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Impact Assessment of Changing Environmental and Socio-Economical Factors on Crop Yields of Central Himalaya with Emphasis to Climate Change

Manmohan Singh Kanwal, Sandipan Mukherjee, Rajesh Joshi, Sumit Rai

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Abstract The present study attempts to assess impact of changing socio-economical and environmental factors affecting yield of rice, wheat and madua, 3 traditional crops of central Himalaya on a district level spatial scale having objectives : (1) To quantify the critically low yield limits of crops and associated critical limits of significant factors (2) To estimate the role of individual factors responsible for the critically low yields of crops and (3) To study impact of futuristic climate change on the yield of these crops. The study was carried out for Almora district of Uttarakhand State. Seasonal total rainfall, seasonal average temperature, soil pH, volumetric soil moisture content, cropping area, number of livestock and number of cultivators were identified as important factors affecting crop yields. Annual data of these selected factors were collected for the period of 1990 to 2010. It was found that the critically low yield limits of rice, wheat and madua were 21625, 36932 and 35521 Mt, respectively. Conditional probability (Pc) values of critical low yield occurrences and individual factors were found to indicate that the reduction in rice and madua yield were attributed to decrease in cropping area (Pc=0.6,0.8) followed by decline in number of cultivators (Pc=0.04, 0.04) and decreased total rainfall (Pc=0.04, 0.04). Similarly, for wheat yield reduction, soil pH (Pc=0.6) and increased livestock number (Pc=0.6) were the most significant factors indicating farmers shifting to animal husbandry during winter months. When climate change impact on crop yield was assessed using Generalized Linear Model predictions, yield of rice and wheat was found to increase with increasing temperature and rainfall while yield of madua was found to decrease.

Keywords Crop yield, Socio-economic change, Environmental change, Climate change, Generalized linear model.

Introduction

A bulk of the Himalaya's total population lives in rural areas and depends primarily on farming for their day-to-day sustenance and well-being. The region has along heritage of subsistence economy, with agricul-

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Manmohan Singh Kanwal, Sandipan Mukherjee,
Rajesh Joshi, Sumit Rai*
G. B. Pant National Institute of Himalayan Environment and Sustainable Development, Kosi-Katarmal, Almora 263643, Uttarakhand, India
e-mail : sumitssac101@gmail.com
*Corresponding author

ture being the core component involving over 70% of its population. Agriculture and allied activities not only provide livelihood to large sections of Himalayan population but also play a pivotal role in their way of living (Agnihotri et al. 2014). The traditional farming operation in this region is a complex product of animal husbandry and forest resources constituting interlinked diversified production systems. Rural community of the region has developed several indigenous and traditional methods of farming to conserve the crop diversity and rejoice agro-diversity with religious and cultural vehemence. They are not only the custodians but also managers of the crop diversity and maintain dynamic processes of crop evolution and adaptation, the key elements of sustainable agricultural productions. The traditional settled agriculture of central Himalaya exhibits a great deal of variability in crop diversity, crop composition and crop rotations along an altitudinal transect. Hence, the region can be divided into 4 markedly different agro-climatic zones along the elevation gradient i.e. ,lower altitude,<800 m, middle altitude between 800 to 1500m, higher altitude, 1500 to 2000 m and very high altitude>2000 m (Srivastava 2006). The Central Himalaya is well known for more than 40 food crop species comprising of about 6 types of cereals, 5 types of pseudo cereals, 6 types of millets, 16 types of pulses, 4 types of oilseeds, 5 types of condiments, and 8 types of vegetable (Belsley 1980). Agricultural land in the region is identified either as rainfed or irrigated.

However, rainfed agriculture is the predominant form of land use and only about 15% land falls in the category of irrigated agriculture land. Similarly, use of chemical fertilizer for production of cereals and millets is also very limited in the central Himalayan region due to lack of irrigation. The requirement of fertilizer in the hills is, therefore, satisfied through use of farm yard manure (FYM) produced from household livesstock (Agnihotri et al. 2014). However, during recent past a decline in the interest of local farming communities towards traditional crop cultivation irrespective of cultivars, particularly rice (*Oryza sativa*), wheat (*Triticum aestivum*) and madua (*Eleusine coracana*) has been observed due to changes in several environment and socio-economical factors (Belsley et al. 1980). Consequences of this decline in traditional crop production are disastrous in terms of genetic erosion of local crops and decline in the intensity and net area under cultivation and production of crops in Central Himalaya. A general hypothesis for the declining yields of these traditionally cultivated crops of central Himalayan region is the changing patern of environmental, particularly climatic factors, and socio-economical factors. However, quantitative and numerical assessment of this hypothesis is largely lacking for this part of the Himalayan region.

In view of this lacuna, overarching aim of this study is to assess the impact of changing environmental and socio-economical factors affecting yield of 3 traditionally cultivated crops of the central Himalayan region. Under this overarching aim, specific objectives of this study are to : (1) Quantify the critically low yield limits of selected crops over a central Himalayan district and associated critical limits of significant factors (2) To estimate the role of individual factors responsible for the critically low yields of selected crops over a central Himalayan district and (3) To study impact of futuristic climate change on the yield of rice, wheat and madua of the study area.

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Materials and Methods

Study area of this work was selected to be the Almora district of Uttarakhand state of India (Fig.1) representing almost 90% land mass of the Kosi-watershed. The Almora district is composed of 11 blocks having altitudinal variation from 457 m to 2742 m. Total geographical area of the district is 3139 km^2 with a population of 631 thousands (2011 census of Govt. of India). The rationale behind selecting Almora district for this study was the socio-economical and agro diversity within the study do main. This district has an average of 16,53 and 7.1% of agriculture, forest and grazing area with 80% of population attached to agriculture representing typical average values of central Himalayan districts and making this study

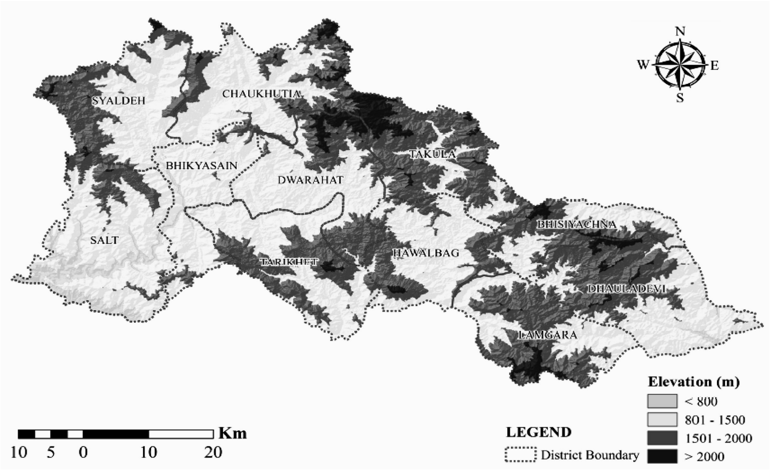

Fig. 1. The altitudinal variation of the study area (Almora district) is represented using agro-ecological classifications. Different block boundaries within the district boundary are also represented.

area a true representative of central Himalayan. Furthermore, most of the major components of land based yields of this region as well as components of socio-economical and environmental factors were found to be well documented over time.

In order to identify significant factors affecting rain fed agricultural yields of rice, wheat and madua of Almora district, factors controlling agricultural yield were broadly categorized into 2 parts : (i) Environmental factors and (ii) Socio-economical factors. Broad categories were further divided into different factors, such as monsoon/winter seasonal total rainfall and average temperature, soil pH, volumetric soil moisture fraction, cropping area as environmental factors; no. of cultivators and no. of livestock as socio-economical factors. Among these factors only the number of livestock population was considered as indirect factor having significant impact on yield of crops due to enhancement in the number of livestock population per house hold implies shifting from crop cultivation to animal husbandry and relatively higher income generation. Individual factors were selected based on expert opinion of agricultural scientists, cultivators and local government representative of the region through a Workshop on Factors of Central Himalayan land based productivity organized at the GBPNIHESD Kosi-Katarmal, Almora on 1st June, 2015. Few other very significant factors, such as human-animal conflict, implication of national policies, out migration, outbreak of pests were also identified by the participants of the workshop. However, such variables could not be included in the modeling exercise either due to qualitative nature of the factor or due to lack of long term database. The baseline data of agricultural yields and their factors were collected as an annual time series for the period of 1990-2010 with very few missing values. Gaps in time series data were filled using simple linear trend. Details of the individual data were provided in Table 1.

Before establishing a weightage based relationships between factors and agricultural yields, linear trends on both yields and factors were estimated and correlation signs between yield of a crop and factors were evaluated (Table 2, Fig.2). To estimate weightage based relationships between identified factors and agricultural yields, a direct one-to-one relationship of crop yield and factors were produced. The focus of this study was to find significant factors for critically low production of certain crops. The range of critically low yields of rice, wheat and madua were identified by 25th percentile value of the total data distribution using correlation sign between factors

Table 1. Details of factors influencing the yields of rice, wheat and madua.

Factors		Data period	Remarks
I. Environmental	1. Rainfall	1990-2010	Seasonal total rainfall of Jun—Sep and Nov-Dec were used for from
	2. Temperature	1990-2010	Seasonal average temperature of Jun-Sep and Nov-Dec were used for
	3. Soil pH	Isolated point data interpolated to annual values for 1990-2010	Soil pH data source. Linear trends during study period and average rate was added or subtracted from previous year. Field observations during 2013-14 were also used to validate the trend
	4. Volumetric soil	1990-2010	Data source : NCEP reanalysis data area averaged for Almora district
II. Socio-economical	1. Cropping area	1990-2010	Cropping area data of rice, wheat and madua were available in yearly published district statistical handbook for the study period
	2. Livestock population	Five yearly livestock data linearly interpolated to 1990-2010	Livestock population of study period was available in district statistical handbook Categories of different livestock were converted into cattle unit following
	3. Number of	Decadal data linearly	Decadal data were available on district statistical handbook

and yield. Similarly, critical low yield limit associated to each driver was identified by 25th (or 75th) percentile value of the total data distribution. Once the critical low yield limits were identified, time series of both yields and factors were made dichotomous, i.e. when any yield value was less than the critical limit was denoted by '1' otherwise '0'. A similar approach was also adopted for the factors. Once, the dichotomous time series were prepared, conditional probabilities between yields and factors were identified following :

$$P_c\,(A/B) = P\,(A \cap B) \,/\, P\,(B) \qquad (1)$$

Where, A = occurrence of events of critical yield under the occurrence of event B. Here , B is a predictor or driver responsible for events of critical yield. Conditional probability was estimated between individual yield of a crop and factors to establish a weightage based relationship. Finally, to assess the impact of changing climate on the annual yield of rice, wheat and madua (district level cumulative production in Mt), a Generalized Linear Model (GLM) as :

$$E\,(Y) = L^{-1}\,(X\,\beta) \qquad (2)$$

was constructed considering the annual crop yield (represented in the model as E (Y) as functions of environmental and socio-economical factors (repre-

Table 2. Correlation coefficients between yield of each crop and factors. (*) values are statistically significant with p-value<0.01; and (**) values are statistically significant with p-value<0.05.

Factors	Rice	Yields Wheat	Madua
Jun-Sep total rainfall	0.20	NA	0.19
Jun-Sep avg temperature	0.45**	NA	0.23
Nov-Dec total rainfall	NA	0.10	NA
Nov-Dec avg temperature	NA	-0.12	NA
Soil pH	0.56**	0.54**	0.12
Volumetric soil moisture fraction	-0.06	0.01	0.02
Cropping area	0.92*	0.82*	0.73*
No. of cultivators	0.88*	0.80*	0.41**
No. of livestock	-0.76*	-0.70*	-0.37**

sented as linear predictors X β with a link function L^{-1}). The GLM is extensively used in agriculture, ecological and natural resources science (Gbur 2012). The GLM was selected for this study due its simplicity and flexibility of usage towards environmental data.

The predictor factors for rice, wheat and madua are already provided in Table 1. Before the GLM model training and validation, collinearity amongst the input factors were estimated following (Gbur 2012). It is to be noted raw data of factors and yields were pre-processed separately before the GLM was constructed. All the input factors and yields were normalized within 0-1 to make the time series dimensionless following :

$$x_n = \frac{x_i - x_{min}}{x_{max} - x_{min}} \qquad (3)$$

where, x_n, x_{min}, x_{max} are the normalized value of x_i, minimum and maximum of the entire x time series, repectively. Each dimensionless time series was then randomized and, the model was trained using randomized data for the period of 1990-2002 representing 2/3rd of the total data set. The rest of the data were used for validation. Normal distribution was used for all the predictors and identity link function was used in the GLM.

The statistical indicator of r^{2-} values and root mean squared error (rmse = $\sqrt{\frac{1}{n}\sum_{i=1}^{n}(o_i - m_i)^2}$, where o and m are observed and model simulated values and n is number of total data) were used as performance indicators after denormalizing the model output.

After the model training and validation, impact of futuristic climate change on the yield of rice and madua was assessed by simulating the trained model for 3 cases : Case 1 : Increase in Jun —Sep average temperature of 2.4°C and 2.9°C from the base line Jun–Sep average temperature of 29.1°C and 831.1 mm rainfall where rests of the predictors having baseline value of 2010. Case 2 : 5 and 10% increase in the Jun—Sep total rainfall from the base line Jun—Sep average total rainfall value of 831.1 mm and average temperature of 29.1°C where rests of the predictors having baseline value of 2010. Case 3 : Both increase in Jun—Sep average temperature of 2.4°C and 2.9 °C from the baseline value of 29.1°C and 5 and 10% increase in the Jun—Sep total rainfall from the base line value of 831.1 mm where rests of the predictors having baseline value of 2010.

Similarly, impact of futuristic climate change on the yield of wheat was assessed by simulating the model for 3 cases : Case 1 : Increase in Nov—Dec average temperature of 2.4°C and 2.9°C from the base line Nov—Dec average temperature of 18.2°C and 20.2 mm rainfall where rests of the predictors having baseline value of 2010. Case 2 : 5 and 10% increase in the Nov—Dec total rainfall from the base line Nov—Dec total rainfall from the base line Nov—Dec average total rainfall value of 20.2 mm and average temperature of 18.2°C where rests of the predictors having baseline value of 2010. Case 3 : Both increase in Nov—Dec average temperature of 2.4°C and 2.9°C from the baseline value of 18.2°C and 5 and 10% increase in the Nov—Dec total rainfall from the base line value of 20.2 mm where rests of the predictors having baseline value of 2010.

These climate change scenarios were obtained from the PRECIES model predictions over Himalaya (Chandra et al. 2010). Finally, the model simulated yields for these cases were compared with the 1990-2010 average yield values of rice, wheat and madua over the study area.

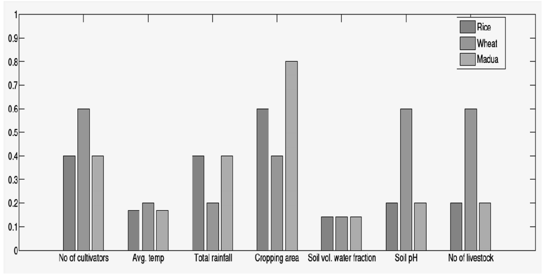

Fig. 2. Conditional probability values between yields of rice, wheat, madua and individual factors.

Results and Discussion

Changes in the crop yields and factors affecting yields

The cumulative yields of rice, wheat and madua were found to decrease during the study period. Linear trends of yield reduction of these crops were found to be 1400, 1800 and 300 Mt/year, respectively. The reductions in crop yields were found to corroborate well with the reductions in cropping area of rice, wheat and madua. The cropping area reduction rates were found to be 680, 960 and 450 ha/year, respectively. However, during the same period of observation, i. e. 1990-2010, livestock population of the study area was found to be increasing at a rate of 21000 cattle unit/year. This significant enhancement of livestock population can also be considered as an indicator of changing farming practices of the region as livestock rearing is economically more beneficial to the farmers than the traditional agro-practices. Furthermore, reduction in the number of cultivators were also noted during 1990-2010 over the study area, annual rate of reduction of cultivators was 2300, resulting decline in the farm yields. Finally, soil pH from the rice-wheat farming system of the region was also found to become more acidic than the reported values of 1973.

Weightage based relationship between yield and factors

Before establishing the weightage based relationships between yields of crops and factors, correlation coefficints between crop yields and individual factors were estimated (Table 2). The critical low yield limit for each crop was then estimated from 25th percentile values. Next, following the sign of correlation coefficient and considering 25th or 75th percentile of individual factor critical limit for a factor was estimated. Critical low yield limits and associated low (or high) limits of factors are provided in Table 3.

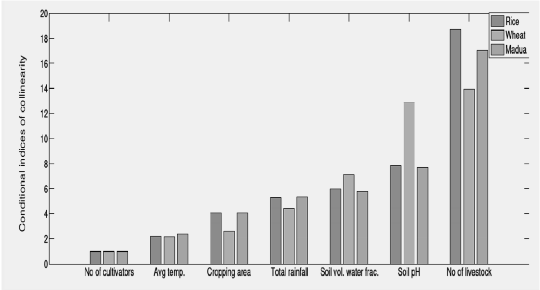

Fig. 3. Condition indices of collinearity obtained for each driver associated to each crop.

Details of the Pc value of each driver and yield are provided in Fig. 3. One can note from the figure that cropping area, number of cultivators and total rainfall were the most significant factors controlling district level yield of traditional crops. However, decreasing soil pH (Pc = 0.6) and increasing number of livestock (Pc = 0.6) were found to have significant impact on the reducing yield of wheat. Individually, the recent decrease in rice and madua productions were found to be due to significant decrease in cropping area (Pc = 0.6, 0.8), number of cultivators (Pc = 0.4, 0.4) and erratic behavior of monsoon rainfall (Pc =0.4, 0.4) indicating a substantial role of both climatic and socio-economical factors for yield reduction.

Impact of climate change on the yield of rice, wheat and madua

Before analyzing the GLM model performances, collinearity amongst different factors was estimated using (Gbur 2012) method. The condition index of

Table 3. Critical ranges of individual crops and factors. Total rainfall values are for a point location.

Crops	Yield (Mt)	J-S total rain (mm)	J-S avg temp (^{o}C)	ND total rain (mm)	ND avg temp (^{o}C)	Soil moisture fraction	Cropping area (ha)
Rice	21625	740.4	29.5	NA	NA	0.28	16088
Wheat	36932	NA	NA	3	18.4	0.21	36308
Madua	35521	740.4	29.5	NA	NA	0.28	34237

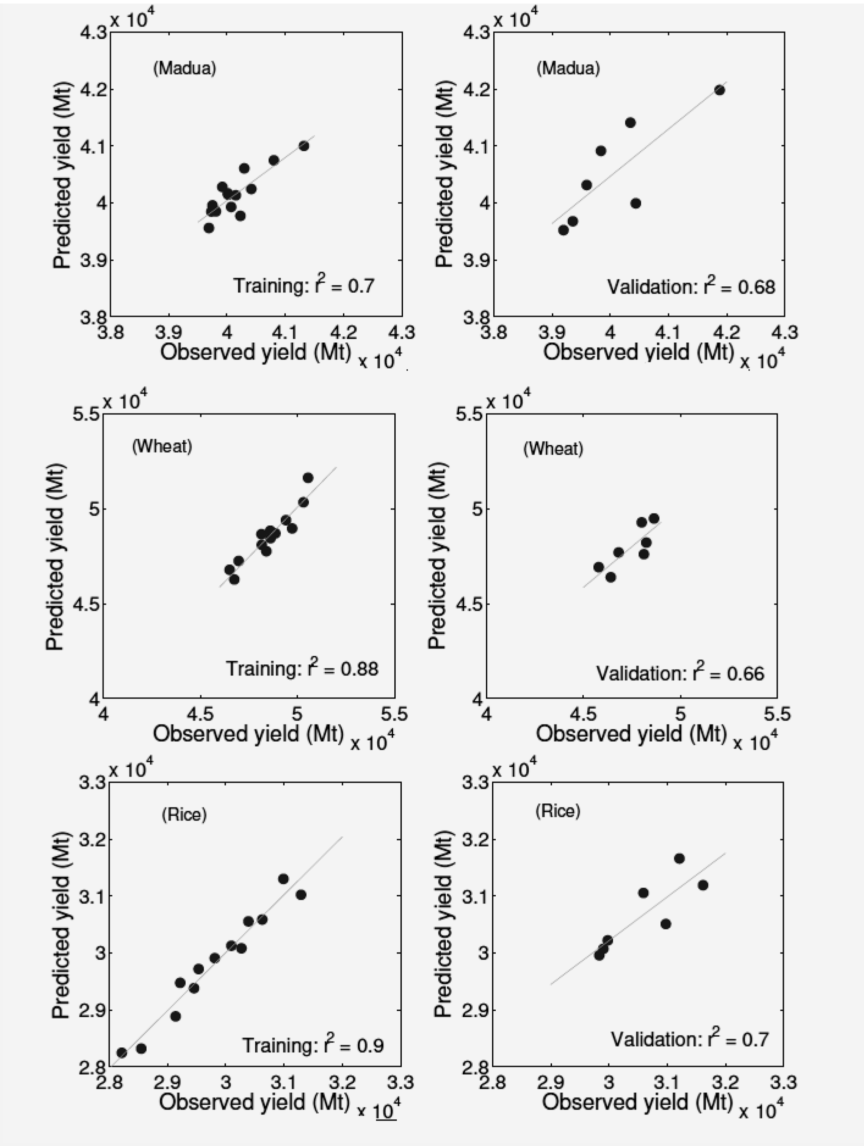

Fig. 4. Comparison of model simulated and actual yield during training and validation.

collinearity for each driver of each crop is provided in Fig. 4. Following (Gbur 2012), any condition index <10 shows weak degree of collinearity whereas, 10<condition index <30 shows moderate degree of collinearity amongst variables. It is eminent from Fig. 4, that except for moderate collinearity of No of livestock for all 3 crops and soil pH for wheat, degree of collinearity amongst other factors were negligible. Subsequently, all the factors were used to develop the GLM for future yield prediction under different climate change scenarios.

The GLM model performances during training and validation period of rice, wheat and madua yields were evaluated using statistical measure of r^2-values and rmse. The model performances during training and validation are provided in Fig. 4. The rmse values during training and validations were found to be :

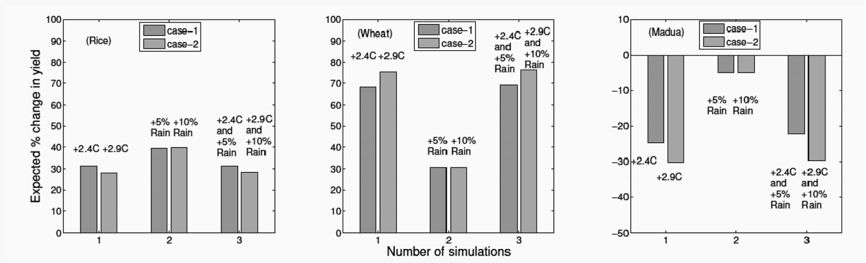

Fig. 5. Expected changes in the yield of rice, wheat and madua under different climatic conditions.

247.8 and 694.6.0 Mt for rice, 456.0 and 815.0 Mt for wheat. The same for madua were found to be : 225.0 and 675.0 Mt with r^2 values for rice wheat and madua of [0.9, 0.7], [0.88, 0.66] and [0.7, 0.68] for training and validation, respectively, inferring a satisfactory performance by the model.

Finally, impact of changing climate on the yields of rice, wheat and madua was assessed using 3 different cases and 6 simulations. Results are shown in Fig. 5. It was found that increase in both temperature and total rainfall from the baseline values of 29.1°C and 831.1 mm were expected to enhance the district level yield of rice by 30% and 40%, respectively, of the average yield between 1990-2010 values. Furthermore, enhancement only of average temperature was found to significantly increase yield of both rice and wheat by 28-31% and 68-75% from the average yield values of 1990-2010, respectively. Impact of temperature rise on yield of madua was found to significantly reduce yield by 25–30% whereas rainfall enhancement up to 10% of 831.1 mm is expected to lower the madua yield by 5% with respect to average yield of 1990-2010. Subsequently, it can be inferred that under the changing climate scenario, enhancement in rainfall and temperature can accelerate yield of both rice and wheat but the same cannot be true for yield of madua.

Conclusion

The present study aimed to assess the impact of environmental and socio-economic factors on yields of 3 important hill crops from rainfed area. Available trends of the major crops indicated cropping area as well as yield of rice, wheat and madua has declined during the recent period. The values of critically low yield limits of rice, wheat and madua were identified as 21625, 36932 and 35521Mt, respectively. Weightage based relationship using conditional probability between crop yields and significant factors revealed decrease in cropping area, decline in number of cultivators and low seasonal rainfall were responsible for the reduction in farm yields. Furthermore, future yield under climate change is expected to increase for rice by 30 to 40% of the average yield of 1990-2010. Results of this simulation are found to contradict (Birthal et al. 2014) who have projected average decrease in yield of rice and wheat by 15 and 22% by 2100 with increasing temperature and rainfall for all the districts of India. The contradiction may be corroborated to the fact that a temperature rise up to 3°C at the Himalayan region may result in a better rice producing condition unlike the Gangetic and peninsular India where it may lead to heat stress (Maurya et al. 2014, Sharma 2010). This study also found enhancement in wheat production by 28-31% to 68-75% of the average yield of 1990-2010 if the temperature rises by 2.4 and 2.9 °C and rainfall increase by 5 and 10% of the baseline values (Vishvakarma et al. 2005, Yatagai et al. 2009, Yurembam et al. 2015). However, excessive rainfall and higher average temperature during maturity period of wheat in India (i.e. March and April months) are expected to reduce yield. This notion may not be reflected in the model simulated projections as only average temperature and total rainfall was considered for the growing period of wheat (i.e. October to November). Unlike rice and wheat, yield of madua is expected to decrease by 25—30% and 5% if temperature and rainfall increases, respectively. However, this is to be noted that this study is limited to only one district of central Himalaya and, much larger impact assessment of environmental and climatological change on the subsistence farming of the central Himalaya could be achieved if a similar exercise is carried out over a state level scale. Furthermore, due to constraint of long term data availability, these studies do not include some important factors like Human animal conflicts, out migrations, pest outbreak.

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