of districts from each state was done randomly from top 10 and it was selected after arranging them with respect to crop acreage.

Apart from the primary data, secondary data pertaining to crop yield and weather parameters were collected from relevant published documents/ reports/ websites. Data on yield for the selected districts were collected from the Directorate of Economics and Statistics, Government of India (http://aps.dac.gov.in/APY/Public_Report1.aspx). Weather data was collected from both the Indian Meteorological Department (IMD: www.imd.gov.in/) as well as from the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) Web service (http://www.soda-pro.com/web-services/meteo-data/merra). MERRA-2 delivers daily timeseries of weather data since January 1980 and for our study we have collected temperature (at 2 m), relative humidity (at 2 m), wind speed (at 10 m) and rainfall for each day since 1986-87 to 2015-16 (November 1 to April 30 for every crop season) spanning for 30 years. The data had a spatial resolution of approximately 50 km. The collected data were coded, tabulated and analyzed based on the objectives of the study. Apart from conventional analytical tools like mean and percentages, stepwise regression, graphical and frequency scoring tools were used for arriving meaningful conclusions.

Stepwise Regression

The unique approach of the study was to disaggregate the meteorological variables (1986-87 to 2015-16) into 26 weeks (November to April for each Rabi season) for identifying the sensitive weeks towards climate change and it was done in two stages (Sendhil et al., 2016). First, the yield of wheat has been regressed with the respective weekly climate variables following a stepwise regression to reduce the number of variables in each category as well as eliminating the effect of multicollinearity.

Stage 1: Regression for crop yield (Y) vis-à-vis weekly variables (with intercept)

$Y_i = f(\text{Temperature}_{wi})$ for i = 1 to 30 years and w = 1 to 26 weeks

$Y_i = f(\text{Rainfall}_{wi})$ for i = 1 to 30 years and w = 1 to 26 weeks

$Y_i = f(\text{Relative humidity}_{wi})$ for i = 1 to 30 years and w = 1 to 26 weeks

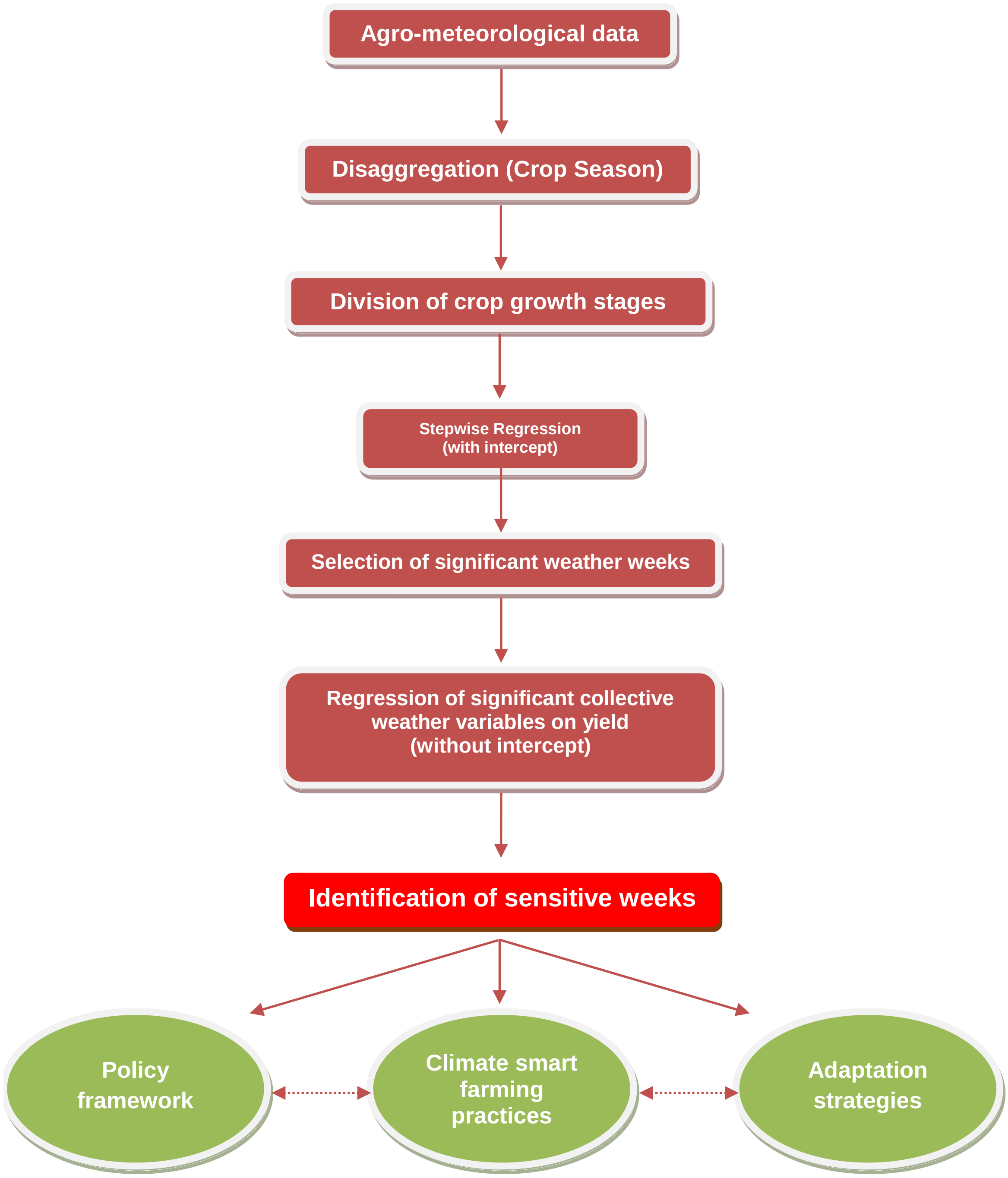
$Y_i = f(\text{Wind speed}_{wi})$ for i = 1 to 30 years and w = 1 to 26 weeks

The above function was run following the stepwise regression approach for each district separately to identify the exact weeks in each category of weather variables that influence the crop yield. In the second stage, the significant weather weeks in all categories are collectively regressed on the crop yield without intercept to find the sensitivity of the selected weekly weather variables on wheat yield.

Stage 2: Regression for yield (Y) vis-à-vis significant variables (without intercept)

$Y_i = f(\text{collective significant metrological variables}_{wi})$ for i = 1 to 30 years and w = 1 to n weeks of significant weather variables resulted from stage 1 stepwise regression function. The present study utilizes this unique approach in two stages developed by Sendhil et al. (2016) by considering only the climate variables in the regression model as furnished in Welch et al. (2010) and Karn (2014). Resources used by the households were omitted since they are under the control of farmers' and likely endogenous having no impact with respect to climate change.

Price variables were also ignored since they do not lead to any biased estimate of the coefficients as the weather variables are exogenous. Consequently, in the regression function it is preferable to exclude the farm input variables in order to ensure that the estimated effects of the climate variables are fully captured (Karn, 2014).



Source: Adapted from Sendhil et al. (2016)

Figure 2: Approach to assess the crop yield sensitivity

Results and Discussion

Socio-economic Profile: Socio-economic characteristics influence largely the scale of farming and adoption practices (Sahu and Mishra, 2013). Literacy level was found to be high in all the selected states (Table 1) ranging from 95 per cent (Maharashtra) to 82 per cent (Bihar). Age and experience in farming is a major factor deciding the risk taking behavior. The average age of the respondents was hovering between 40 to 50 years (Table 1). It was highest in Himachal Pradesh (49 years), followed by Bihar (47 years) and Maharashtra (45 years). In the case of farming experience, a majority of the respondents was found to have more than 50 per cent of their age as their experience. The number of years of experience was more in Bihar (27 years), followed by Maharashtra (24 years) and Himachal Pradesh (25 years). On an average, the sample respondents had an experience of 24 years in farming. The average family size was highest in Madhya Pradesh (7 persons), followed by Bihar and Maharashtra. It is also an indicator for progressiveness in society. The higher family size in Madhya Pradesh was due to the prevailing of joint family system in the state.

Possession of Kisan card and cooperative society membership facilitates for easy access to loans, fertilizers, seeds etc and thereby influence the adaptation behavior (Sahu and Mishra, 2013). Perusal of Table 1 indicates that only 52.6 per cent of the total sample respondents had Kisan cards and strangely only 6 per cent has enrolled in cooperative society membership. Among the states, the possession of Kisan cards was highest in Madhya Pradesh (86%), followed by Haryana (82%) and Bihar (35%). The survey also identified that the society membership was very poor among the sample farmers. In fact, none of the farmers had membership with societies in Bihar. The level of membership was relatively more in Maharashtra (16%) but in absolute terms it was too less. Only a meager amount of farmers were having membership in one or more societies in the selected states. This is a serious concern since their access to inputs and other services has been restricted. Suitable policy interventions have to be made to enroll the farmers for availing the benefit out of memberships.

Table 1: Distribution of the sample by literacy, age, experience, family size and membership

Districts/State	Literacy (number)		Age (years)	Experience in farming (years)	Average family size (number)	Kisan card possession (number)	Cooperative society membership (number)
	Literate	Illiterate					
1. Bihar	**82**	**18**	**47.05**	**27.44**	**6.73**	**35**	**0**
Purbi Champaran	42	8	49.96	30.70	7.74	22	0
Rohtas	40	10	44.14	24.18	5.72	13	0
2. Haryana	**86**	**14**	**43.20**	**19.47**	**5.74**	**82**	**5**
Hisar	42	8	43.02	19.64	5.70	42	3
Sirsa	44	6	43.38	19.30	5.78	40	2
3. Himachal Pradesh	**91**	**9**	**48.76**	**25.20**	**5.80**	**33**	**3**
Kangra	48	2	47.00	22.10	6.20	19	1
Mandi	43	7	50.52	28.30	5.40	14	2
4. Madhya Pradesh	**89**	**11**	**40.14**	**22.45**	**7.38**	**86**	**5**
Ujjain	42	8	40.46	23.18	7.18	40	3
Vidisha	47	3	39.82	21.72	7.58	46	2
5. Maharashtra	**95**	**5**	**45.26**	**23.54**	**6.41**	**27**	**16**
Solapur	49	1	46.44	24.28	5.94	17	12
Ahmednagar	46	4	44.08	22.80	6.88	10	4
All States	**443 (88.6%)**	**57 (11.4%)**	**44.88**	**23.62**	**6.41**	**263 (52.6%)**	**29 (5.8%)**

Income source is a major factor to analyze the level of diversification of enterprises which decides the preference and extent of climate-smart technology adoption (Sahu and Mishra, 2013). The share of income from different sources (Figure 3) indicates that barring Madhya Pradesh and Maharashtra, the rest of the states have shown at least 60 per cent contribution from crop production and it was more in Himachal Pradesh followed by Bihar and Haryana.

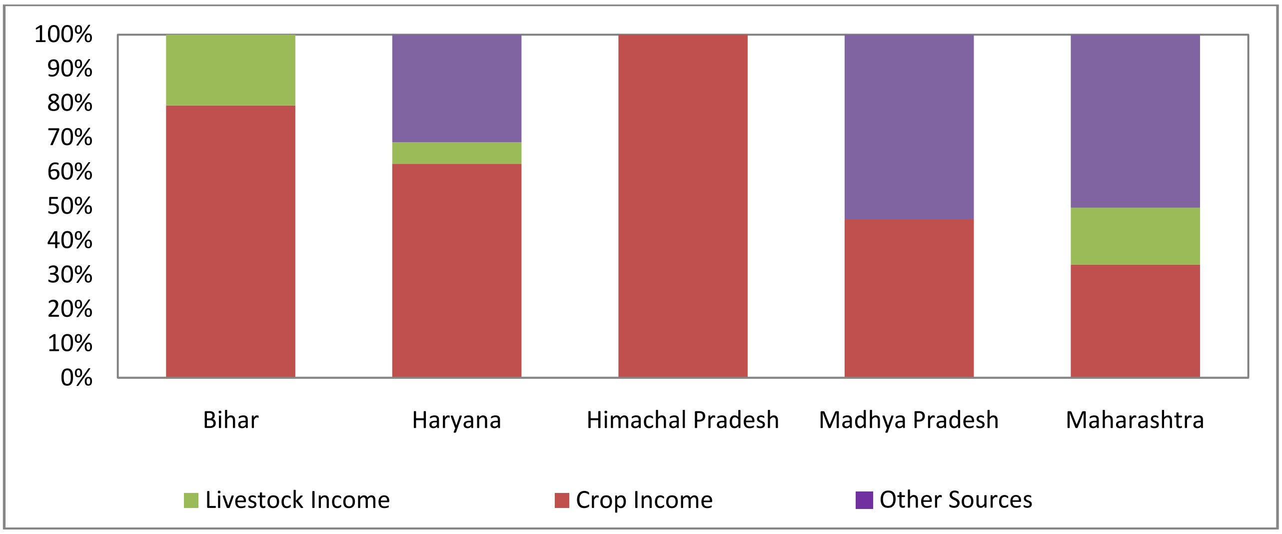


Figure 3: Share of income from different sources

Acreage under wheat indicated that, on an average, 8.5 acres (69.95% share of operational holdings) has been under the cereal cultivation (Table 2). It was highest in the case of Madhya Pradesh (13.48 acres, 64.05%), followed by Haryana (8.68 acres, 88.16%) and Bihar (8.11 acres, 86.14%). Table 2 also furnishes the information on average crop area owned by farmers (12.07 acres), with operational holdings size (12.21 acres). The operational holdings were more due to the prevailing of leasing-in land for cultivation especially in Haryana (Kumar et al., 2017a). Among the districts, the crop acreage allotment was more in Sirsa, Haryana (91.06%) and least in Solapur, Maharashtra (29.53%).

Table 2: Farm holding size (in acres) of the sample respondents

Districts/State	Area Owned	Operational Holdings	Area under Wheat	Share in Operational Holdings (%)
1. Bihar	**9.55**	**9.42**	**8.11**	**86.14**
Purbi Champaran	10.93	10.81	9.40	86.96
Rohtas	8.16	8.02	6.82	85.04
2. Haryana	**9.17**	**9.84**	**8.68**	**88.16**
Hisar	9.30	10.17	8.69	85.45
Sirsa	9.03	9.51	8.66	91.06
3. Himachal Pradesh	**10.61**	**10.56**	**7.98**	**75.50**
Kangra	8.91	8.96	7.08	79.02
Mandi	12.17	12.17	8.87	72.91
4. Madhya Pradesh	**21.05**	**21.05**	**13.48**	**64.05**
Ujjain	15.02	15.02	10.21	67.98
Vidisha	27.46	27.07	16.75	61.88
5. Maharashtra	**10.08**	**10.18**	**4.46**	**43.81**
Solapur	12.33	12.46	3.68	29.53
Ahmednagar	7.82	7.90	5.24	66.33
All States	**12.07**	**12.21**	**8.54**	**69.95**

Perception of Farmers on Climate Change: Perception of sample farmers on climatic variables over the past 30 years (Table 3 and Figure 4) matched with the climatology i.e., long-term trend (Rathore et al., 2013) corroborating the findings of Tripathi and Mishra (2017) and Banerjee (2015). The scores indicated that a majority reported for increased frequency of drought, no change in the frequency of flood, late onset of monsoon, decreased frequency of rain with increased erratic pattern and less quantum of rainfall, increased sunshine hours and day/night temperature, no change in the hail storm incidents, and, decreased frost damage, windstorms & relative humidity. Interestingly, the farmers' responses fall on all three given choices *viz.,* increase, decrease or no change for a particular climate change indicator similar to Dhanya and Ramachandran (2016).

Table 3: Perception of the sample respondents on climatic variables over the past 30 years

Parameter	Bihar		Haryana		Himachal Pradesh		Madhya Pradesh		Maharashtra	
	Champaran	Rohtas	Hisar	Sirsa	Kangra	Mandi	Ujjain	Vidisha	Solapur	Ahmednagar
Frequency of drought										
Increased	49	46	36	30	47	44	22	24	44	50
Decreased	1	0	0	6	2	3	3	12	5	0
No change	0	4	14	14	1	3	25	14	1	0
Frequency of flood										
Increased	0	0	2	1	0	0	2	0	0	0
Decreased	25	14	10	19	1	0	10	16	18	0
No change	25	36	38	30	49	50	38	34	32	50
Onset of rainfall / monsoon										
Earlier	0	0	1	1	0	0	0	0	0	0
Late	27	25	41	39	50	50	27	38	49	50
No change	23	25	8	10	0	0	23	12	1	0
Frequency of rain										
Increased	23	0	2	1	48	50	10	19	3	0
Decreased	16	25	41	40	2	0	26	20	46	42
No change	11	25	7	9	0	0	14	11	1	8
Erratic rainfall pattern										
Increased	0	1	34	35	50	50	23	15	32	46
Decreased	39	24	1	6	0	0	10	22	15	0
No change	11	25	15	9	0	0	17	13	3	4
Quantity of rainfall										
Increased	0	13	1	1	0	0	8	8	5	0
Decreased	39	2	43	40	50	50	22	27	40	50
No change	11	35	6	9	0	0	20	15	5	0
Sunshine hours										
Increased	0	2	23	18	48	49	8	14	26	32
Decreased	39	22	9	12	0	1	13	9	7	0
No change	11	26	18	20	2	0	29	27	17	18
Day temperature										
Increased	49	50	38	32	47	49	12	26	45	45
Decreased	1	0	2	7	1	0	8	4	2	0
No change	0	0	10	11	2	1	30	20	3	5
Night temperature										
Increased	23	50	10	16	46	49	12	17	35	43
Decreased	25	0	27	18	3	0	10	12	11	0
No change	2	0	13	16	1	1	28	21	4	7
Hail storm incidents										
Increased	12	13	4	1	46	49	12	28	9	0
Decreased	2	12	16	12	1	0	15	6	31	4
No change	36	25	30	37	3	1	23	16	10	46
Frost damage										
Increased	0	9	2	0	0	0	39	39	6	0
Decreased	38	15	31	21	49	49	4	3	41	41
No change	12	26	17	29	1	1	7	8	3	9
Wind storms										
Increased	1	0	2	7	3	0	6	5	1	5
Decreased	36	24	20	9	46	49	6	13	10	45
No change	13	26	28	34	1	1	38	32	39	0
Relative humidity										
Increased	0	0	11	11	50	50	7	6	6	11
Decreased	36	16	24	16	0	0	24	31	40	39
No change	14	34	15	23	0	0	19	13	4	0

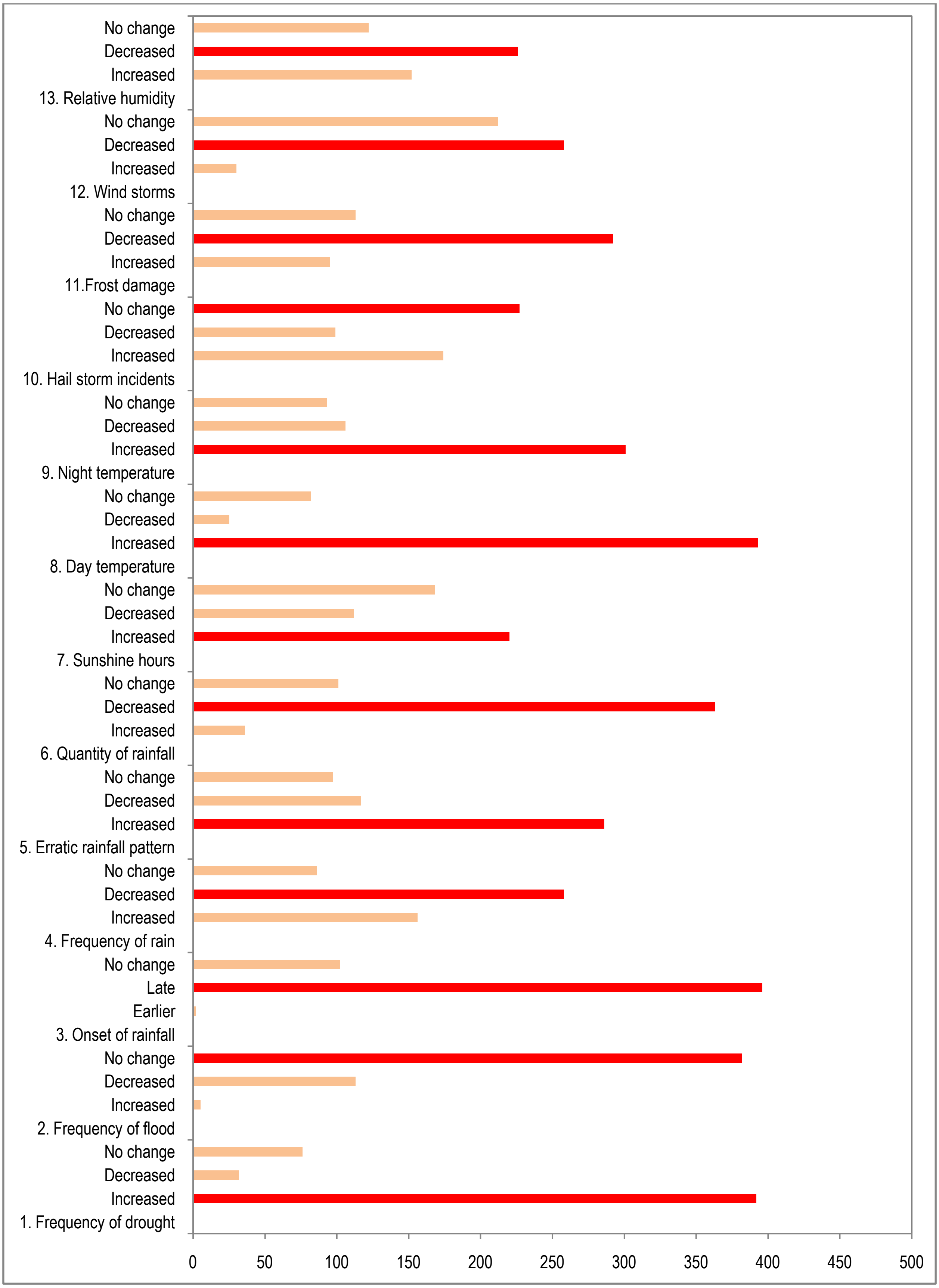


Figure 4: Perception of the sample respondents on climatic variables over the past 30 years

Perception of sample farmers on the impact of climate change has been recorded on various parameters with respect to wheat production (Table 4 and 5, and Figure 5). Frequency analysis as reported in Table 4 alerted that a majority of the wheat growers (56.6%) in the study area have not replaced the varieties despite the belief of climate change (Shankara et al., 2013). It was only in Haryana, the replacement rate was higher. Around 54 per cent of the respondents from Haryana have changed their variety due to the climate change. Higher literacy level and progressive nature were the main factors attributed to this change.

Table 4: Impact of climate change on replacement of wheat varieties by the respondents

Districts/State	Yes	No
1. Bihar	**40**	**60**
Purbi Champaran	20	30
Rohtas	20	30
2. Haryana	**54**	**46**
Hisar	26	24
Sirsa	28	22
3. Himachal Pradesh	**44**	**56**
Kangra	28	22
Mandi	16	34
4. Madhya Pradesh	**42**	**58**
Ujjain	17	33
Vidisha	25	25
5. Maharashtra	**37**	**63**
Solapur	18	32
Ahmednagar	19	31
All States	**217 (43.40%)**	**283 (56.60%)**

Perception of sample farmers on the impact of climate change on wheat production (Table 5 and Figure 5) indicated that wheat area has not changed much in their farm household. Further, it was perceived that wheat yield has increased over a period of time with no change in the straw yield; and, no change in wheat grain, straw quality, crop failure as well as food shortage. A majority of the farmers also reported that the weeds, insects and diseases have increased over a period of time (Shankara et al., 2013). The soil quality and groundwater level has decreased in the past 30 years. Surprisingly, almost equal amount of overall responses were recorded for the irrigation frequency (no change and increased) in the selected states. However, the responses across districts/states varied but followed a similar kind of responses matching the overall scores.

Table 5: Impact of climate change on wheat production

Parameter	Bihar		Haryana		Himachal Pradesh		Madhya Pradesh		Maharashtra	
	Champaran	Rohtas	Hisar	Sirsa	Kangra	Mandi	Ujjain	Vidisha	Solapur	Ahmednagar
Wheat area										
Increased	1	1	25	24	11	17	21	12	12	16
Decreased	1	1	1	4	14	18	1	12	15	7
No change	48	48	24	22	25	15	28	26	23	27
Wheat yield										
Increased	18	10	41	30	49	44	28	34	28	22
Decreased	4	3	6	7	-	-	1	1	5	2
No change	28	37	3	13	1	6	21	15	17	26
Straw yield										
Increased	-	-	11	10	-	-	1	3	-	-
Decreased	-	-	5	5	-	-	10	9	-	-
No change	50	50	34	35	50	50	39	38	50	50
Wheat quality										
Increased	-	-	12	6	-	2	-	-	-	2
Decreased	2	-	10	5	48	46	20	18	4	4
No change	48	50	28	39	2	2	30	32	46	44
Straw quality										
Increased	-	-	2	3	-	-	1	2	-	-
Decreased	-	-	2	2	-	1	5	4	-	-
No change	50	50	46	45	50	49	44	44	50	50
Crop failure										
Increased	2	-	18	6	35	22	9	10	-	2
Decreased	-	-	6	5	-	1	1	1	-	-
No change	48	50	26	39	15	27	40	39	50	48
Food shortage										
Increased	3	3	-	-	-	2	-	-	-	-
Decreased	-	13	13	15	2	-	6	8	-	-
No change	47	34	37	35	48	48	44	42	50	50
Weeds										
Increased	31	11	29	21	50	48	15	13	42	22
Decreased	-	-	1	3	-	-	-	3	-	1
No change	19	39	20	26	-	2	35	34	8	27
Insects										
Increased	22	9	35	29	50	48	38	39	32	27
Decreased	-	-	-	2	-	-	-	-	-	2
No change	28	41	15	19	-	2	12	11	18	21
Diseases										
Increased	42	38	41	36	49	49	40	39	32	31
Decreased	-	5	1	1	-	-	-	3	-	1
No change	8	7	8	13	1	1	10	8	18	18
Soil quality										
Increased	-	-	4	6	-	-	4	2	-	5
Decreased	45	46	39	23	50	50	35	32	32	25
No change	5	4	7	21	-	-	11	16	18	20
Groundwater										
Increased	6	-	5	8	1	-	1	-	-	1
Decreased	40	49	39	33	46	50	39	36	49	45
No change	4	1	6	9	3	-	10	14	1	4
Irrigation frequency										
Increased	13	31	19	18	38	24	18	16	31	20
Decreased	1	2	3	2	1	8	4	9	7	1
No change	36	17	28	30	11	18	28	25	12	29

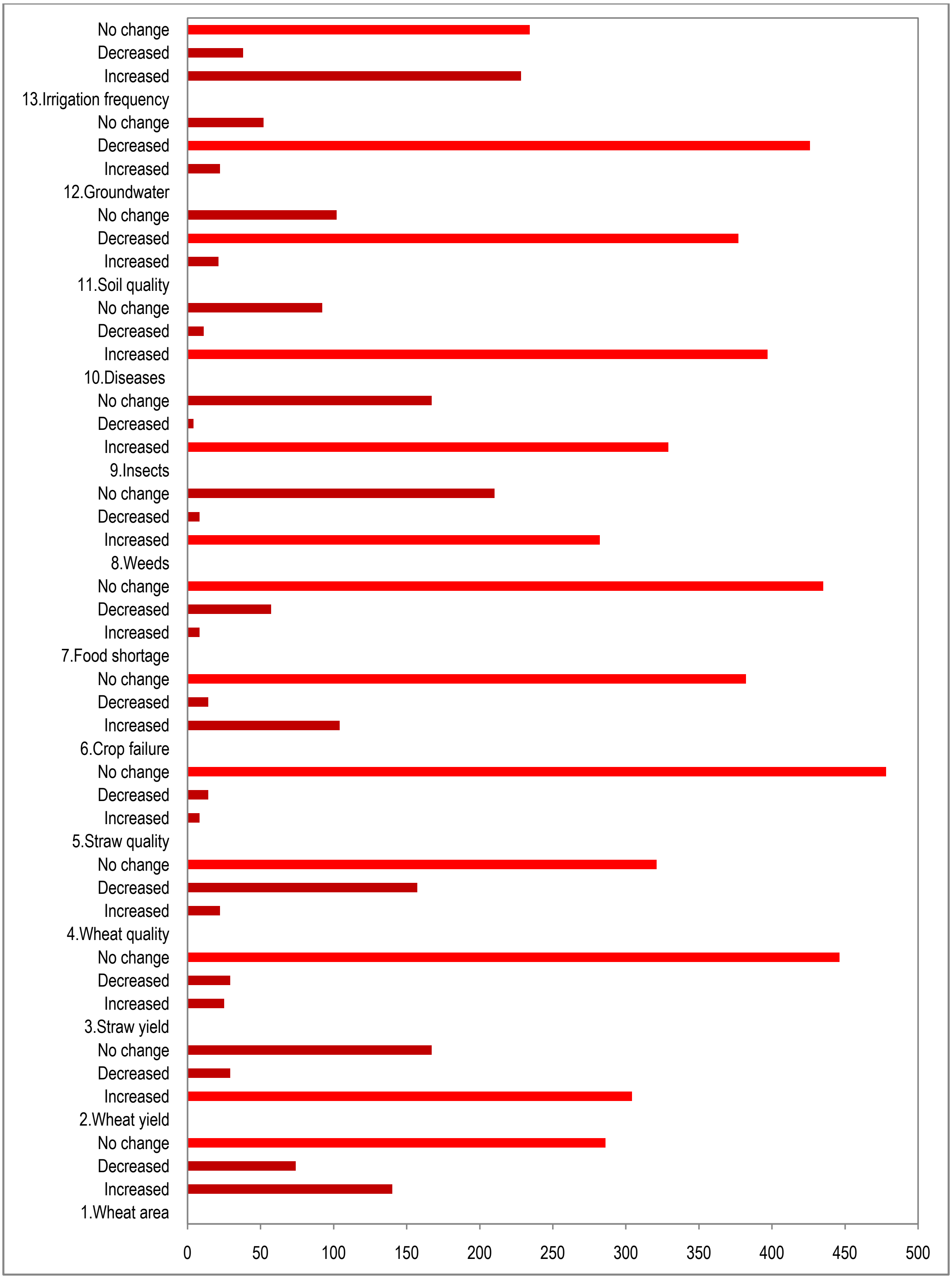


Figure 5: Impact of climate change on wheat production

Wheat Yield Sensitivity: Yield sensitivity with respect to farmers' perception (frequency analysis) was matched with the econometric approach of step-wise regression (Sendhil et al., 2016 and 2015). Figure 6 and 7 shows the trend in yield for the selected districts since 1966-67. The actual yield levels (Figure 6) indicates the clear-cut fluctuations which shall be attributed to the climate change apart from other factors. However, the normalized data (Figure 7) by taking the triennium ending moving average of yield levels show a smoothed pattern but with increasing trend corroborating the findings of Sendhil et al. (2015) and perception of farmers as reported in Table 5 and Figure 5.

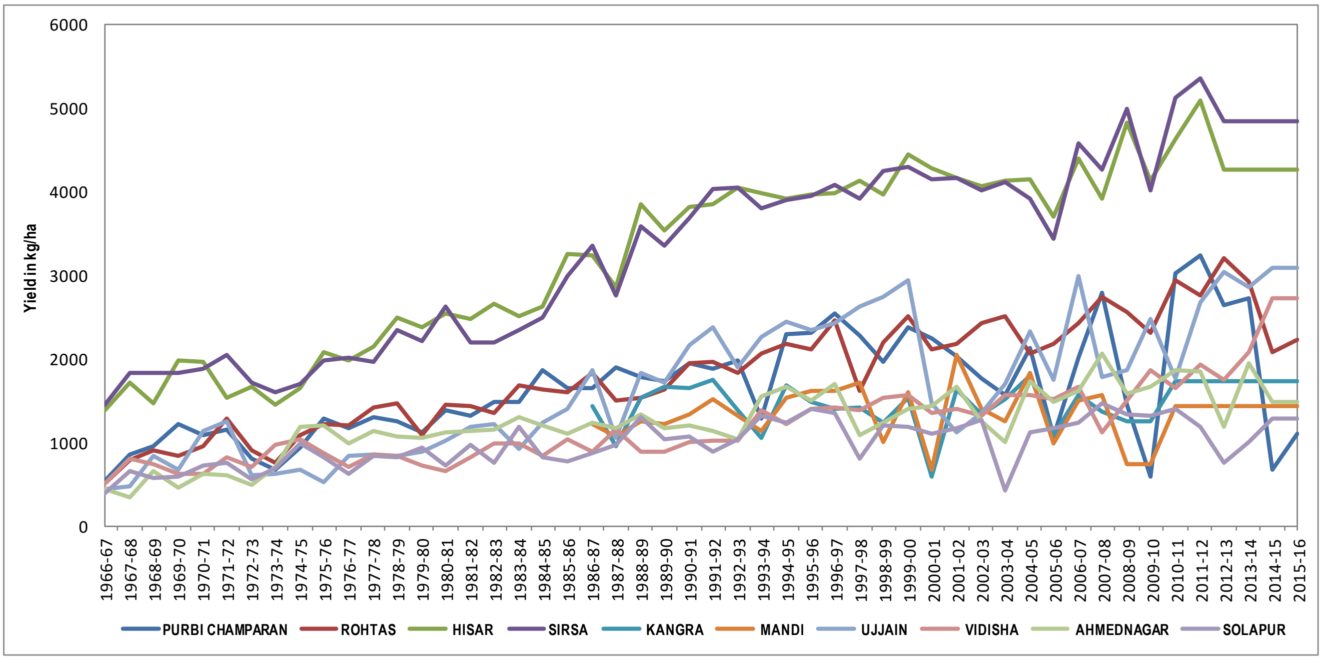


Figure 6: Trend in wheat yield (actual) for the selected districts

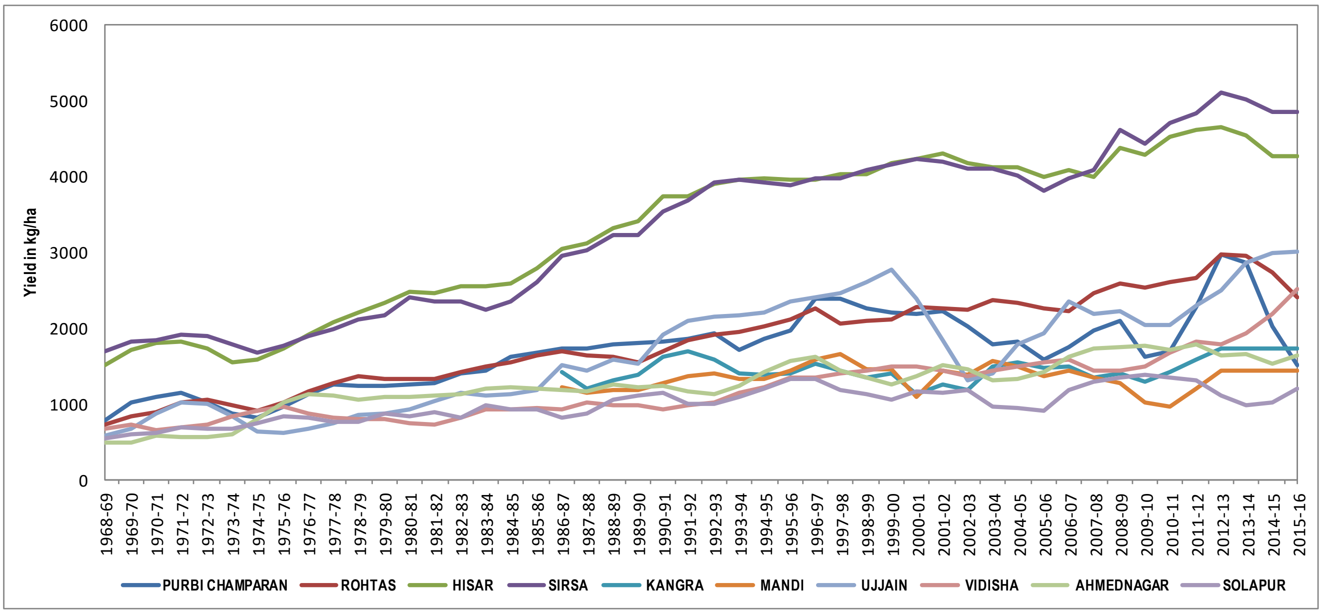


Figure 7: Trend in wheat yield (triennium ending) for the selected districts

Table 6 and Figure 8 show the responses recorded on the extent of sensitivity in crop yield. Any changes in the weather variables like maximum temperature (T.Max), minimum temperature (T.Min), relative humidity (RH), rainfall (RF), evapotranspiration (ET), sunshine hours (SS) and wind speed (WS) at different crop growth stages, affects the overall yield level. Identification of sensitive stages will help the researchers from agronomy, resource management, crop physiology, breeding and extension to set adaptation strategies and/or climate-smart farming practices in order to encounter the negative impact of climate change.

Sensitive stages require the following research outcomes *viz.*, policies to address yield sensitivity in the long-run, climate-smart farming practices and region-specific strategic adaptation to weather anomalies. For instance, increase in temperature (maximum and minimum) during the crop growth stage indicates a need to breed wheat genotypes resilient to climate change (resistant to biotic stress and tolerant to abiotic stress) without compromising yield (Singh et al., 2017; Sendhil et al., 2016 & 2015; Sharma et al., 2013a).

Climate change has affected the crop phenology to a larger extent and hence crop advisories need to be released at each sensitive stage that affects the productivity. Increase in maximum temperature during crown root initiation requires irrigation to cool-off the micro-environment. Zero tillage, a resource conservation agriculture technology which is widely practiced under rice-wheat system in the Indo-Gangetic plains comprising Punjab, Haryana, Uttar Pradesh and Bihar has to be adopted in a larger scale where micro-environment temperature shoots-up consistently (Kumar et al., 2017a). Further, adjusting sowing dates based on the seasonal weather anomalies will counter the yield sensitivity at initial crop growth stage. Clearly, climate-smart farming practices and adaptation strategies assume significance to manage the yield sensitivity in wheat.

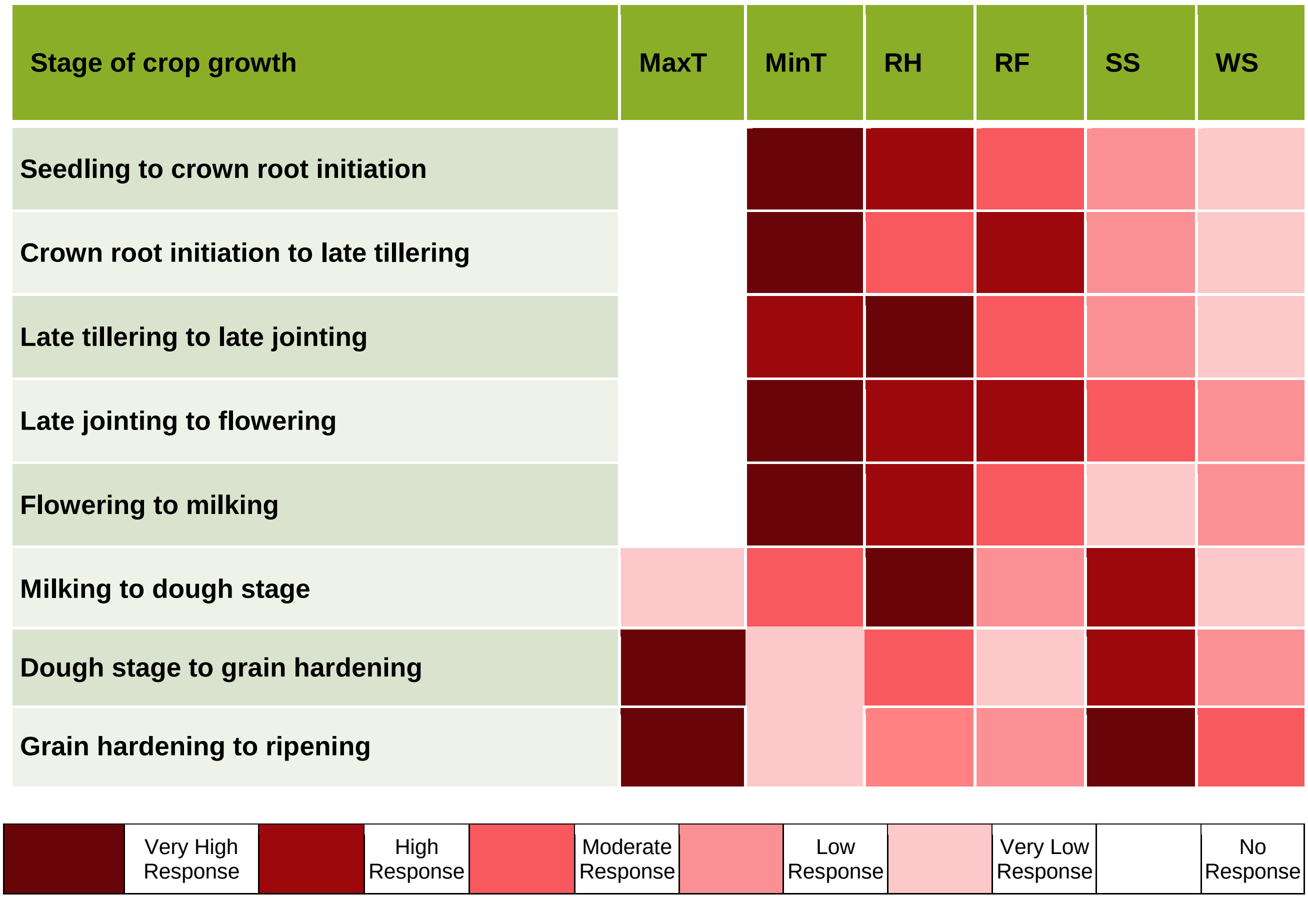


Figure 8: Mapping of sensitive stages in wheat production

Table 6: District wise sensitive stages in wheat production (frequency analysis)

Growth Stages	Bihar		Haryana		Himachal Pradesh		Madhya Pradesh		Maharashtra	
	Champaran	Rohtas	Hisar	Sirsa	Kangra	Mandi	Ujjain	Vidisha	Ahmednagar	Solapur
Seedling to crown root initiation (1-3 weeks)										
Max. temperature	0	0	1	2	0	0	2	1	0	0
Min. temperature	50	48	49	48	49	50	48	50	50	48
Relative humidity	50	47	49	45	43	41	48	49	47	50
Rainfall	47	41	23	21	50	50	46	46	50	49
Evapotranspiration	0	0	0	0	0	0	0	0	0	0
Sunshine hours	48	38	31	26	38	23	41	46	44	47
Wind speed	20	17	3	5	15	0	20	31	29	34
Crown root initiation to late tillering (4-6 weeks)										
Max. temperature	0	0	0	0	0	0	0	1	0	0
Min. temperature	49	47	48	50	50	50	47	47	50	50
Relative humidity	44	48	41	44	48	45	49	50	50	49
Rainfall	45	46	50	49	50	47	48	49	50	49
Evapotranspiration	0	1	0	0	0	0	0	0	0	0
Sunshine hours	34	47	24	24	50	48	38	44	42	46
Wind speed	22	23	0	4	18	3	23	31	30	38
Late tillering to late jointing (7-9 weeks)										
Max. temperature	0	0	1	1	0	2	0	1	0	0
Min. temperature	48	49	43	48	45	41	48	48	49	50
Relative humidity	48	49	45	47	46	43	48	49	48	48
Rainfall	48	38	48	48	44	45	48	49	48	49
Evapotranspiration	0	0	0	0	0	0	0	0	0	0
Sunshine hours	4	21	38	30	44	42	39	45	46	48
Wind speed	34	21	16	22	28	15	32	39	39	39
Late jointing to flowering (10-11 weeks)										
Max. temperature	0	0	0	0	0	0	0	1	0	0
Min. temperature	47	50	50	45	46	46	47	47	49	48
Relative humidity	48	48	42	44	35	29	49	49	48	48
Rainfall	47	41	32	41	46	43	49	48	47	47
Evapotranspiration	0	0	0	0	0	0	0	0	0	0
Sunshine hours	30	32	44	39	40	20	41	47	46	43
Wind speed	19	12	21	20	40	41	29	44	39	41
Flowering to milking (12-14 weeks)										
Max. temperature	4	0	0	0	0	0	0	1	2	0
Min. temperature	46	45	50	47	48	45	47	47	48	50
Relative humidity	48	49	42	48	39	37	49	49	47	47
Rainfall	42	46	36	37	41	43	50	50	49	49
Evapotranspiration	0	0	0	0	0	0	0	1	0	0
Sunshine hours	24	32	39	28	40	15	42	46	45	39
Wind speed	33	37	34	23	47	43	38	43	40	40
Milking to dough stage (15-17 weeks)										
Max. temperature	26	28	30	31	22	33	7	6	15	23
Min. temperature	38	49	17	17	43	28	37	41	35	50
Relative humidity	44	41	40	43	38	33	45	49	48	48
Rainfall	35	40	34	26	24	22	39	44	34	46
Evapotranspiration	0	0	0	0	0	0	0	0	0	0
Sunshine hours	44	38	32	34	35	36	45	44	45	40
Wind speed	10	12	30	26	44	49	33	39	39	43
Dough stage to grain hardening (18-20)										
Max. temperature	49	46	46	49	49	50	47	48	48	50
Min. temperature	36	34	5	2	28	7	4	2	6	50
Relative humidity	39	46	38	34	39	25	36	40	35	49
Rainfall	39	24	6	8	19	5	6	12	11	46
Evapotranspiration	0	0	0	0	0	0	0	1	0	0
Sunshine hours	44	44	42	46	44	45	47	46	48	46
Wind speed	34	20	20	23	42	44	23	32	35	43
Grain hardening to ripening (21-22 weeks)										
Max. temperature	50	50	50	50	50	50	50	50	50	50
Min. temperature	42	40	0	0	37	9	0	0	4	49
Relative humidity	49	40	28	29	44	17	27	25	22	50
Rainfall	40	31	4	9	15	4	0	5	3	46
Evapotranspiration	0	0	0	0	0	0	0	0	0	0
Sunshine hours	47	49	37	39	44	46	49	48	48	49
Wind speed	40	40	31	31	43	39	16	28	29	48

The step-wise regression analysis indicated that the identified sensitive weeks (Table 7) during stage 1 analysis (with intercept) have not been the same when analyzed together in stage 2 (without intercept). For instance, *Rabi* season temperature during week 7 and week 16 in Purbi Champaran which are identified as sensitive weeks to crop growth in stage 1 were found to be insignificant in stage 2. Similarly, for the same district, wind speed in week 2 which was identified as a sensitive week was found to be insignificant at stage 2 analysis. The identified weeks need suitable region-specific adaptation strategies and/or climate-smart farming practices (Sendhil et al., 2016). Temperature increase during the initial stages of crop growth particularly in December and January may not have much impact on crop yield if the grain filling days were relatively cooler. Rise in temperature during the grain filling stage in relation to vegetative stage will affect the crop yield significantly.

Table 7: District wise sensitive weeks in wheat production (step-wise regression)

Districts/State	Sensitive weeks	
	Stage 1 (yield regressed with individual climate variables by including intercept)	**Stage 2** (yield regressed with only the significant weeks of climate variables by excluding intercept)
1. Bihar		
Purbi Champaran	Temp (Week 7 and 16) WS (Week 2, 6, 8, 12 and 13)	WS (Week 6, 8, 12 and 13)
Rohtas	Temp (Week 9, 10, 15 and 22) RH (Week 14, 20 and 25) WS (Week 13 and 24) RF (Week 16)	Temp (Week 9, 15 and 22) RH (Week 14) RF (Week 16)
2. Haryana		
Hisar	Temp (Week 5 and 10) RH (Week 3 and 25) WS (Week 1, 8, 9 and 23)	Temp (Week 5) RH (Week 3 and 25)
Sirsa	Temp (Week 15) RH (Week 2, 8, 11, 12, 15 and 24) WS (Week 1 and 23)	RH (Week 2, 8, 12, 15 and 24) WS (Week 1)
3. Himachal Pradesh		
Kangra	Temp (Week 8 and 16) RH (Week 9 and 15) RF (Week 15)	RH (Week 9 and 15)
Mandi	Temp (Week 5, 13, 17, 25 and 26) WS (Week 15) RF (Week 25)	Temp (Week 17 and 25) WS (Week 15)
4. Madhya Pradesh		
Ujjain	Temp (Week 12) RH (Week 1) WS (Week 12) RF (Week 23)	RH (Week 1) WS (Week 12)
Vidisha	Temp (Week 5 and 8) RH (Week 10, 13 and 15) WS (Week 11 and 16) RF (Week 2, 13, 17, 18 and 21)	Temp (Week 5) RF (Week 2, 13, 17 and 18)
5. Maharashtra		
Solapur	Temp (Week 4) RH (Week 2 and 21) WS (Week 7 and 15) RF (Week 1, 13, 16 and 21)	Temp (Week 4) RH (Week 2) WS (Week 7 and 15) RF (Week 1, 13 and 16)
Ahmednagar	Temp (Week 4) RH (Week 2 and 21) WS (Week 12, 24 and 25) RF (Week 25)	Temp (Week 4) RH (Week 2 and 21) WS (Week 12 and 24)

Similarly, increased temperature also increases the number of sunshine hours per day during vegetative growth, which will have positive effect on photosynthesis in comparison to foggy days. The light intensity required for optimum photosynthesis is 100Wat/m^2 and a crop season which encounters drastic deviation from the optimal level will impact the yield to a larger extent. Temperature or sunshine hours increase during the crop growth stage can be countered by application of farmyard manure and following mulching practice. In the case of temperature increase after milking stage till ripening stage, apart from the above suggested practices, two sprays of KCl @ 0.5% will help to maintain expected yield level. Further, adjusting sowing dates based on the seasonal anomalies will counter the sensitivity at initial crop growth stage. Line sowing should be done to avoid the negative impact of wind speed. Plant growth regulators (PGRs) shall be used as an adaptation strategy post late jointing stage to ripening stage. Salicylic acid (1mM) spray shall be done as an external application in the field at any growth stage which will maintain high relative water content in the cells under stress and helps in mitigating high temperature effect.

The effect of climate change on farm households were also analyzed using frequencies (Figure 9). The results indicated that a majority of the respondents reported that they had left the all the cultivable land fallow for atleast once in a period of 30 years. Even they reported that they left sometimes a part of land under fallow, sold or leased-out a part of land and sold livestock. However, a majority (66.6%) responded that they had not shifted to another crop or non-farm employment despite climate change impact which contradicts the findings of Tripathi and Mishra (2017) and the possible reason might be the crop serving as a major staple. A majority reported that they received support from the government organizations or non-governmental organizations, consumed less food when there is a natural calamity, and even shifted to other regions for search of jobs. The number of responses recorded for each parameter varied across the selected districts/states but followed almost a uniform pattern.

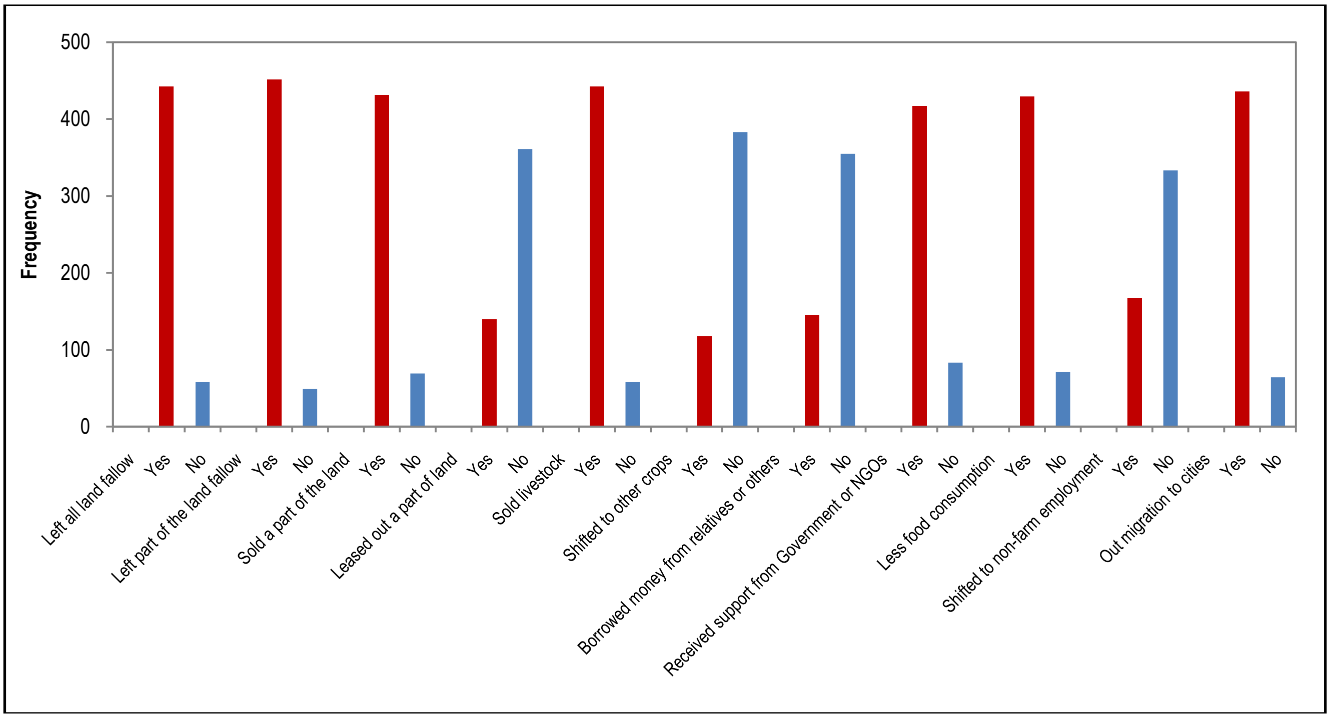


Figure 9: Effect of climate change on farm households

Climate Change Adaptation: Table 8 furnishes the level of awareness of climate change adaptation strategies, its access and extent of adoption in the study region. It is explicitly clear that barring a few strategies like application of organic manures, new varieties, crop insurance and irrigation management, the rest of the adaptation strategies awareness is very low among the wheat producers.

Table 8: Climate change adaptation strategies in the study region (frequency analysis)

Adaptation Strategies	Bihar		Haryana		Himachal Pradesh		Madhya Pradesh		Maharashtra		Overall
	Champaran	Rohtas	Hisar	Sirsa	Kangra	Mandi	Ujjain	Vidisha	Ahmednagar	Solapur	
SWI (with all recommended practices)											
Awareness	1		0	0	0	0	1	0	0	0	1
Access	0		0	0	0	0	0	0	0	0	0
Adoption	0		0	0	0	0	0	0	0	0	0
Modified SWI (some practices modified)											
Awareness	0	0	0	0	6	8	0	0	0	0	14
Access	0	0	0	0	0	1	0	0	0	0	1
Adoption	0	0	0	0	0	1	0	0	0	0	1
Improved management with new varieties											
Awareness	24	15	50	50	23	18	6	5	7	30	228
Access	24	15	50	49	9	15	6	5	6	3	182
Adoption	24	15	50	49	10	15	6	5	6	3	182
Apply more organic manures											
Awareness	44	41	50	49	22	33	37	26	41	14	357
Access	39	41	50	49	17	32	33	24	41	7	333
Adoption	39	41	50	49	15	32	33	24	41	6	330
Zero tillage											
Awareness	32	36	50	50	1	2	2	0	0	1	174
Access	22	30	50	50	0	2	0	0	0	0	154
Adoption	22	30	50	46	0	2	0	0	0	0	150
Zero tillage with residue retention											
Awareness	0	0	11	5	0	0	0	0	0	0	16
Access	0	0	7	2	0	0	0	0	0	0	9
Adoption	0	0	7	2	0	0	0	0	0	0	9
Rotary tillage											
Awareness	0	0	2	1	0	0	0	0	0	0	3
Access	0	0	2	0	0	0	0	0	0	0	2
Adoption	0	0	2	0	0	0	0	0	0	0	2
Laser land leveling											
Awareness	0	0	45	30	0	0	0	0	0	0	75
Access	0	0	36	24	0	0	0	0	0	0	60
Adoption	0	0	36	24	0	0	0	0	0	0	60
Furrow irrigated raised bed (FIRB)											
Awareness	0	0	0	0	0	0	0	0	0	0	0
Access	0	0	0	0	0	0	0	0	0	0	0
Adoption	0	0	0	0	0	0	0	0	0	0	0
Happy seeder/ Turbo seeder											
Awareness	0	0	31	17	0	0	0	0	0	0	48
Access	0	0	8	3	0	0	0	0	0	0	11
Adoption	0	0	8	3	0	0	0	0	0	0	11
Crop insurance											
Awareness	0	1	42	44	45	47	44	46	36	40	345
Access	0	0	36	33	22	44	35	38	32	20	260
Adoption	0	0	36	33	11	45	35	38	32	6	236
Supplemental irrigation through groundwater											
Awareness	50	50	50	50	40	35	50	50	50	39	464
Access	50	50	50	50	11	33	50	50	50	9	403
Adoption	50	50	50	50	11	33	50	50	49	9	402
Micro irrigation (drip/sprinkler)											
Awareness	0	3	46	42	10	8	49	47	48	6	259
Access	0	0	0	1	15	8	19	21	33	6	103
Adoption	0	0	0	1	12	6	19	21	33	5	97
Irrigation depth and frequency											
Awareness	24	23	50	49	43	25	26	25	29	40	334
Access	22	23	50	49	18	23	23	23	24	4	259
Adoption	22	23	50	49	18	22	23	23	24	5	259

Climate response validated adaptation techniques like conservation agriculture (CA) practices – zero tillage and laser land leveling – are only popular in Haryana (Kumar et al., 2017a&b) and passive in other regions (Tripathi and Mishra, 2017). The CA practices have to be outscaled and upscaled to other regions in the context of changing climate scenario. However, there are some constraints associated with the dissemination of technologies which need policy interventions. Cost of machines including custom hiring charges and its availability is a major concern (Kumar et al., 2017b). Lack of awareness was the major constraint reported by the respondents which was followed by too technical to understand the principles and lack of skills to apply in their farm. Targeted capacity building programs for farmers as well as extension functionaries, and publication of literature on local languages should be taken extensively for reaching the stakeholders. Further, ITKs practiced by the local people at different regions have to be validated and documented for outscaling and upscaling.

Conclusions and Policy Implications

Climate change is a serious concern causing yield sensitivity affecting the wheat production prospects and sustainability. The present study suggests the following research outcomes *viz.*, policies to addresses yield sensitivity in the long-run, climate-smart farming practices and region-specific strategic adaptation to weather anomalies. Yield sensitivity has to be managed by appropriate adaptation practices and agronomic interventions like adjusting sowing time, application of manures, mulching, choice of variety and irrigation scheduling. To match with the climatology, breeders have to develop genotypes that are adaptable to climatic shocks at multi-locations. Crop phenology has changed in due course of time and hence crop advisories need to be developed and/or disseminated at each sensitive crop growth stage which can capitalize the advantage of information and communication technologies (ICTs). Validated climate response technologies like zero tillage and laser land leveling have to be adopted in a larger scale (upscaling and outscaling) following the successful cases or regions. On the policy front, research prioritization should be made for identifying sensitive stages for all wheat growing districts followed by developing region-specific climate-smart technologies. Clearly, climate-smart farming practices and adaptation strategies assume greater significance to manage the yield sensitivity in wheat for ensuring sustainable production in the long-run.

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