

Managing impacts of extreme weather events on crop productivity in mountain agriculture

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सार – जलवायु परिवर्तन और कृषि परस्पर संबंधित प्रक्रियाएँ हैं जो भूमंडल तथा क्षेत्रीय स्तर पर भिन्न भिन्न परिमाणों में घटित होता है। अन्य उद्यमों की तुलना में कृषि भूमंडलीय उष्णता के प्रति सबसे अधिक संवेदनशीलता होती है। हिमाचल प्रदेश के पर्वतीय क्षेत्रों में किए गए अध्ययन से पता चला है कि अधिकतम और न्यूनतम दोनों तापमानों की सीमा में 0.4 से 2.4 डिग्री सेल्सियस की वृद्धि, वार्षिक वर्षा में 10 से 40 प्रतिशत की कमी तथा मौसमी प्राचलों में परिवर्तन हुए हैं। जलवायु के संबंध में किए गए अन्वेषणों से पता चलता है कि तापमान में वृद्धि और जलवायु में परिवर्तनशीलता के कारण हिमाचल प्रदेश में सब की फसल अब ऊँचाई वाले इलाकों की तरफ होने लगी है। खराब जलवायविक परिघटनाओं के समय कार्बन डायऑक्साइड के वर्तमान 370 पी पी एम स्तर में 50 से 100 पी पी एम तक की वृद्धि होने पर किए गए अनुरूपण अध्ययनों से पता चला है कि हिमाचल प्रदेश के वर्षा आधारित और सिंचित दोनों क्षेत्रों के भिन्न-भिन्न कृषि जलवायविक परिस्थितियों में मक्का (1.3 से 5.4 प्रतिशत), गेहूँ (3.6 से 7.3 प्रतिशत) चावल (7.6 से 20.8 प्रतिशत) सोयाबीन (1.3 से 3.5 प्रतिशत) और सरसों (4.0 से 6.0 प्रतिशत) की पैदावार में वृद्धि हुई है। खराब मौसमी परिघटनाओं पर किए गए अनुरूपण अध्ययनों से पता चला है कि 1 और 2 डिग्री सेल्सियस तापमान के वृद्धि से मक्का और सोयाबीन की पैदावार में कमी आई है जबकि तापमान बढ़ने के कारण चावल, गेहूँ तथा सरसों की पैदावार में वृद्धि हुई है। अल्पार्द्र और अल्प तापमान वाले कृषि जलवायविक क्षेत्र में 10 से 20 प्रतिशत की वर्षा में कमी होने से मक्का तथा सोयाबीन की पैदावार में कुछ कमी आई है वर्तमान परिस्थितियों में इस क्षेत्र में वर्षा के पैटर्न के अनुसार देरी से बुआई करने से प्रचण्ड मौसमी परिघटनाओं के प्रभाव का प्रबंधन करना लाभप्रद रहा है। 20 वर्षों के अनुरूपण परिणामों से पता चला है कि हिमाचल प्रदेश के दोनों ही कृषि जलवायविक क्षेत्र में 10 दिनों की देरी से बुआई करने पर 1 एवं 2 डिग्री सेल्सियस तापमान की वृद्धि से मक्का, सोयाबीन तथा गेहूँ के फसल की पैदावार में क्षतिपूर्ति हुई है। इसी प्रकार 20 वर्षों के अनुरूपण से पता चला है कि गेहूँ और सरसों की बुआई में नवम्बर के प्रथम पखवाड़े तक विलम्ब करने से इनकी पैदावार में लाभ होता है।

ABSTRACT. Climate change and agriculture are interrelated processes both of which take place on global and regional scales with varying magnitude. Agriculture is most vulnerable to global warming as compared to other enterprises. The studies conducted in mountains of Himachal Pradesh showed increase in both maximum and minimum temperature range from 0.4 to 2.4 °C, decrease of annual rainfall amount from 10 to 40 per cent and change of weather parameters. The investigations with respect to climate, the impact of increasing temperature and climate variability showed shift of apple crop to higher elevations in H.P. The simulated studies on elevated carbon dioxide levels of 50 to 100 ppm as extreme climatic events from existing 370 ppm showed increase in yield of maize (3.0 to 5.4%), wheat (3.6 to 7.3%), rice (7.6 to 20.8%), soybean (1.3 to 3.5) and mustard (4.0 to 6.0 %) both in rainfed and irrigated conditions under different agro-climatic conditions of Himachal Pradesh. The simulated studies on extreme events of 1 and 2 °C rise showed decrease of maize and soybean yield whereas rice, wheat and mustard showed increase in yield due to rise in temperature. The 10 to 20 per cent decrease in rainfall showed less reduction in the yield of maize and soybean under sub-humid and sub-temperate agro climatic region. The delay of planting windows according to rainfall pattern in the region under present conditions proved beneficial for managing impacts of extreme weather events. The 20 years simulated results showed that delay of sowing by 10 days in both agro climatic zone of H.P. offsets 1 and 2°C rise in temperature on crop productivity of maize, soybean and wheat. Similarly, 20 years simulation indicated benefit in yield of wheat and mustard where sowing was delayed upto first fortnight of November.

Key words – Extreme weather, Crop productivity, Impact management, Gramin Krishi Mausam Sewa.

1. Introduction

Climate is a critical factor in the lives and livelihoods of the people and socioeconomic development as a whole. Climate has shown warming of 0.89 [0.69 to 1.08] °C over the period 1901-2012 which is mainly attributed to anthropogenic activities (IPCC, 2013). Himachal Pradesh is a mountainous state dominated by rainfed farming (82%) on sloppy farmlands. Climate is the major determinant responsible for fluctuations in agricultural productivity and largely determines the suitability of vegetation in particular area. The economy of the state is highly dependent on agriculture with 19.6 per cent share in NSDP of the state during 2005-06 which revealed a significant growth of 6.9 per cent compared to the last decade. The state of Himachal Pradesh in the Indian Himalayas situated between 30° 22' 44" and 33°12' 40" N latitude and 75°45' 55" to 79°04' 20" E longitude. The physiographic features comprise of different mountain ranges, hills and valleys exhibiting an altitudinal variation from 350 m to about more than 6,975 m above mean sea level. Its one-third area remains snow covered for about seven months in a year. This snowy part of the State is the source of three major rivers – Beas, Ravi and Chenab while Sutlej and Yamuna rivers originate from Tibet and Yamnotri, respectively (Anonymous, 2010). More than 64 per cent area of the state is having more than 30 degree slope, 52 per cent faces south and west, 47 per cent faces north and east, and only 0.19 per cent is flat land (Sharma and Phartiyal, 2014) which necessitate the immediate strategies of adaptations in the face of climate change. The biophysical and socio-economical nature of the mountains is characterized by extreme diversity and non homogeneity. The effects of extreme climate in different mountain systems are more perceptible in high crop production areas and regions where extensive animal husbandry and pasturelands are confined. To cap the negative impacts of extreme climate on agricultural, other sectors and societies and to maximize the beneficial ones, it is essentially to adapt or manage the impacts of climate. The management strategies for crops have not been equally considered in planning and execution of climate issues earlier. The adaptation strategies have recently attracted the climate scientist and policy planners.

2. Data and methodology

2.1. Crop simulation models

InfoCrop growth model, a decision support system (DSS) was used to simulate the effects of extreme climatic elements on crops, viz., maize, rice, soybean, mustard and wheat. More details of the model are provided by Aggarwal *et al.*, (2006a, b). The input data files required for running the InfoCrop growth model are crop/variety

master, soil texture master and weather data files. *Crop/variety file*: is used to enter the crop variety details and its parameters. These parameters the so called genotypic coefficients, characterize the basic physiological behavior of a variety. *Weather file*: daily radiation or bright sunshine hours, daily maximum and minimum temperature, rainfall are essential parameters, whereas wind speed and vapour pressure are the optional parameters required to run the model. In addition to this latitude, longitude and altitude of the area is also required to calculate the solar radiation receipt on the earth surface in the model. *Soil texture file*: For three soil layers depth (mm) the parameters like organic carbon (%), soil texture (sand, silt, clay %), bulk density, hydraulic saturated conductivity and NH₄-N and NO₃-N content are needed. *Plant*: Seed rate, specific leaf area of variety, grain weight. *Crop management*: includes date of sowing, dates of irrigation and fertilizer application. The standard output comprises dry weight of roots, stem, leaves, grain number and grain yield, leaf area index, N uptake by crop, soil water and N content, evapotranspiration, N and water stress. Crop coefficients for crops were calculated by using information from a wide literature survey. These coefficients were used in the subsequent validation and application. To evaluate model performance and accuracy in prediction, statistical indicator of root mean square error (RMSE) was computed from observed and simulated variables. An excellent parity between observed and simulated phenological events in varied weather condition reflects the consistency in model performance. The crop seasonal climate scenarios/grids of 1 and 2 °C rise in maximum and minimum temperature, elevated carbon dioxide by 50 and 100 ppm and 10 per cent reductions deficit rainfall were used in the model to assess the impact of projected climate variability. The crop simulation models of individual crops were validated at Palampur agro climatic conditions representing sub humid and sub-temperate climate under mid hill with yield data obtained from All India Coordinated Research Projects (ACRIPs) of individual crops. The impact assessment of climatic parameters on crops were designed after validation of crop simulation models for different crops. The mustard field experiments were conducted for two years at CSKHPKV, Palampur during 2008 and 2009 and data generated were used for validation of mustard crop. The model was run for 20 years from 1989 to 2008-09 for weather stations of Palampur and Dhaulakuan for maize and Palampur for wheat, mustard, rice and mustard crops. The weather data of 1989 to 2008-09 was used and mean simulated yield of 20 years and coefficient of variance were worked out to draw the conclusion. The elevated levels of carbon dioxide, temperature and change in rainfall were compared with control. The control signifies no change in rainfall and temperature and 370 ppm carbon dioxide level or the prevailing climatic conditions in the

region. The Probability Distribution Function (PDF) was used for the results to evaluate the best yields. The crop simulation model for maize crop was run for 1989 to 2008-09 under two agro-climatic conditions, *viz.*, Palampur representing mid hill sub humid and sub temperate climate and Dhaulakuan representing low hill sub-tropical climate of Himachal Pradesh. The other crop simulation models for wheat, rice mustard and soybean were run for 1989 to 2008-09 under mid hill sub humid and sub temperate climate.

Farmer's perceptions

The study was carried out across different agro-climatic zones representing different elevations of Himachal Pradesh from 340 amsl to 3500 amsl of crop lands. A multistage stratified sampling technique was used to select the sample communities. After initial reconnaissance, field visits to the entire state and discussions with key informants/ stakeholders/ farmers in the different areas of the state, we identified five suitable pilot sites, where the impact of changing climate was particularly pronounced. In the first stage of sampling, five areas were selected for our investigation: Fatehpur valley in Sirmour district representing an elevation of 700 m asl with a sub tropical climate; Bajaura Valley in Kullu district located at an elevation of 1500-2500 m asl with a sub-temperate to temperate climate; Theog region in Shimla district representing an elevation of 2000-3250 m asl with a temperate climate; Palam valley in Kangra district with an elevation of 700-1500 m asl within sub-humid and sub temperate climates; and Lahaul valley in Lahaul and Spiti district, at an elevation above 3251 m asl and with a dry temperate climate. In the second stage of sampling, clusters of 4 to 5 villages were drawn from each of the selected study area for the final selection of farmers for interviewing. In the last stage of sampling, an adequate sample of 40 households/ farmers was drawn from each cluster of villages, making a total sample of 200 households. Based on the area of land holdings, the farmers were classified into three categories: those owning less than one hectare (termed marginal); those owning one to two hectares (small); and those owning more than two hectares (large). The results obtained from farmers perceptions were used to design the impact assessment of climatic parameters using crop simulation models for elevated temperature and carbon dioxide and decreasing rainfall in H.P.

2.2. Data collection

The primary data were collected on the basis of a well-structured and pre-tested interview schedule. The

data were collected for two time periods: *viz.*, 2005-06 (period-I) and 1995-96 (period-II). The farmers awareness programme were organized in eight districts *viz.*, Kangra, Una, Hamirpur, Chamba, Lahaul and Spitti, Mandi, Kullu, Kinnaur of the state and Participatory Rural Appraisal (PRA) was done using well tested questionnaire during 2012-13 in order to validate ITKS and adaptations strategies for managing the extreme climatic events.

3. Results and discussion

3.1. Climate of Himachal Pradesh

Himachal Pradesh situated in the lap of Western Himalayas. Its climatic conditions vary from extremely hot to severe cold regions like Chamba, Kinnaur and Lahaul and Spiti. Average rainfall of the state is 1122 mm. Western part of state situated in foothills of Dhauladhar ranges of the Himalayas has the highest annual precipitation ranging 1844 mm to 2601 mm. The areas like Lahaul and Spiti, Kinnaur receive normal precipitation of 300 mm, during winter season. Northern part of the state is having by and large temperate climate receiving precipitation between 332 to 1088 mm annually. Annual mean temperature of the state remains between 10.4 to 22.7 °C, with temperature decrease from south west to north east part of the state. Maximum and minimum temperature varies between 19.5 to 31.9 °C and 0.4 to 17.0 °C, respectively with mean annual temperature up to 24 °C.

3.2. Extreme climate indicators in mountains of Himachal Pradesh

Mean temperature trends at different elevations showed enhancement in all the locations with exception at Shimla during 1969 to 1987. The increase was more during *Rabi* season than *Kharif* season. The mean annual rainfall trends showed decrease in all locations in different elevations. The decrease of rainfall was more in Palampur region compared to other regions under study. The rainfall during *Kharif* season showed increasing trends at Fatehpur in Dhaulakuan and Palampur whereas in higher elevations at Shimla, it showed decreasing trends. The rainfall during *Rabi* showed decrease in all the stations including higher elevation areas. The increasing trends of evaporation were observed at lower plains regions at Fatehpur, Sirmour whereas at higher elevations *viz.*, Palampur and Kullu registered decreasing trends. Relative humidity in general showed increasing trends at Palampur and Dhaulakuan. The recent reports indicated that the long term temperature trends revealed an increase in annual

maximum temperature in Himachal Pradesh where the rate of change is $+0.06$ °C per year. The increase in maximum temperature was also evident during the monsoon season. However, the minimum temperature trends are inconsistent. The rainfall trends during the annual monsoon and post monsoon seasons have shown decreasing trends for the duration of 1991-2010. Whereas the summer rains have shown increasing trends (Rathore *et al.*, 2013). The study conducted under Network Project of Climate Change indicated that increase in temperature in H.P. forced the maturity of *Rabi* and *Kharif* by five to fifteen days (Bhagat *et al.*, 2007).

3.3. *Farmers' perceptions on changing climate in Himachal Pradesh*

Climate change is described by farmers as temporal displacement of weather cycles, reflecting changes in crop enterprises and livelihood options. Increasing temperature during summers, prolonged summers, delayed onset and uneven distribution of SW monsoon, delayed onset of winter, short winter periods, temperature above normal during winters, decreasing snowfall during winters, low temperature spells at high altitudes during winters and unpredictable rainfalls were the main experiences of the farmers regarding change in climate across the elevation zones. Farmers' perceptions clearly indicated a shift in crop production in the low and mid hill regions, from crops requiring high moisture, like basmati rice and sugarcane, to those tolerating lower water like maize and local paddy rice. In addition, a shift of the apple growing belt to higher altitudes was noted, with former apple production areas replaced by vegetable crops and fruits like plum, peach and pomegranate. The study concludes that climate variability has a clear impact on crop productivity. In all elevations, farmers opined that a shift of labour earlier engaged in agriculture, to other enterprises is primarily due to handsome earnings in other enterprises, reflecting reduction in profits from agriculture and increase in vulnerability in climate dependent agricultural systems. Farmers in marginal areas are more vulnerable than small and large farmers from sub tropical climates in the mid hills to sub temperate climates at higher elevations (Rana *et al.*, 2013).

Study conducted on trends of snowfall indicated the decrease in monthly average snowfall from September to December and March to May. Whereas, snowfall amount showed increasing trends during January and February months reflecting delay of snowfall in winter season. The delay of snowfall occurrence and early withdrawal reflected in short winter period (Rana *et al.*, 2014a).

3.4. *Impact of climate change on surface water resources*

The study revealed that the surplus water balance in all the agro-climatic zones during past three decades showed decreasing trends and maximum availability of surplus water balance period also showed a shift during July to August and registered a decrease of 35.7 per cent in mid hill region. The low hill regions exhibited water surplus during *Kharif* season and water deficit during *Rabi* season, while, mid hill regions exhibited water deficit during *Kharif* season and water surplus during *Rabi* season during past three decades. The significant decrease of surface water flow of river Beas observed in Kullu district during all the months. The water flow of river Sutlej in Kinnaur district also showed significant decreasing trends during winter months. The water resources have been impacted due to changes in climatic conditions in mountains of Himachal Pradesh during past three decades (Rana *et al.*, 2014a).

3.5. *Simulated impacts of extreme weather events on agriculture*

The simulated studies on the increase of carbon dioxide levels by 50 to 100 ppm from existing 370 ppm showed increase in yield of maize, wheat, rice, mustard and soybean both in rain fed and irrigated conditions under Agro-climatic zone I and II (Low hill and Mid hill Zone) and wheat, rice, mustard and soybean under Agro-climatic II of Himachal Pradesh. The increase was more in rainfed conditions than irrigated conditions. The simulated studies on the decrease of 10 to 20 per cent rainfall in sub-humid and sub-temperate agro climatic region caused the reduction in yields of maize and soybean during *Kharif* season. Whereas, the decrease of *Rabi* season rainfall decreased the crop productivity of wheat and mustard. The increase in temperature to the tune of 1 and 2 °C rise caused less reduction in maize, rice and soybean. The *Rabi* crops *viz.*, wheat and mustard showed increase in yield with rise in temperature under rainfed conditions (Rana *et al.*, 2013).

3.6. *Management approaches for extreme weather events in mountains*

Management strategies for extreme weather events are to be planned differently in mountainous regions than the plain regions. The mountain agriculture is a low input agriculture having less climatic resilience and more of the adaptation measures correlate to the Indigenous

Traditional Knowledge (ITKs). Role of climate resilient practices and ITKs used by the farmers have been validated and showed great promise to conserve mountain agriculture. The mountain agriculture ecosystems changes after every 15-20 km and is bestowed with new climate niches which are having thin boundaries between two agro-climatic situations. In the event of increasing temperature and changing rainfall pattern the thin boundaries of climatic conditions are drastically changing. There are many different adaptation options available to the agricultural sector, which vary greatly in their application and approach.

3.7. Simulated management options for extreme climatic events on crops of mountains

(i) Maize

The magnitude of impact of elevated CO₂ was more under rainfed conditions. Under no resource limitation conditions, 50 and 100 ppm levels indicated an increase of more than 3.0 and 5.4 per cent in 10th June sown crop. In districts of coastal Andhra Pradesh, Kumar *et al.*, (2011) suggested 10 per cent increase in rainfed maize yield with increased CO₂ levels. Similar results were reported by Sharma *et al.*, 2013 with elevated levels of CO₂ viz., 414, 522, 682 and 970 ppm. However, 1 and 2 °C rise in temperature at 370 ppm CO₂ levels showed decrease in yield due to increase in temperature in sub humid and sub temperate climate (Palampur) of H.P. Reduction in yield due to increase in temperature was also reported by Byjesh *et al.* (2010). Under Sub tropical agro-climatic conditions (Dhaulakuan), the best simulated planting window was 20th June under increased temperature of 1 and 2 °C based on 20 years simulations (1989 to 2008-09). The simulated management options were validated under similar climatic conditions at farmers field in Una and Kangra districts for three years from 2010-2012 which showed that sowing done after 10-20th June resulted 4.6 q/ha higher yield as compared to 3rd week of June sowing (Rana *et al.*, 2013). The RMSE value for grain yield between observed and simulated yield of maize was 724.5 (13.11%).

(ii) Wheat

The increase in yield with elevated levels of CO₂ to the tune of 4.9-7.3 per cent on early sown conditions *i.e.*, 15th October further, skipping two irrigations in wheat caused 15-24 per cent reduction in yield. 1°C rise in both maximum and minimum temperature under recommended package of practices with four and six irrigations indicated

10 per cent increase in yield with six irrigations and 4.9 per cent with four irrigations. In case of late sown wheat, 30th November sown crop proved to be the best planting window under irrigated conditions. Further, elevated levels of CO₂ over 370 ppm by 50 and 100 ppm under irrigated conditions, indicated increase of 3.6 to 4.0 per cent and 1.7 to 7.5 per cent wheat yield. Similarly, 1 and 2 °C rise in temperature increased the yield in all the planting windows to the tune of 17.9 to 63.0 per cent and 33.2 to 113.4 per cent, respectively. Combined effect of increased temperature of 1 and 2 °C with elevated CO₂ levels of 50 and 100 ppm also resulted in higher yield under Palampur conditions. The RMSE value for grain yield between observed and simulated yield of wheat was 426.8 (10.1%).

(iii) Rice

Among all the transplanting windows from 10th June to 10th July, the 20th June transplanting proved to be the best and showed maximum rice yield followed by 30th June under Sub humid agro-climatic conditions (Palampur, H.P.). Elevated levels by 50 and 100 ppm over 370 ppm CO₂ level showed an increase of 7.6 to 11.7 per cent and 14.8 to 20.8 per cent in yield of rice in all the transplanting under Palampur conditions. Similarly, elevated temperature levels of 1 and 2 °C showed an increase of 6.8 to 25 per cent and 14.8 to 35.6 per cent. Increase in carbon dioxide level by 100 ppm coupled with temperature rise of 1 °C also showed increase in the yield to the tune of 3.3 to 9.5 per cent in all the transplanting windows except 10th June transplanting. However, reduction of 10 and 20 per cent of rainfall caused reduction in the rice yield to the tune of 0.1 to 0.7 per cent and 1.0 to 9.6 per cent, respectively. The delay in transplanting after 10 June helped to reduce the impact of 1 and 2 °C rise in temperature under sub humid agro-climatic conditions of Himachal Pradesh. The RMSE value for grain yield between observed and simulated yield of rice was 401.8 (11.7%).

(iv) Soybean

Under rainfed conditions of sub humid agro-climatic conditions (Palampur, H.P.) 10th June sown crop was found to be the best planting window. Elevated levels by 50 ppm and 100 ppm CO₂ showed an increase by 5.0 and 10.2 per cent in soybean yield, respectively (Rana *et al.*, 2014b). Plants grown at elevated CO₂ had higher efficiency of water, light and nutrient utilization (Jacob *et al.*, 2001). The findings are in accordance with Madhua and Hatfield (2013). While, rise of temperature

by 1 and 2 °C showed reduction in yield to the tune of 1.3 to 3.5 and 4 to 6 per cent, respectively. However, the temperature rise of 1 and 2 °C coupled with 50 ppm elevated CO₂ increased the yield in all planting windows. The further increase in CO₂ level to 100 ppm increased the yield ranging 11.0 to 13.6 per cent in 1 °C and 7 to 10 per cent in 2 °C rise in temperature. However, rainfall decrease of 10 per cent increased the yield by 1.0 to 1.5 per cent, but with 420 ppm CO₂ increased the yield by 8.4 to 12.7 per cent in all dates of sowing. The RMSE value for grain yield between observed and simulated yield of soybean was 190.3 (9.1%).

(v) *Mustard*

The mustard crop model was validated for Palampur region and used for assessment of climate change impact under different situations. The results revealed that 9th November was the best planting window but this planting shifted to early date to 20th October under two and three irrigations conditions. Under the four and six irrigations levels, 10th October was the best planting date. Yield showed decrease with delay in sowing from 10th October to 9th November. Under rainfed and two irrigation conditions 1 °C rise temperature caused reduction in yield in 10th October to 9th November sown crop (Rana *et al.*, 2011). Warmer temperature accelerates growth and development leading to less time for carbon fixation and biomass accumulation before seed set resulting in poor yield (Boomiraj *et al.*, 2011). Four and six irrigation conditions were benefited with 1-2 °C rise in temperature in all the sowing windows. Elevated levels of CO₂ by 420 and 470 ppm showed general increase in yield in all dates of sowing under irrigated conditions. The yield in general increased under two irrigation and rainfed conditions at higher levels of CO₂. However, under rainfed and two irrigation conditions yield of mustard decreased with rise in 1 and 2 °C temperature over different dates of sowing. The four and six irrigation levels showed increase in yield in all planting windows with 1 and 2 °C rise in temperature + 50 ppm CO₂. The 10 per cent rainfall reduction plus 1 °C rise in temperature showed decrease in yield in all the planting windows as compared to normal conditions based on last one decade data. Lower yield with rise in temperature and reduction in rainfall was also found by Singh *et al.*, (2008). The RMSE value for grain yield between observed and simulated yield of soybean was 74.8 (6.7%).

3.8. *Farmers' perceptions for managing extreme events in agriculture & horticulture in the mountainous regions*

In order to sustain the productivity of apple in low lying areas in the Kullu district of Himachal Pradesh, the

farmers opted for the plantation of low chill cultivars (Gala, Spur, Vance etc.) in orchards which are less sensitive to climatic changes (Aditya *et al.*, 2013). Majority of farmers in the lower belts also shifted their choice of crops to other fruits like pears, pomegranate, kiwis etc. and commercial vegetables which fetched higher prices. As the chilling requirement was not met in lower areas, many farmers felt that higher altitudes have become more suitable for apple cultivation and shifted their orchards to higher altitudes. The farmers revealed that beside these other adaptation strategies such as, beekeeping, floriculture, polyhouses, sprinkler irrigation methods, inter cropping, introduction of pollinizer plants etc. were adopted to compensate the loss. The five days forecast based agro advisory proved beneficial in managing the extreme events as indicated from farmer survey of 8 districts of H.P. The advance weather forecast helped in adjusting sowing windows for both *Rabi* and *Kharif* crops. The farmer's perception clearly deciphered the crop diversification and growing mixed crops as adaptation for managing extreme weather events. Due to rise in temperature and reduction in chill units have caused shift of apple belt to higher elevations whereas as reduction in chill units hours did not impact the other stone fruits productivity, *viz.*, pear, peach, plum and apricot in mountain regions of H.P. (Rana *et al.*, 2010). The inference of the study indicated that rise in temperature in apple growing regions have increased the opportunity for growing stone fruits in regions as alternative crops.

3.9. *Practices followed by the farmers for managing extreme events in mountains*

As per the farmer perceptions local varieties were most adapted to the extreme climate events. The sowing across the slope was found beneficial by 80-90 per cent farmers out of 1189 farmers surveyed. Diversification of cereals crops with vegetables and shifting from high water requiring crops to low water requiring crops are the practices adopted by the farmers for managing the extreme weather events of climate change.

3.10. *Protected agriculture in managing impacts of extreme climate in H.P.*

The 95 per cent farmers reported that protected agriculture to be a best option under extreme cold climate in mountains specifically for *Rabi* and vegetables crops. The vegetable crops and nursery can be grown in all seasons of the year's especially tomato, capsicum and

flowers. Protected cultivation of vegetables and plastic mulches are field worthy technologies for sustainable vegetable farming in high hills including cold arid of Lahual and Spitti, Kinnaur and Ladakh.

3.11. *Organic Agriculture (OA) a new paradigm for managing extreme climatic conditions in mountains*

The study examined that consumption of fertilizers in Himachal Pradesh is 35.53, 7.19 and 7.51 kg/ha of N, P₂O₅ and K₂O, respectively which is very low as compared to the other counter parts and national average consumption. This warrants the scope for upscaling of OA in mountains and can be major contributor for mitigating effect of climate change. Out of total cropped area (9,40,597 ha) Himachal Pradesh has 6,31,902 ha area under organic agriculture. Hence, the remaining area under inorganic conditions is 3,08,695 ha (32.82%). Assuming 10 per cent of the inorganic area is converted to organic *i.e.*, 30869.5 ha, production of 1516587.7 kg CO₂/ha can be reduced. So, there is great potential to make the state as Organic state. Similarly, pesticide use in H.P. is 0.335 g/ha and if we go for OA on an area of 30869.5 ha we can save 10341.3 kg CO₂/ha emission. Further, there is 20-30 per cent irrigation water saving in OA as reported earlier by different workers. As 100 mm irrigation water causes 5 kg CO₂/ha emission, then assuming one irrigation (10 mm) skipped in OA, thus reduction of 15434.8 kg CO₂/ha emission can be done. In HP, 2.85 MT residues are produced annually, out of which 0.41 MT is burnt. On an average 1 tonne of residue burning produce 48 and 40 kg CH₄ and N₂O, respectively. If residue burning is stopped 3436.56 kg CO₂/ha of these gases can be reduced (Rana *et al.*, 2014c).

3.12. *Gramin Krishi Mausam Sewa for managing extreme weather events*

Under the changed scenario where agriculture has become highly input and cost intensive, today the weather forecasts relating agriculture are indispensable to reduce the cost of cultivation for crops. The agro-advisory services based on medium range weather forecast on agricultural component technology are useful for strategic as well as tactical decision making in agriculture. The tactical decisions based on medium range weather forecast are more effective in low external input sustainable agriculture, regarding time of cultural practices, such as ploughing, sowing/planting, mulching, time of application of organic manures, weeding, thinning, pruning and harvesting. Rana *et al.* (2005) also concluded

that 3 days forecasts were more than 50 per cent accurate for Palampur region and proved beneficial to crop activities compared to recommended practices. The agro advisory services proved beneficial for rice, maize and wheat cultivations which showed a benefit of 7, 4 and 8 per cent in the production respectively in the region. The correct cloud cover forecasts were helpful in saving Rs. 350 to 500 (44 to 75 kg fish feed) in fishery enterprises in the region during SW monsoon. About 10 to 20 per cent feed in poultry was saved due to the higher accuracy in temperature forecast. Medium range rainfall forecasts were also helpful in saving Rs. 400 per irrigation for drainage of maize, vegetables and pulses (Rana *et al.*, 2013). The advance information on weather parameters *viz.*, rainfall, cloud cover, temperature, humidity, wind speed and direction and cumulative rainfall at district are useful for both strategic and tactical decisions.

3.13. *Per cent replacement of crop area*

The area under basmati rice and maize crops in low hill zone at Fatehpur valley showed a decline of about 37 and 26 per cent, respectively as revealed from farmers survey. Sugarcane, a cash crop of farmers in the past, registered a decline of about 50 per cent in its area over recent years. Farmers of the region have diverted toward local paddy rice and vegetable crops like cauliflower, garlic and potato. Crops of the high hill zone *i.e.*, Theog region were formerly dominated mainly by food grains with 62 per cent total area under field crops. In the present scenario, seasonal and off-season vegetables (such as cabbage, cauliflower and tomato) together cover more than 84 per cent of the area in the valleys. The total area under apples and other fruit crops generally recorded less change over the same period. A remarkable increase in the area under off-season vegetables was noted in Bajaura valley representing mid hill sub-temperate climate mainly due to a shift in the area formerly under food grains and fruits (*e.g.*, apple, plum) to off-season vegetable cultivation, with a reduction of over 50 per cent. Notably, there was a significant increase in the total cropped area in the present scenario over the past scenario. This might be due to the ability to raise 3-4 crops of offseason vegetables within a year.

In the Palam valley representing Sub humid and sub temperate climatic conditions of the state, no significant shift occurred in the overall cropping pattern as indicated in the farmers' survey. However, a shift of paddy crop area to maize production was noted, with nearly 18 per cent more area diverted to the maize cultivation in the present scenario. The area under oilseeds such as sarson is also declined by about 76 per cent.

In high hill dry temperate region (Lahaul valley), there is an increase of about 8-9 per cent in area of potato and peas whereas the area under various traditional mountain crops like kuth (*Saussurea costus* (Falc.) Lipsch}, saffron (*Crocus sativus* L.), kala zira (*Bunium persicum* Bioss.), buckwheat (*Fagopyrum esculentum* Moench.), hops (*Humulus lupulus* L.) and amaranth (*Amranthus candatus* L.) decreased drastically. The farmers in this valley are devoting less area to crops like barley, which had been the main crop of the valley in the past. The area under apples increased by 122 per cent (*i.e.*, from 0.49 ha per farm to 1.09 ha) in recent times.

3.14. ITK's to combat the climate change impacts

(i) Insect pest disease protection:

- During the late onset of SW monsoon, the seeds of the *Kharif* crops *viz.*, maize and soybean are sown in dry soil after soaking the seeds in the cow urine for 10-12 hours to protect the seeds into dry soils from insects/disease attack.
- Seeds are treated with mixture of ash & cow dung before sowing to prevent attack of pests and diseases. Ash acts as mechanical barriers to pests and pathogens.
- Ramban (*Agave americana*) is crushed and put into the water for irrigation of paddy field to protect the crop from insect disease *i.e.*, leaf folder, rice hispa etc and bacterial blight and blast.
- Ankhar plant leaves are placed at the entry point of the kuhl (irrigation channel) to the fields for the control of rice hispa. The leaves of this plant are placed before the attack of rice hispa locally called as chitri.
- Use of chullah (wood ash) ash on vegetable crops like cucurbits, onion, brinjal, tomato, garlic controls the insects like red pumpkin beetle, defoliating beetle, thrips and aphids especially in kitchen gardening.

(ii) Storage of food grains

- Food grains are stored in a large spindle shaped basket made of bamboo (Paru) and entirely sealed

with cow dung mixed with cow urine to protect grains from pests and diseases for long time. In such practice no weevil attack is observed even under longer storage period.

- Spreading of lantana, eupatorium and eucalyptus plant leaves for potato tuber moth control in stored potato.
- To protect wheat from pests, dry leaves of Bangru (Wild pudina), kali basuti or safada (*Eucalyptus* spp.) is put into the base and top of the container.

4. Conclusion

The climatic parameters clearly indicated the increase in temperature in low to high hills of H.P and North Western Himalayas. The surface water balance and surface water resources also showed reduction in the region based on past three decades data. The farmers' preconception also portrayed that temperature is showing increasing trends and winters are shrinking due to decreasing trends of snowfall and variability in rainfall. The simulated studies showed that increase of CO₂ levels increased the yield of maize, wheat, rice, mustard and soybean both in rainfed and irrigated conditions under Agro-climatic zone I representing low hill sub tropical and Zone - II representing the mid hill sub temperate agro climatic conditions of Himachal Pradesh. The increase in temperature also showed increase in yield of wheat and mustard under rainfed conditions. While the decrease of 10 to 20 per cent rainfall in sub-humid and sub-temperate agro climatic region caused reduction in yields of maize and soybean. The farmers perception clearly indicated that ITKS used are climate resilient. The simulated planting windows for *Kharif* crop showed 10 days delay can offset the elevated temperature regime of 1 and 2 °C in low hill regions. Adoption of low chill requiring cultivars of apple, shifting to other fruits like pears, pomegranate and kiwis etc. and commercial vegetables, diversification of cereals crops with vegetables, growing mixed crops and shifting from high water requiring crops to low water requiring crops are the practices adopted by the farmers for managing the extreme weather events of climate change. The five days forecast based agro advisory proved beneficial to help in adjusting sowing windows for both *Rabi* and *Kharif* crops. Adoption of protected agriculture and organic farming proved to be the best option under extreme climate in mountains.

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