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Ecological niche modelling for mapping *deenanath* grass (*Pennisetum pedicellatum*) distribution in India

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Abstract
Ecological niche modelling or predictive habitat distribution modelling framework for deenanath (*Pennisetum pedicellatum*) grass was analyzed using maximum entropy (MaxEnt) method. Presence points (geographical coordinates) were collected using a global positioning system during an exploration for the collection of forage germplasm in Karnataka. MaxEnt software was used for habitat modelling.The climate models generated for the present and future climates indicated that climate suitable regions are available in parts of Andhra Pradesh (Cuddapah, Kurnool, Prakasam, West Godavari), Chhattisgarh (Bastar), Goa (South Goa), Gujarat (Valsad), Karnataka (Belgaum, Chikmagalur, Dakshin Kannad, Dharwad, Hassan, Mandya, Mysore, Shimoga, Tumkur, Uttar Kannad), Maharashtra (Ahmadnagar, Kolhapur, Nashik, Pune, Raigarh, Ratnagiri, Sangli, Satara, Thane), Odisha (Ganjam) and Telangana (Khammam). Highest probability value of 0.79 to 1.00 was obtained for the above mentioned states in India for climate suitability. These states of India could be targeted for future exploration missions, selection of cultivation sites of elite germplasm based on climate suitability and for identifying *in-situ* conservation areas, and for managing other related genetic resources activities in the climate change regime. Accordingly, a contingent plan needs to be developed for sustainable cultivation and on-farm conservation of deenanath grass.

Keywords: Conservation, Cultivation, Deenanath grass, DIVA-GIS, MaxEnt

Introduction

Deenanath (*Pennisetum pedicellatum* Trin.) grass is one of the important species of the tribe Paniceae. The species is presumed to be native to tropical Africa (Schmelzer and Renno, 1997). It is wide spread in west to east Africa, south-east Asia and northern Australia (Schmelzer, 1997). In India, the species is distributed in Andhra Pradesh, Bihar, Uttar Pradesh, Chhattisgarh, Jharkhand, Karnataka, Maharashtra, Andaman and Nicobar Islands, Odisha and West Bengal (Upadhyaya *et al*., 2014). It is mainly found on disturbed land, road edges, recent fallows, and areas where annual rainfall ranges from 600 to 1500 mm with a rainy season of 4-6 months and where average day-temperatures are about 30 to 35°C. Deenanath grass (2n=2x=36, 2n=6x=54) is found on cultivated and pasture land as a high yielding grass of short duration (Zadoo *et al*., 1997). It is tolerant to salinity, though increased salinity affects crop growth (Varshney and Baijal, 1977). The species control water loss effectively and has very strong recovery ability after watering even under severe drought conditions (Noitsakis *et al*., 1994). The species does not survive well under shed condition (Roy *et al.,* 2019).

Pennisetum pedicellatum is a profusely tillering annual grass with high leaf/stem ratio and low oxalate content. It is quick growing, luscious, leafy and thin stemmed grass and grows well even on poor, eroded soils (Mukherjee *et al*., 1982). The plants are having good vigour, tall (0.6-1.0 m high), erect, culms light reddish at base, leaves about 45-60 cm long, light to dark green in colour, inflorescence big fluffy, pink in the beginning and white at maturity. It is widely used as green fodder for cattle (Skerman and Riveros, 1990; Cisse *et al*., 2002). The chemical composition of *P. pedicellatum* grass varied with the phenology (Banerjee and Mandal, 1974; Upadhyay *et al*., 1978; Jakhmola and Pathak; 1983). It had high crude protein (9.06%) and crude fat (2.55%), but low crude fibre (28.95%) contents when harvested at 60-65 days of sowing (Khan *et al*., 1995). It is maintenance type forage with less than 4 percent digestible crude protein and 50-52 percent total digestible nutrients and can be conserved as hay, if harvested at 50% flowering stage (Mahanta *et al*., 2014). It has been sown to control soil erosion and to improve the physical and chemical properties of the soil (Kumar and Jena, 1996), and recommended for reseeding/introduction in degraded grazing lands of dry areas (Shinde and Mahanta, 2020). *Pennisetum pedicellatum* was also considered as an important source for higher levels of downy mildew resistance (Singh and Navi, 2000). But rapid genetic erosion in wild habitats is a major concern in the climate change regime. In order to ensure sustainable cultivation of deenanath grass and to prevent genetic erosion in wild habitats, suitable strategies need to be evolved to safeguard the existing species. Mapping the climate suitable regions using ecological niche modelling is one such step for predicting the spatial distribution, spatial abundance, sustainable cultivation and on-farm conservation (Peterson *et al.,* 2011). Hence, to predict the potential region of distribution of the species and for locating climate suitable regions for cultivation of deenanath grass in India, we have used maximum entropy species distribution modelling approach so as to manage the genetic resources activities effectively.

Materials and Methods

Data collection: In the present study, we analyzed the potential distribution of deenanath grass using the maximum entropy (MaxEnt) niche modelling method. The geographical coordinates recorded during the exploration mission conducted in 2015 for *Pennisetum pedicellatum* in Karnataka state was used as presence points for the species (Fig 1). Twenty-four presence points (GPS coordinates) recorded from northern dry zone of Karnataka were used for the present study.

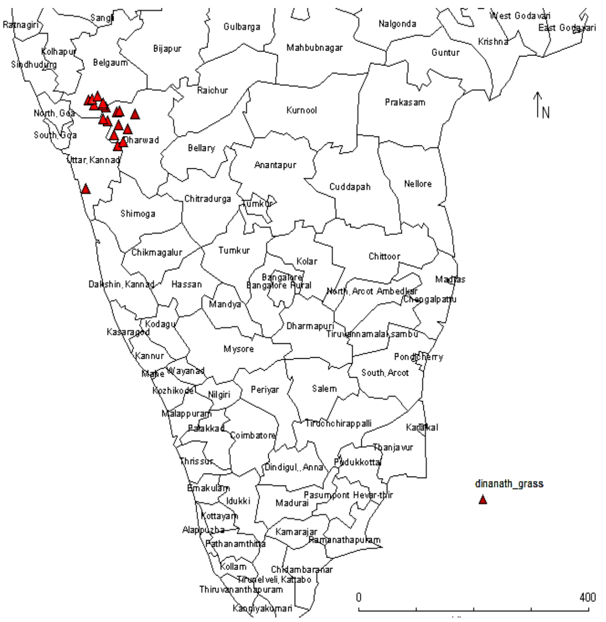


Fig 1. Presence points for deenanath grass recorded in Karnataka state, India

Agro-climatic characteristics of the study area: This zone covers an area of 4.78 million hectares covering Dharwad, Belgaum and Uttara Kannada districts. The annual rainfall ranges from 464.5 to 785.7 mm and about 52% of the annual rainfall is received during *Rabi* season. The elevation is between 450 and 900 m. The soils are shallow to deep black clay in major areas. Temperature is the lowest in the beginning of January and increases thereafter gradually at first and rapidly after the middle of February or the beginning of March in the study area. The mean annual range of temperature (difference between highest mean daily maximum temperature and the lowest mean daily minimum temperature) is greatest in this zone.

Environmental variables: Nineteen bioclimatic predictor variables (BC) were selected (Table 1) for building the ecological niche models which represent annual trends, seasonality and extreme or limiting environmental factors. Bioclimatic variables are generally selected based on species ecology (Roura-Pascual *et al*., 2009). For the current and future climate (base line) of India we used monthly data from the WorldClim (WC) database (2019), sourced from global weather stations. The variables, including annual mean temperature, mean diurnal range, maximum temperature of warmest month, minimum temperature of coldest month, annual precipitation, and precipitations of the wettest and driest months were downloaded from the WorldClim database. The WorldClim data provides interpolated global climate surfaces using latitude, longitude and elevation as independent variables and represents long term (1950-2000) monthly means of maximum, minimum, mean temperatures and total rainfall as generic 2.5 arc-min grids.

Model building: MaxEnt 3.3.3k software was used as it requires only presence records and its efficacy has been well recognized (Elith *et al*., 2006; Phillips *et al*., 2006; Phillips and Dudik, 2008).These models included the regularization multiplier (1), maximum number of iterations (500), maximum number of background points (10 000) and convergence threshold (0.00001) and 25% of the data were reserved to test the model. The outputs of ten replicates were combined to give a mean output. A logistic output for constructing the predictive models was selected as it is the easiest to comprehend, giving a value between 0 and 1 as the probability of occurrence of grass species (Phillips and Dudik, 2008). Jackknife analyses and mean area-under-curve (AUC) plots were created using MaxEnt. AUC is commonly used as a test

Table 1. Estimates of relative contributions of the environmental variables to the MaxEnt model for deenanath grass (current and future climate)

Variables	Current climate		Future climate	
	Percent contribution	Permutation importance	Percent contribution	Permutation importance
Precipitation of driest month (Bio 14)	42.9	44.3	24.4	0
Precipitation of warmest quarter (Bio 18)	13.7	0.7	5.3	0
Mean temperature of wettest quarter (Bio 8)	11.8	1	0	0
Mean temperature of warmest quarter (Bio 10)	11.2	3	0.2	0.1
Annual mean temperature (Bio 1)	6.8	0	2.9	1.9
Precipitation of coldest quarter (Bio 19)	6.5	0	13.8	0.4
Precipitation of driest quarter (Bio 17)	3.8	41.1	0.3	0.4
Mean temperature of driest quarter (Bio 9)	2.1	0	0	0
Mean diurnal range (Bio 2)	0.8	9.8	0	0
Mean temperature of coldest quarter (Bio 11)	0.3	0	52.5	96.9
Temperature annual range (Bio 7)	0.2	0.1	0.4	0
Isothermality (Bio 3)	0	0	0.2	0.3
Temperature seasonality (Bio 4)	0	0	0	0
Max temperature of warmest month (Bio 5)	0	0	0	0
Min temperature of coldest month (Bio 6)	0	0	0	0
Annual precipitation (Bio 12)	0	0	0	0
Precipitation of wettest month (Bio 13)	0	0	0	0
Precipitation seasonality (Bio15)	0	0	0	0
Precipitation of wettest quarter(Bio16)	0	0	0	0

of the overall performance of the model (Elith *et al.*, 2006) and it is also a handy indication of the usefulness of a model (Elith *et al.*, 2006; 2011). A value of 1.00 was an exact agreement with the model, while a value of 0.50 represented a random fit. Jackknife analysis indicated which variable had the greatest stimulus on the model and the overall success of the model. DIVA-GIS software version 7.5, a freely downloadable software from www.diva-gis.org was used to generate the potential distribution map with input ASCI file obtained in MaxEnt analysis (maximum entropy method).

Results and Discussion

MaxEnt analysis: Maximum entropy (MaxEnt) is a niche modelling approach that has been developed linking species distribution information built only on identified presences and is a general-purpose method for making predictions or inferences from incomplete information. MaxEnt can take the environmental conditions at occurrence locations and produce a probability distribution that can then be used to assess every other location for its likely occurrence. The result was a map of the probability of conditions being favourable to occurrence. It estimated target probability distribution of deenanath grass in India by finding the highest probability of distribution of the maximum entropy (*i.e.*, most spread out or closest to uniform with indication to a set of bioclimatic variables).

The MaxEnt model showed the potential habitat distribution of deenanath grass based on the present and future climate scenario respectively, in south India (Fig 2). Warmer colours indicated the highest probability of occurrence of *Pennisetum pedicellatum* in India. Eight states covering 28 districts (Andhra Pradesh: Cuddapah, Kurnool, Prakasam, West Godavari; Chattisgarh: Bastar; Goa: South Goa; Gujarat: Valsad; Karnataka: Belgaum, Chikmagalur, Dakshin Kannad, Dharwad, Hassan, Mandya, Mysore, Shimoga, Tumkur, Uttar Kannad; Maharashtra: Ahmadnagar, Kolhapur, Nashik, Pune, Raigarh, Ratnagiri, Sangli, Satara, Thane; Odisha: Ganjam; Telangana: Khammam), were found as the best climate suitable regions for the cultivation of deenanath grass.

The omission rate and predicted area as a function of the cumulative threshold was also recorded (Fig 3). The omission rate was calculated both on the training presence records, and (if test data were used) on the test records. Indeed, the omission rate should be close to the predicted omission, because of the definition of the cumulative threshold.

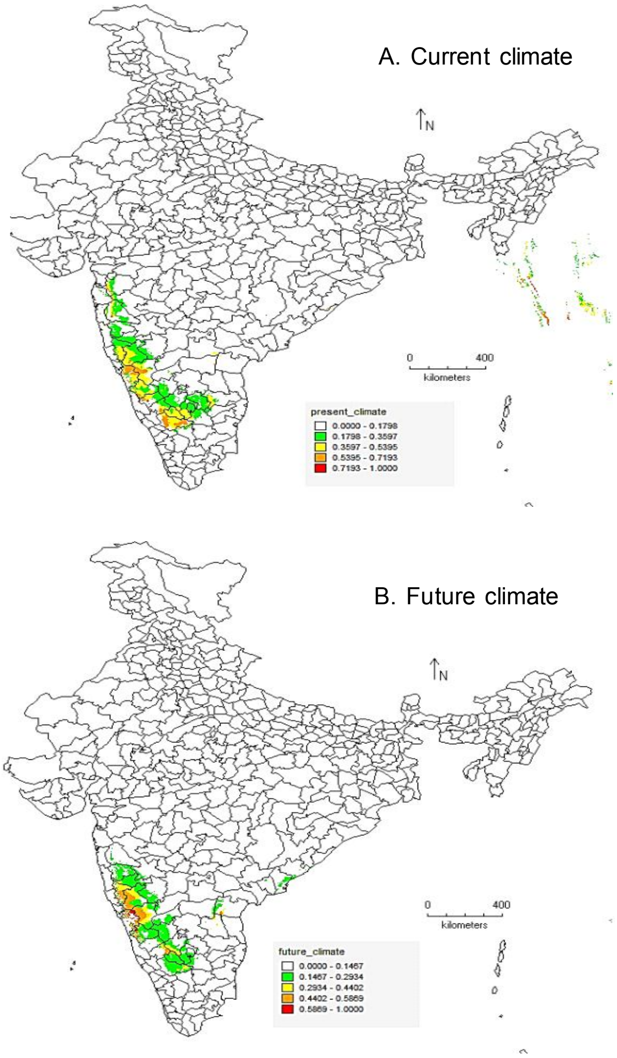
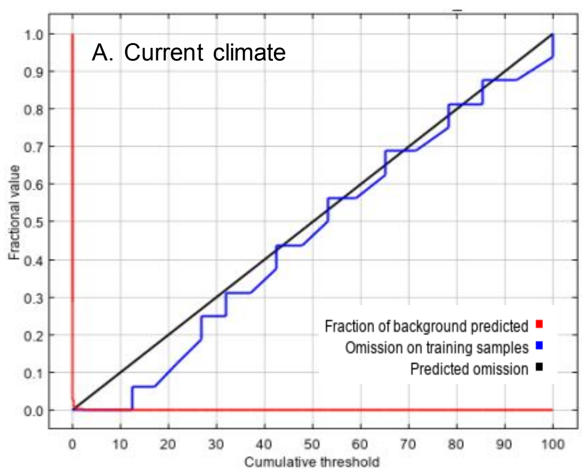


Fig 2. Map showing habitat distribution of deenanath grass in (A) current climate and (B) future climate



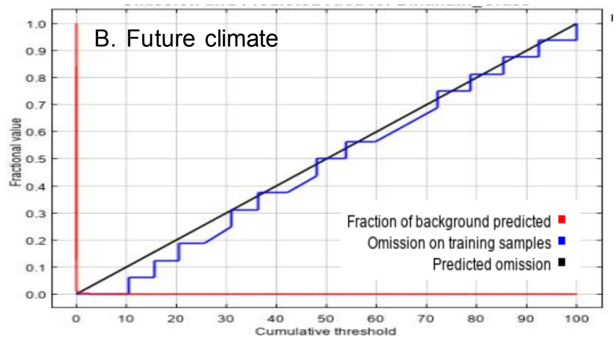


Fig 3. Omission and predicted areas depicted for deenanath grass in MaxEnt model

The estimates of relative contributions of the environmental variables to the MaxEnt model for current and future climatic scenario were worked out (Table 1). To determine the first estimate, in each iteration of the training algorithm, the increase in regularized gain was added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda was negative. For the second estimate, for each environmental variable in turn, the values of that variable on training presence and background data were randomly permuted. The model was re-evaluated on the permuted data, and the resulting drop in training AUC has been shown in the table, normalized to percentages. The regularized training gain was 6.137, training AUC was 0.999, unregularized training gain was 6.339 in case of current climate scenario, while the regularized training gain was 6.139, training AUC was 0.999, unregularized training gain was 6.354 for the future climate. As with the variable jackknife, variable contributions should also be interpreted with caution when the predictor variables are correlated. Precipitation of driest month (Bio 14), precipitation of warmest quarter (Bio 18), mean temperature of wettest quarter (Bio 8) and mean temperature of warmest quarter (Bio 10) were the top four variables contributing maximum to MaxEnt model for current climate with 42.9%, 13.7%, 11.8% and 11.2% respectively, while for future climate model, mean temperature of coldest quarter (Bio 11), precipitation of driest month (Bio 14), precipitation of coldest quarter (Bio 19) were the major contributors with 52.5%, 24.4% and 13.8% respectively (Table 1). Interestingly, in both the models the following bioclimatic variables *viz*., temperature seasonality (Bio 4), maximum temperature of warmest month (Bio 5), minimum temperature of coldest month (Bio 6), annual precipitation (Bio 12), precipitation of wettest month (Bio 13), precipitation seasonality (bio15) and precipitation of wettest quarter (Bio16) had no contribution.

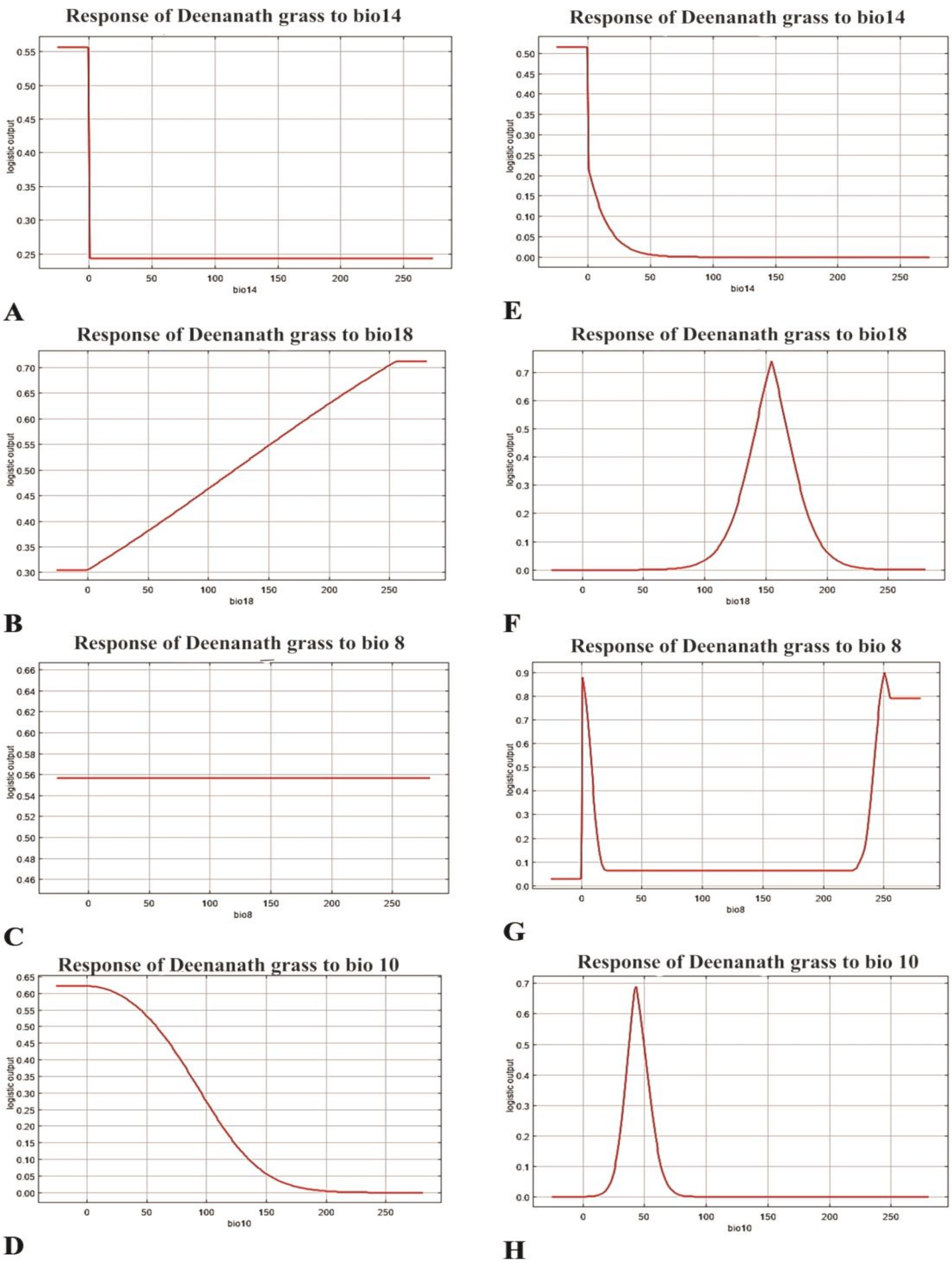


Fig 4. Response curves for bioclimatic variables having high influence on the MaxEnt model for current climate (A, B, C, D) and dependencies induced by correlations (E, F, G, H)

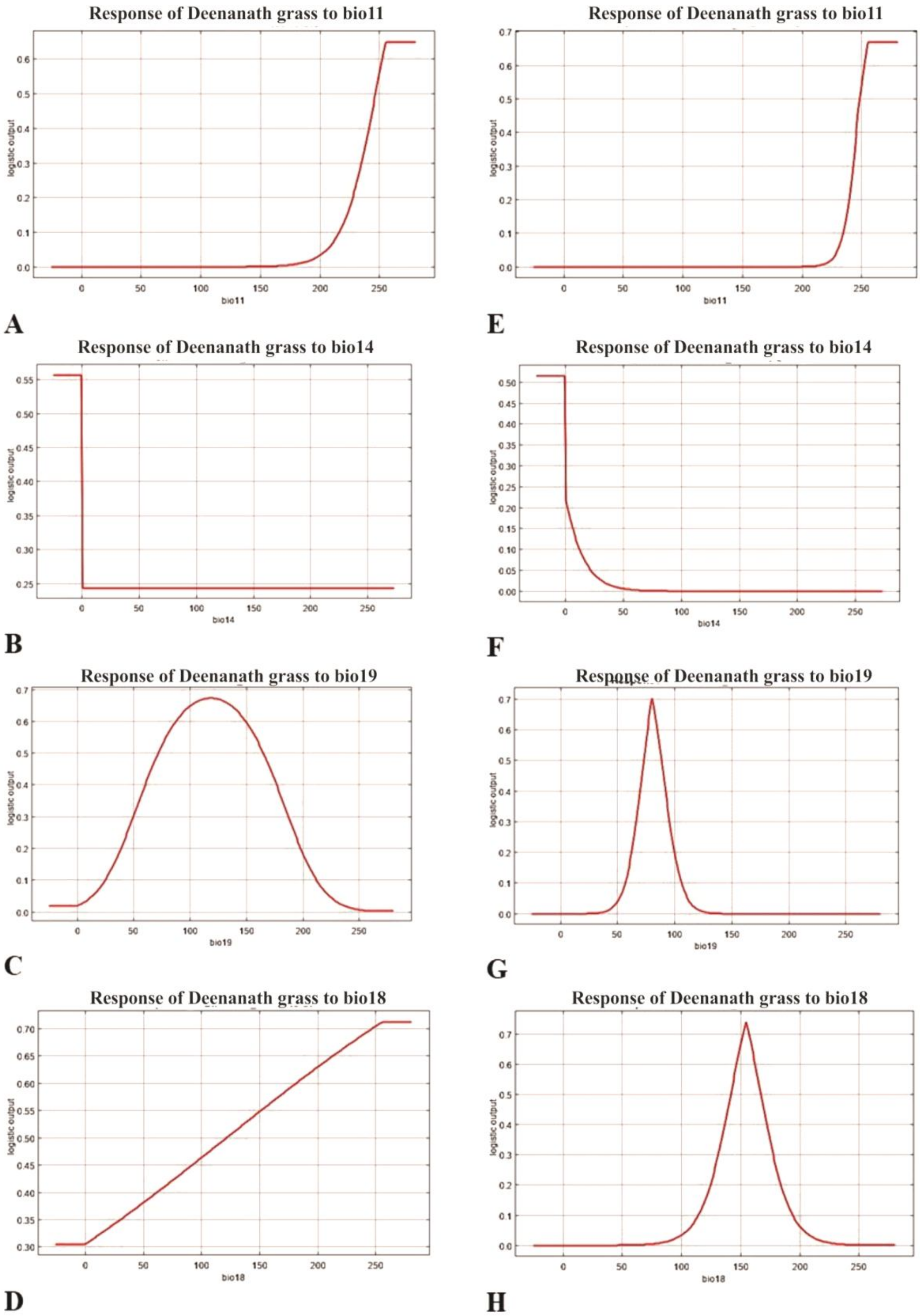


Fig 5. Response curves for bioclimatic variables having high influence on the MaxEnt model for future climate (A,B,C,D) and dependencies induced by correlations (E, F, G, H)

Response curves: The response curves showed that how each environmental variable affected the MaxEnt prediction for current climate model influenced by environmental variables of Bio14, Bio18, Bio8 and Bio10 (Fig 4: A, B, C, D). The curves showed how the predicted probability of presence changed as each environmental variable were varied, keeping all other environmental variables at their average sample value. The response curves showed the marginal effect of changing exactly one variable, whereas the model might take advantage of sets of variables changing together. In contrast to the above marginal response curves, the other curves (Fig 4: E, F, G, H) represented a different model, namely, a MaxEnt model created using only the corresponding variable. These plots reflected the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables. Similarly, Fig: 5 (A, B, C, D) represented the response curves for high influence bioclimatic variables (Bio11, Bio14, Bio19 and Bio18) for future climate prediction model and Fig: 5 (E, F, G, H) presented the dependence of predicted suitability for future climatic model.

In fact, maximum entropy (MaxEnt) is considered as the most accurate model performing extremely well in predicting occurrences in relation to other common approaches (Elith *et al*., 2006; Hijmans and Graham, 2006), especially with incomplete information. MaxEnt is a niche modelling method that has been developed involving species distribution information based only on known presences. MaxEnt modelling method was selected to model potential current and future climate suitability for cultivation of deenanath grass in the present study. MaxEnt was successfully used by many researchers earlier to predict distributions such as stony corals (Tittensor *et al*., 2009), green bottle blue fly (Williams *et al*., 2014), macrofungi (Wollan *et al*., 2008), seaweeds (Verbruggen *et al*., 2009), forests (Carnaval and Moritz, 2008), rare plants (Williams *et al*., 2009) and many other species (Elith *et al*., 2006). Several articles describe its use in ecological modelling and explain the various parameters and measures involved (Phillips *et al*., 2004, 2006; Elith *et al*., 2011). Reddy *et al*. (2015a-b) presented a novel approach to assess the potential areas for extending the cultivation of Roselle and Ceylon spinach using MaxEnt with regional level occurrence data.

Conclusion

From the above study it was concluded that the identified districts (28) from different states (Andhra Pradesh, Chhattisgarh, Goa, Gujarat, Karnataka, Maharashtra, Odisha and Telangana) of India could be targeted for future exploration missions, selection of cultivation sites of elite deenanath grass germplasm based on climate suitability and for identifying *in-situ* conservation areas, and for managing other related activities of genetic resource management.

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References

Banerjee, G. C. and L. Mandal.1974. Nutritive value of *Pennisetum pedicellatum* grass for adult sheep. *Indian Veterinary Journal* 51: 620-625.

Carnaval, A .C. and C. Moritz. 2008. Historical climate modelling predicts patterns of current biodiversity in the Brazilian Atlantic forest. *Journal of Biogeography* 35: 1187-1201.

Cisse, M., I. Ly, A. J. Nianogo, I. Sane, J. G. Sawadogo, M. N. Diaye, C. Awad and Y. Fall. 2002. Grazing behavior and milk yield of Senegalese Sahel goat. *Small Ruminant Research* 43: 85-95.

Elith, J., C.H. Graham and R. P. Anderson. 2006. Novel methods improve prediction of species distributions from occurrence data. *Ecography* 29: 129-151.

Elith, J., S. J. Phillips, T. Hastie, M. Dudik, Y. E. Chee and C. J.Yates. 2011. A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions* 17: 43-57.

Hijmans, R J. and C. H. Graham. 2006. The ability of climate envelope models to predict the effect of climate change on species distributions. *Global Change Biology* 12: 2272-2281.

Jakhmola, R. C. and N. N. Pathak.1983. Chemical composition and nutritive value of dinanath grass for sheep. *Indian Journal of Animal Sciences* 53: 94-95.

Khan, A.K. F., M. Paramathma, A. Amirthadevarathinam, N. Sivasamy, D. Sudhakar andS.C. Bose.1995. Deenanath Co-1: a new annual fodder grass for Tamil Nadu. *Madras Agricultural Journal* 82: 510-511.

Kumar, U. and S. C. Jena. 1996. Trial of integrated biotechnical approach in biological reclamation of coal mine spoil dumps in South-Eastern Coalfields Limited (SECL), Bilaspur (Madhya Pradesh). *Indian Forester* 122: 1085-1091.

Mahanta, S. K., K. K. Singh, M. M. Das and A. K. Misra. 2014. Nutritional profile of improved fodder varieties for livestock feeding. ICAR-Indian Grassland and Fodder Research Institute, Jhansi, India. pp. 1-26.

Mukherjee, A.K., M. A. Roquib., S. K. Bandopadhyay and B. B. Mandal. 1982. Review of research on deenanath grass (*Pennisetum pedicellatum* Trin.). *Forage Research* 8: 11-17.

Noitsakis, B., A. Nastis, Z. Koukoura, N. P. Zervas and Hatziminaoglou. 1994. The optimal exploitation of marginal Mediterranean areas by extensive ruminant production systems. *EAAP Publication No. 83. In: Proceedings of an International Symposium Organized by HSAP, EAAP and CIHEAM* (June 18-20, 1994). Thessaloniki, Greece. pp. 217-220.

Peterson, A.T., J. Soberón and R.G. Pearson. 2011. *Ecological niches and geographic distributions*. Princeton University Press, Princeton, New Jersey.

Philips S J. and M. Dudik. 2008. Modelling of species distributions with MaxEnt: new extensions and a comprehensive evaluation. *Ecography* 31: 161-175.

Phillips, S. J., M. Dudik and R. E. Schapire. 2004. A maximum entropy approach to species distribution modelling. In: *Proceedings of the Twenty-First International Conference on Machine Learning*. Banff, Canada. pp. 655-662.

Phillips, S. J., R. P. Anderson and R.E. Schapire. 2006. Maximum entropy modelling of species geographic distributions. *Ecological Modelling* 190: 231-259.

Reddy, M. T., B. Hameedunnisa, S. Neelam, Someswara Rao Pandravada and N. Sivaraj. 2015a. Assessing climate suitability for sustainable vegetable roselle (*Hibiscus sabdariffa* var. sabdariffa L.) cultivation in India using MaxEnt model. *Agricultural and Biological Sciences Journal* 1: 62-70.

Reddy, M. T., H. Begum, N. Sunil, P. S. Rao, N. Sivaraj and S. Kumar. 2015b. Mapping the climate suitability using MaxEnt modelling approach for ceylon spinach (*Basella alba* L.) cultivation in India. *The Journal of Agricultural Sciences* 10: 87-97.

Roura-Pascual N., L. Brotons, A.T. Peterson and W. Thuiller. 2009. Consensual predictions of potential distributional areas for invasive species: a case study of Argentine ants in the Iberian Peninsula. *Biological Invasions.* DOI 10.1007/s10530-008-9313-3.

Roy, A. K., D.R. Malaviya and P. Kaushal. 2019. Genetic improvement of dominant tropical Indian range grasses. *Range Management and Agroforestry* 40:1-25.

Schmelzer, G. and J. Renno. 1997. Genetic variation in the agamic species complex of *Pennisetum* section *Brevivalvula* (*Poaceae*) from West Africa: ploidy levels and isozyme polymorphism. *Euphytica* 96: 23-29.

Schmelzer, G. H. 1997. Review of *Pennisetum* section *Brevivalvula* (Poaceae). *Euphytica* 97: 1-20.

Shinde, A. K. and S. K. Mahanta. 2020. Nutrition of small ruminants on grazing lands in dry zones of India. *Range Management and Agroforestry* 41: 1-14.

Singh, S. D. and S. S. Navi. 2000. Genetic resistance to pearl millet downy mildew II. Resistance in wild relatives. *Journal of Mycology and Plant Pathology* 30: 167-171.

Skerman, P. J. and F. Riveros. 1990. *Tropical Grasses*. FAO Plant Protection Series 23. FAO, Rome, Italy.

Tittensor, D. P., A. R. Baco, P. E. Brewin, M. R. Clark, M. Consalvey, J. Hall-Spencer, A.A. Rowden,T. Schlacher, K. I. Stocks and A.D. Rogers. 2009. Predicting global habitat suitability for stony corals on seamounts. *Journal of Biogeography* 36: 1111-1128.

Upadhyay, V.S., A. P. Singh and A. Rekib. 1978. Studies on nutritive value of *Pennisetum pedicellatum* Trin. at flowering stage. *Forage Research* 4: 191-194.

Upadhyaya, H. D., K. N. Reddy, S. Singh, M. Irshad Ahmed, V. Kumar and S. Ramachandran. 2014. Geographical gaps and diversity in deenanath grass (*Pennisetum pedicellatum* Trin.) germplasm conserved at the ICRISAT Genebank. *Indian Journal of Plant Genetic Resources* 27: 93-101.

Varshney, K. A. and B. D. Baijal. 1977. Note on the influence of salinity on early seedling growth of some pasture grasses. *Indian Journal of Agricultural Research* 11: 59-61.

Verbruggen, H., L. Tyberghein, K. Pauly, C. Vlaeminck, K. Van Nieuwenhuyze, W. Kooistra, F. Leliaert and O. De Clerck. 2009. Macroecology meets macroevolution: evolutionary niche dynamics in the seaweed Halimeda. *Global Ecology Biogeography* 18: 393-405.

Williams, J. N., C. W. Seo, J. Thorne, J. K. Nelson, S. Erwin, J. M. O'Brien and M.W. Schwartz. 2009. Using species distribution models to predict new occurrences for rare plants. *Diversity and Distributions* 15: 565-576.

Williams, K.A., C.S. Richards and M.H. Villet. 2014. Predicting the geographic distribution of *Lucilia sericata* and *Lucilia cuprina* (Diptera: *Calliphoridae*) in South Africa. *African Invertebrates* 55: 157-170.

Wollan, A. K., V. Bakkestuen, H. Kauserud, G. Gulden and R. Halvorsen. 2008. Modelling and predicting fungal distribution patterns using herbarium data. *Journal of Biogeography* 35: 2298-2310.

Worldclim. 2019. Global climate layers- 1km resolution grids of climate and derived bioclimate datasets: http://www.worldclim.org (accessed on Jan. 20, 2019).

Zadoo, S. N., A. K. Roy and R. N. Choubey. 1997. Cytology of a perennial octoploid cytotype of *Pennisetum pedicellatum* Trin: a new report. *Range Management and Agroforestry* 18: 35-39.