**Potential suitable habitat of *Eleusine coracana* (L) Gaertn (Finger millet) under the climate change scenarios in Nepal using Maxent model**

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**Abstract**

Finger millet is a fourth major crop species in Nepal having high diversity of land races and cultivated as traditional integrated subsistence crop. This crop has superior quality of nutrition. Mapping the current suitable habitat and predicting the potential change in the future is crucial for minimizing the loss of local landraces. Maxent model was used in this study to quantify the current suitable habitat and changes in the future habitat suitability under different climate change scenarios, based on representative concentration pathways (RCP's)(RCP 2.6, 4.5, 6.0 and 8.5) in two different time periods (2050 and 2070AD) using climatic predictive variables and species localities. The most suitable area of cultivation, area loss or gained and remaining stable for finger millet habitat was calculated. The model showed that 39.7% (58512.71km2) area of Nepal is highly suitable for finger millet cultivation, mostly from Siwalik, mid-hills and lower parts of mountains within 96-2300m asl, elevation though only 4.5% (2636km2) area of most suitable land is under cultivation at present. Similarly, eastern and central parts of Nepal have more suitable areas than western part within the elevation range of 76m to2300m. Our research clearly shows that the future climatic suitable area of finger millet would shrink by about 3.5 to 6.9% under all RCPs in 2050 and 0.4 to 7.6 % under different RCPs by 2070.

**Key words**: Climate change, finger millet, habitat, Maxent model

**Introduction**

Agriculture is the major source of economy of Nepal contributing 32% of total GDP and shape the foundation of 63% of the population. The rural population in the hilly area depends primarily on traditional subsistence rain-fed agricultural practices, which is climate dependent (Shrestha *et al*., 1999). The fourth major crop finger millet [*Eleusine coracana* (L.) Geartn , family: Poaceae] occupies an important place in the Nepalese agriculture especially in mountainous remote areas(MOAC, 2017). It is considered as an under-exploited, poor people's and neglected crop and cultivated mostly in mid-hills and mountainous regions (Ghimire, 2015, Luitel *et al*., 2017).Though the nutritional value of finger millet is very high, it is generally considered as an inferior food grain as compared to other common food crops like rice, wheat and even maize .

Total cultivation area of finger millet was 265,496ha in 2007 and 263,596 ha in 2017.The national production of finger millet was 291,098t in 2007 and increased to 306,704 t in 2017 (MOAC, 2017). The increase in production of this crop could not fulfill the national demand so it is being imported from neighboring countries. The import of finger millet was 1217t in 2017 (MOAC, 2017). It seems that the national demand is continuously increasing even though the national yield is abruptly soaring. But the area of production has decreased in the past 10 years.

The future projections based on four representative concentration pathways (RCPs) (2.6, 4.5, 6.0 and 8.5) show that the earth atmosphere will gain 2.6-3.8 oC temperature by 2100. In Nepal, the mean annual temperature is projected to increase by 1.40C by 2030, 2.80C by 2060 and 4.70C by 2090. Based on the Regional Circulation Model (ReCM), the total precipitation and its intensity may increase by 15-20% during the summer (NCVST, 2009). The total precipitation is projected to increase by 6% and 12% by 2050 and 2080s, respectively (MoSTE, 2014), however precipitation projection from observed historical trends show decrease in post monsoon rainfall (Hijioka *et al.,* 2014), with more erratic, heavy and unpredictable rain with in shorter period potentially leading to extreme drought (Shrestha *et al.,* 2000).Similarly annual precipitation of Nepal is increasing by 13mm and days of rainfall are decreasing by 0.8 days per year (Manandhar *et al*., 2011).These changing patterns of climatic variables are expected to severely affect the crop production, livelihood and food security in Nepal (Sujakhu *et al*., 2016)

The species distribution modelling (SDM) is one of the simple and quick tools for identifying the climatic covering and projections of climatic impacts on species and can be used to match adaptation policies and practices. Understanding exact suitable area of crop and prediction of suitable area is essential to know for further expansion or shrinkage of cultivation area that may open new avenue to rescue of neglected local landraces. In Nepal, study of climatic variables on modeling for habitat suitability of minor crop species is virtually absent. This work not only fulfills the gap but also opens new avenue to analyze the habitat of crop species in response to different environmental variables and predict the habitat suitability by using the machine learning software Maxent.

**Materials and Methods**

**Study area**

Nepal, having an area of 147,181 km2 lies on the southern slope of the Central Himalayas. It has wide range of variation in physiographic, topographic, climatic and edaphic conditions, and has tropical to tundra climatic conditions within a narrow band of 185 km north-south. Rice, wheat, maize, finger millet and buckwheat are the major cereal crops of Nepal. The diversity of finger millet (*Eleusine* sp.) is quite high indicating that Nepal is one of the centers of origin (Paudel *et al*., 2016) but a number of local landraces are either getting lost or at verge of extinction.

**Crop species and location points**

Finger millet (*Eleausine coracana),* was selected for modeling and its habitat suitability under climatic change scenarios. A total of 352 occurrence points of finger millet were collected from the field survey from 19 districts of central Nepal. In order to reduce the sampling biases in the location data of central Nepal, the spatial filtering of occurrence points was used employing fishnet option in Arc GIS10.3, which reduced the presence points to 101 for better performance of the model (Borai et al. 2014). Additional 53 points were collected from the database of National Agriculture Genetic Resource Centre (NAGRC) and 250 points were collected from geo-referencing, principally based on the records of NAGRC that included spatial location names without geological coordinates. Thus, total of 404 presence points of finger millet were employed in Maxent model.

**Bioclimatic variables**

For current and future time periods (2050 and 2070 AD), all nineteen bioclimatic variables (bio30s) on 30-arc-sec resolution at ESRI grids format were downloaded from worldclim data set (Hijamans *et al.*, 2005). The Community Climate System Model (CCSM4) (Gent et al., 2011) was followed under Representative Carbon Pathway of RCP 2.6, RCP4.5, RCP 6.0and RCP 8.5for future (year 2050 and 2070) because CCSM4 is mostly used in South-Asian region for modeling. These data were statistically downscaled from Global Circulation Model (GCM) using worldclim 1.4 at present baseline climate. The altitude, slope and aspect were derived from the digital elevation data based on Shuttle Radar Topographic Mission (SRTM) at 90m spatial resolution and were re-sampled to 30s spatial resolution to match with the resolution of climatic variables. The raster data from the global scale was masked for Nepal. All RCPs (RCP's 2.6, 4.5, 6.0 and 8.5) greenhouse concentration trajectories for two different time periods (2050 and 2070) were selected to determine the future habitat suitability of species under different climatic scenarios. The lowest greenhouse concentration (GHG) pathway is RCPs 2.6(aggressive mitigation / lowest emissions), RCPs 4.5 and RCPs 6.0 are intermediate and RCPs 8.5 (highest emission scenario) is maximum. GHG concentration pathways in which radioactive forcing (global energy imbalance) stabilizes 2.6 W/m2, 4.5 W/m2, 6.0 W/m2 and 8.5 W/m2, respectively by 2100 (Clarke *et al.,* 2007, Fujino *et al.*, 2006).

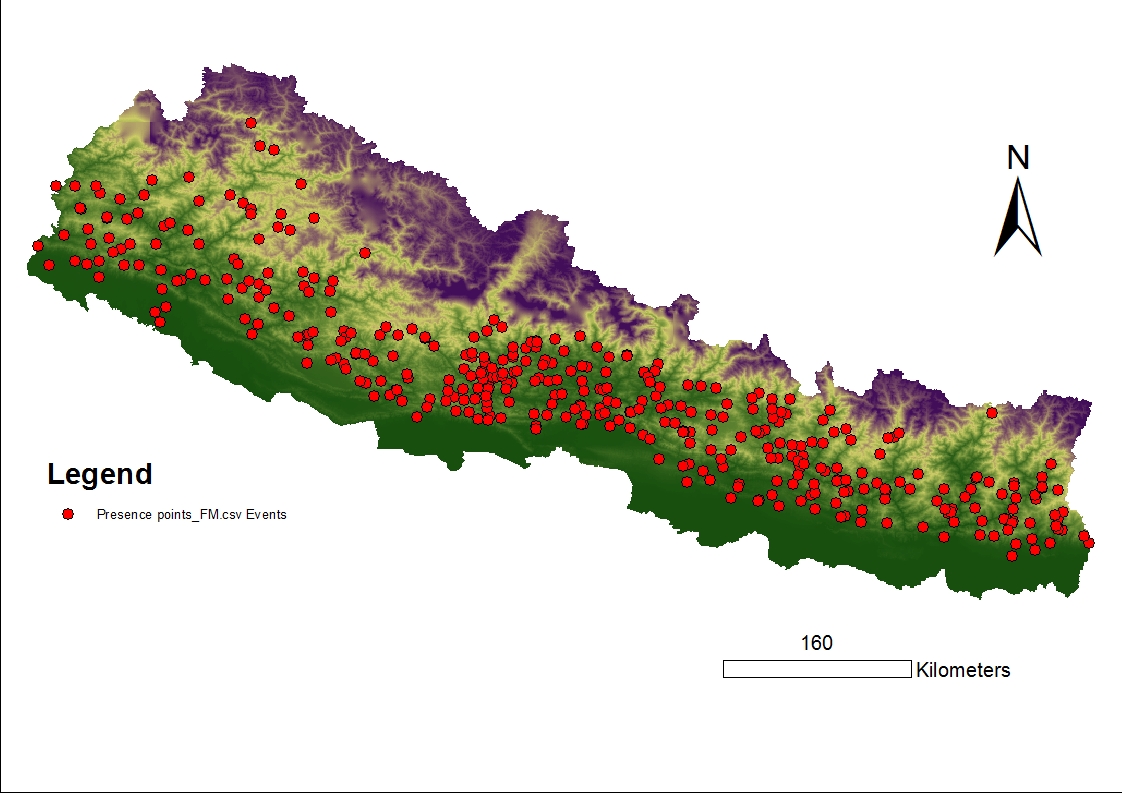


Figure 1: Study area showing the presence points used in modeling of finger millet in Nepal.

Pair wise correlation and Variation Inflation Factors (VIFs) were performed by using program R (R core team, 2018) to test the multi co-linearity test among the environmental variables and omitted highly correlated bio-variables with a Pearson correlation (r.≤±0.80) and VIF>5 in order to reduce the effect of multico-linearity among the variables, which enables over fitting of the model (Rogerson, 2001; Shrestha *et al.,* 2018).

The remaining nine variables viz. aspect, slope, mean diurnal range (mean of monthly{max temp-min temp}), isothermality (Bio\_2/Bio\_7) (\* 100),temperature seasonality(standard deviation \*100), mean temperature of driest quarter, annual precipitation, precipitation of coldest quarter and soilwere used to model the habitat suitability of finger millet in current and future climatic condition. All the bioclimatic data sets were converted into ASCII files in Arc GIS 10.3 to make the acceptable format for Maxent software. The same process was repeated to produce the projected maps in all future scenarios forthe year 2050 and 2070 considering the soil condition to remain constant in the future under RCP2.6, RCP4.5, RCP6.0 and RCP8.5.

**Modeling by Maxent**

Freely available Maxent software (Maxent 3.4.1) was used to quantify (model) the current and future habitat suitability of finger millet cultivation area in Nepal. Maxent is a machine learning method that estimates the probability distribution of a species occurrence based on environmental conditions of a location in which the species is found by calculating the distribution of maximum entropy i.e. the most spread out distribution in space for a given set of constraints (Philips *et al.,* 2006). In this study, the Maxent software was modeled by applying the following parameters- 25% random test percentage, ie, 75% of presence points data were used for training and the remaining 25% to test the predictive ability of Maxent model, 1 regularization multiplier, 10,000 maximum numbers of background points, 10 replicates, subsample replicate type, 5000 maximum iterations, 0.00001 convergence thresholds. The file format was set for logistic output, which provides predicted probabilities in between 0 and 1. Write background prediction was set in environment setting of the model.

**Model validation**

The Area Under Receiver-operating Characteristic Curve (AUC), Kohan's Kappa and true skill statistic (TSS) were used for model evaluation (Allouche *et al.,* 2006).

The presence data set was divided 75 percent into training data, which were used to build a model and remaining 25 percent for test data was used to test the model performance (Death and Fabricius, 2000). The values of AUC range from 0.5 to 1.0, with 0.5indicating no (random) fit to the data, 1.0 indicating perfect model performance, 0.7–0.79, reasonable; 0.8–0.89, excellent; and values >0.9 indicating high performance (Pearce and Ferrier, 2000). The TSS account for both sensitivity and specificity and its values lies within +1 to -1, where +1 indicates the perfect model performance(Allouche *et al.,* 2006).To assess the importance of used variables to the model, Jackknife procedure was used.

The final potential distribution map with values 0 to1 were grouped in to two classes viz.0.00 to 0.5 and 0.5-1.0. We considered pixels with or more than 0.50value to consider areas that depict at least 50% probability of species cultivation suitability (Thapa *et al*., 2018).The stability gain and loss of predicted suitable area was calculated for future in each RCP scenario through Arc GIS 10.3. To calculate stability, gain and loss on predicted area the final output map of Maxent was binarized (ie presence /absence) by using lowest value of 10 percentile training presence Logistic threshold of Maxent results. The stable, gain and loss of suitable area map was determined by using intersect and symmetrical analysis tools in Arc GIS 10.3.

**Results**

**Contribution of predictor variables and model accuracy**

From the Jackknife analysis, among the nine bioclimatic variables used for the modeling Altitude (nalt), annual rainfall (nbio12), slope of the region (nslope) and soil (nsotar) together contributed about 93% in predicting the suitable habitat of finger millet (Figure 2). Altitude (nalt) had the highest contribution (33.8%) followed by annual rainfall (nbio12) with 32.4% contribution to the model. The mean temperature of driest quater (nbio9), aspect (naspect), mean diurnal range(nbio2), and temperature seasonality(nbio4) variables showed least contributions but he isothermality (nbio3) showed no contribution. (Figure 2).

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| H:\DRL_hard\Finaloutput\fingermillet\current\plots\Finger_millet_9_jacknife.png | |  |  | | --- | --- | | **Variable** | **% Contribution** | | nalt | 33.8 | | nbio12 | 32.4 | | nslope | 14.3 | | nsotar | 12.4 | | naspect | 2.7 | | nbio19 | 2.2 | | nbio2 | 1.7 | | nbio9 | 0.2 | | nbio4 | 0.2 | | nbio3 | 0 | |
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Figure 2: The results of the Jackknife test of variables’ contribution in modelling finger millet habitat suitability. (The regularized training gain describes how much better the Maxent distribution fits the presence data compared to a uniform distribution. The dark blue bars indicate that the gain from using each variable in isolation, the light blue bars indicate the gain lost by removing the single variable from the full model, and the red bar indicates the gain using all of the variables. The individual variables contribution in percentages is presented in right-side table within the figure.

Overall accuracy was high (>0.80, which refers to 80% accuracy) for predictions under present and future time periods by AUC. The model performances evaluated by difference statistic score/matrices are give in Table 1.The validity of the model for current habitat suitability of finger millet was excellent with AUC=0.832 indicating that the variables used in modeling described well to determine the habitat suitability of finger millet in Nepal. The AUC, prediction accuracy of the model used for analyzing the distribution under present and future time period of finger millet were ranges from 0.806 to 0.845, TSS between0.576 and 667, and the Kappa between 0.601 and 631.

Table 1: Prediction accuracy of habitat suitability in distribution modeling of Finger millet

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Model Evaluator** | **Current** | **RCP2.6\_ 2050** | **RCP 2.6 \_ 2070** | **RCP4.5 \_2050** | **RCP4.5 \_2070** | **RCP6.0\_ 2050** | **RCP6.0\_ 2070** | **RCP8.5\_ 2050** | **RCP8.5\_ 2070** |
| **AUC** | **0.832** | **0.833** | **0.841** | **0.845** | **0.841** | **0.838** | **0.838** | **0.806** | **0.838** |
| **Sensitivity** | 0.866 | 0.868 | 0.865 | 0.852 | 0.904 | 0.852 | 0.847 | 0.863 | 0.863 |
| **Specificity** | 0.712 | 0.799 | 0.704 | 0.773 | 0.741 | 0.758 | 0.7150 | 0721 | 0.742 |
| **TSS** | 0.576 | 0.667 | 0.617 | 0.626 | 0.645 | 0.610 | 0.608 | 0.584 | 0.605 |
| **Error rate** | 0.379 | 0.391 | 0.386 | 0.357 | 0.341 | 0.382 | 0.376 | 0.382 | 0.372 |
| **Kohan's Kappa** | 0.621 | 0.607 | 0.606 | 0.631 | 0.601 | 0.616 | 0.622 | 0.616 | 0.626 |

**Distribution of Suitable habitat**

Under present climatic scenarios, the overall distribution of most suitable habitat of finger millet lies between 500-1500m elevation above the sea level (asl) although it occurs between the elevation range of distribution predicted to 96-2300m asl ( Figure3 A and Table 3).At present scenario total suitable habitat for finger millet cultivation was 39.7% (58512.71 Km2) (Table-2). Physiographically, the predicted potential habitat suitability suggested that the most suitable area for finger millet are the Siwalik, mid-hill and lower part of mountain region of Nepal (Figure3A). Similarly, central and eastern part of the country showed more suitable than the western parts.

**Future distribution suitability scenarios (Stable, loss and gain area)**

The current and future potential distribution of finger millet suitable area is presented in Figure3. In the future distribution projections the stable, gain and loss area are presented in solar yellow, green and red colour respectively in each figure and the amount of stability, gain and loss is well presented with bar diagram on top right corners of each figures(Figure 3 B-I).

By undertaking visual inspection of the model prediction based on current climatic condition and occurrence records, it is clear that the western part of country is comparatively less suitable than eastern and central parts. The future distribution was predicted to shift habitat slightly north-east but reduces the total suitable area in the year 2050 and 2070 as compared to the current situation (Figure-3).

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| --- | --- |
| Current | H:\DRL_hard\Finaloutput\fingermillet\reclass\current\suitable current.jpg  A |
| future |  |
| Future |  |

Figure 3: Predicted habitat suitability of finger millet in Nepal (A=current, B-I=future). Future scenarios showed changes in habitat suitability of finger millet crop in Nepal in different RCP's (Red regions represent the area loss, green-gain area and yellow stable areas with respect to current situations.

Our analysis showed that by 2050 there will be decrease in suitable habitat (stable area-yellow colour) by 3.3%, 6.5%, 4.8% and 3.8% in RCP's 2.6, 4.5, 6.0 and 8.5 respectively. The total loss area in different RCP's analysis showed by 2050 ranges from 3.9-10.3% (red colour in map) over the current suitable habitat area and 4.3-10.5% area will loss by 2070. Similarly, the suitable habitat will gain (green colour in map) by 5.6%, 3.4%, 3.8 and 4.6% in RCP's 2.6, 4.5, 6.0 and 8.5, respectively by 2050 and by 6.1%,4.1%, 2.9% and 4.1% , respectively by 2070 (Table-2, figure3 B-I)

Table 2: Habitat stable, gain and loss area of finger millet under different RCPs in 2050 and 2070, Km2 (% area of change)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Area -Km2** | **Current suitable area** | **58512.71(100)** | | |  |
| **Future scenarios** | **Stable area** | **Gain area** | **Loss area** | **Net gain or loss area** | **Sig** |
| RCP 2.6\_year 2050 | 56599.69(96.7) | 3197.33(5.6) | 5133.6(9.1) | -1936.27(3.5) | yes |
| RCP 2.6\_year 2070 | 56082.51(95.8) | 3401.74(6.1) | 2436.77(4.3) | +964.97(1.8) | yes |
| RCP 4.5\_year 2050 | 54717.76(93.5) | 1856.98(3.4) | 5671.18(10.3) | -3814.2(6.9) | yes |
| RCP 4.5\_year 2070 | 56018.34(95.7) | 2248.46(4.1) | 2511.68(4.5) | -263.22(0.4) | yes |
| RCP 6.0\_year 2050 | 55716.17(95.2) | 2120.07(3.8) | 4932.29(8.9) | -2812.22(5.1) | yes |
| RCP 6.0\_year2070 | 54436.83(93.1) | 1595.15(2.9) | 5689.2(10.5) | -4094.05(7.6) | yes |
| RCP 8.5\_year2050 | 56357.93(96.3) | 2594.41(4.6) | 2166.39(3.9) | +428.02(0.7) | yes |
| RCP 8.5\_year 2070 | 55184.56(94.3) | 2248.46(4.1) | 5590.8(10.2) | -3342.34(6.1) | yes |

**Changes in potential suitable area under climate change scenarios**

The predicted climatically suitable area for finger millet under the RCP 2.6 climate change scenario would net loss area (green) by 3.5% within but the model predicted to net gain by 1.8% under 2.6 RCP by2070. Similarly, the net suitable area for finger millet would be lost from 5.1 to 6.9% under RCP 6.0 and 4.5 by 2050 however 0.7% area would gain under extreme condition of climate ie 8.5 RCP . On the other hand net suitable area for 2070 would loss by 0.4- 7.6% under different RCPs (Table-2 Figure3 )

With climate change, the most suitable habitat for finger millet from all level of elevation will decrease with respect to the present climatic scenarios. The net suitable area of finger millet in all RCPs from Nepal would be lost in the year 2050 and 2070 except RCPs 2.6 and 8.5 for year 2050 which showed comparatively small area of gain. Physiographically, a major decrease in the suitable area of finger millet is seen in mid-hills and lower part of high mountain).

By 2050, in RCP's 2.6 the major area will shrink in far western Nepal specifically in Mahakali and Karnali zones and some area Sagarmatha and Koshi zones in east. Similarly, some area will be gained in mid-western region of Nepal (Figure-3B) and almost similar trend for 2070 in 2.6 RCPs (figure3c). In RCP's 4.5 for both 2050 and 2070 year, the major part of suitable area for finger millet will be lose in mid and far regions (green area in map) (Figure 3 D, E). In RCP's 6.0 the suitable area will shrink throughout the country especially in upper mountain and lower parts of mid-hills except some of the areas gain in eastern mid-hills(Figure 3F,G) for both 2050 and 2070 and almost similar pattern followed for RCPs 8.5 for 2050 and 2070 also (Figure3 H, I).

At present the most suitable habitat for finger millet showed a wide distribution of finger millet in between 96-2300 m asl throughout the country but more concentrated in eastern and central Nepal. However, moderate suitable (probability of suitability in between 25-50%) area range from 75-3034m. In the future, most suitable habitat will shrink from 2300m to 2151m in RCP 4.5 in year 2050 and further shrinkage to 2097m asl in RCP 8.5 in year 2050 in Nepal. Similarly, decrease in suitable habitat to 2187m to 2083m under 4.5 and 8.5 RCP in year 2070(Table-3)

Table 3: The predicted uppermost and lowermost elevation range of finger millet suitable habitat in Nepal

|  |  |  |  |
| --- | --- | --- | --- |
|  | | **Suitable elevation range** | |
| Scenarios | | Maximum altitude (m) | Minimum altitude (m) |
| Current | | 2300 | 96 |
| RCP 2.6 | Year 2050 | 2191 | 89 |
|  | Year 2070 | 2175 | 87 |
| RCP 4.5 | Year 2050 | 2151 | 97 |
|  | Year 2070 | 2187 | 96 |
| RCP6.0 | Year 2050 | 2186 | 87 |
|  | Year 2070 | 2198 | 94 |
| RCP 8.5 | Year 2050 | 2097 | 96 |
|  | Year 2070 | 2083 | 98 |

**Discussion**

The coverage of climatically suitable habitats was modeled for the first time in Nepal to delineate the potential suitable habitat of finger millet under current and future climate change scenarios.

Finger millet is considered relatively resistant to different stress conditions like high temperature, drought and salinity of soil (Saxena *et al.,* 2018). Finger millet follows photosynthetically efficient C4 pathway. Climate change projections for higher altitudes including Nepal Himalayas predicted to increase the temperature by 4.7oC (3.0-6.3oC) within 2090 AD as well as monsoon rainfall likely to increase in erratic pattern by 2090(NCVST, 2009). Our results clearly indicate that significant shrinkage of existing suitable area will occur with rising temperatures within 2050 by 3.9-10.3% and by 4.3-10.5% in 2070 however, 4.6-5.6% within 2050 and 2.9-6.1% additional suitable area will emerge by 2070 under different RCPs conditions in Nepal. No particular trends of loss and gain in future were shown by the model but net suitable area will lose for both 2050 and 2070 as compared to current situations. Climate related several factors may play role in decline of suitable area of finger millet by 2050 and 2070. These factors include mainly drought, rise in maximum temperature, increasing erratic pattern of rainfall and the shift of bioclimatic zones in different elevation in Nepal (Zomer et al. 2014). There was loss of agriculture land from Nepal during the period of 1971-2007due to climate related catastrophes like droughts, flood, hailstorm, rain, strong wing, cold wave. Around 38 percent of overall agricultural lost land was from the drought alone (IFAD, 2013). The projected suitable habitat losses mostly from mountains in western Nepal may be due to increasing drought on these regions because annual rainfall is the predictor variables with highest contribution in model performance of this study (Figure-2).

The impact of climate change on suitability of crop habitat would have mix effects. A mixed effect of climate change on crops was shown in banana and coffee in Nepal. With the change in climate, the suitable habitat of banana would increase but that of coffee would worsen (Ranjitkar, *et al.,* 2014). Nevertheless, a mixed effect has been predicted for finger millet crop from maxent model, where loss in suitable habitat in western region and some additional suitable area would be added in eastern and central parts.

The addition of suitable area for finger millet in Nepal and downward shrinkage of highest elevation from 2300m to 2080m may be because of shifting the average growing degree days (GDD) for finger millet from North to South (Grigorieva, et al.2010) as temperature is one of the main limiting factors for crop especially in temperate zones (Førland et al. 2004). GDD is a measure of the heat a plant requires to mature and yield a successful crop. The predicted average rise in temperature of about 4.7oC by 2090 (NCVST, 2009), may not fulfill the daily air temperature at higher altitude during the growing season. Similarly, projected decrease in rainfall along with sharp slopes in the mountains are another limiting factors of the suitability of finger millet crop area from western parts of the country, where average rainfall is already less than other parts.

Changes in climatic condition in future will not only effect the crop distribution but also its quality. A research conducted in USA shows that the season long high temperature stress reduces the chlorophyll index, seed number, grain yield and harvest index, however, some genotypes of finger millet show tolerance with high temperature (Opole *et al*., 2018). Therefore, climate change will have at least double impact on finger millet production -first shrinkage of suitable area climatically and second the reduction in grain yield.

Siwalik, mid-hills between the elevation 500-1500m have maximum suitable habitat for finger millet (Figure-3A). Over mid-hills in Gandaki, Lumbini, Sagarmatha zones in Nepal are the highest producer of finger millet([http://geoapps.icimod.org/agricultureatlas /atlas/index.html](http://geoapps.icimod.org/agricultureatlas%20/atlas/index.html)). The model also showed high potential area in these zones. However, from the visual estimation of model output in figure 3, the model slightly over estimated the suitable habitat in Mechi , Koshi and Narayani zones and under estimated for Karnali zone(Fig-3B-I). Nevertheless, high AUC, TSS and Kappa values suggest that the model has excellent level of accuracy. The model accuracy has been verified with the comparison of elevation under current scenarios and recorded elevation by other researcher. Kachorwa village (85 masl) of Bara district (Amgain *et al.,* 2014) to high hill area: Borounse village (3130 masl) of Humla district (Luitel, *et al*., 2017) in Nepal. From this model, the current moderate suitable (having probability in between 25-50%) climate for finger millet ranges between 75-3034m asl, though most suitable area (having probability >50%) lie in between 96-2300m.

Decrease of habitat suitability of finger millet can create further threat to livelihood of rural communities as well as risk of losing local land races of finger millet. Therefore, adaptation policies, should be formulated and implemented at national level to prioritize this important crop as one of the major staple cereal crops.

**Conclusion**

Maxent modeling for finger millet crop clearly defined the current suitable areas for the cultivation and potential suitable areas for 2050 and 2070AD. The model revealed that 39.7% (58512.71km2) area of Nepal is the most suitable habitat for finger millet, between 96-2300m elevation, though only 4.5% (2636km2) of most suitable land is under cultivation at present . Similarly, eastern and central parts of Nepal have more suitable areas than western parts. Our research clearly showed that the future climatic suitability of finger millet would shrink to about 3-10% under different RCPs from Nepal in 2070 and 2-6% additional suitable area will emerge due to changing scenarios of climatic variables, averaging 3.5 to 6.9% loss of suitable area in 2050 and 0.4 to 7.6% in 2070. The suitable habitat will decrease in the western mountain region (Karnali and Mahakali zones) as compared to other parts of the country.

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