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Spatio-temporal Reconstruction of MODIS Land Surface Temperature over Samastipur district, Bihar with GLDAS using Geo-Matics

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Abstract: Present study aims to estimate LST using GLDAS monthly satellite product over Samastipur district of Bihar using Geomatics. The monthly dataset of LST products of 0.25° × 0.25° grid size for the period of 21 years from 2000 to 2020 were downloaded and monthly LST values were extracted, compared and validated with ground-based Temperature measured at MS, Pusa. Bias in extracted climatic variables was identified and was corrected using linear scaling. The spatial and temporal distribution of LST were developed using inverse distance weighted interpolation (IDW) technique of ArcGIS. The estimated LST values are in good agreement with temperature observed at MS, Pusa with correlation coefficient of 95.56%. The estimated LST was highest in June (30.75°C) and lowest in January (14.39 °C) and gradually increased to July and followed by decreasing trend from July to December.

Keywords: LST, Bias correction, ArcGIS, Spatio-temporal distribution

Land surface temperature (LST) plays a crucial role in regulating regional and global surface energy exchange and the interaction between land and the atmosphere Monitoring LST and understanding its spatio-temporal changes at various scales are essential for comprehending the response of natural ecosystems to climate change and human activities (Li et al 2013, Zeng et al 2015, Li and Wang 2019). LST has found wide applications in climate change assessments, agricultural drought monitoring, urban heat analysis, and land surface modelling Moreover, the Global Climate Observing System (GCOS) recognizes LST as an essential climate variable (ECV) due to its significant influence on Earth's climate characterization. To acquire accurate LST data across different spatial scales, remote sensing techniques offer a valuable solution. They provide extensive spatial coverage, frequent data acquisition, long-term observations, and superior performance compared to ground-based measurements (Chung et al 2020). Among remote sensing methods, thermal infrared (TIR) measurements offer higher spatial resolution and accuracy than passive microwave (MW) sensors, making TIR-based estimations the preferred choice for LST monitoring. The availability of meteorological data has some drawbacks, such as incompleteness, a small area of coverage, and sporadic missing observations. These limitations make it very difficult to study climate science and its processes in depth. On the other hand, satellite-based data provides a valuable resource in the form of extensive and long-term images capturing these variables. However, extracting meaningful information from these satellite images remains a challenging task. Considering above challenges present study is under taken to estimate LST from satellite products using GIS environment.

MATERIAL AND METHODS

Study area: Samastipur district of Bihar is spread between 25° 30" to 26° 05" N latitudes and 85° 37' 50" to 86° 23' 30" E longitude over an area of 2904 km^2, lies about 52 m above mean sea level. The district is surrounded on the north by the Bagmati River, which divides it from Darbhanga, on the west with Vaishali and parts of Muzaffarpur districts, on the south by the Ganges, and on the east by Begusarai and a few parts of Khagaria districts. The primary rivers in the area are the Burhigandak and Ganga, which provide the majority of the drainage.

Climate: The district is located in the monsoon tropical zone and has a semi-arid to subtropical climate. The temperature ranges from 6 °C in winter to 45°C in summer. The annual rainfall varies from 1100 mm to 1250 mm. The soil has a light to clay texture and suitable for growing rice, maize, wheat, pulses, oilseeds, tobacco, sugarcane, spices and vegetables. Pre-monsoon ground water levels range from 7.2 to 11.10 m bgl, whereas post-monsoon levels range from 3.2 to 6.4 m bgl.

Soil type and cropping pattern: Samastipur is located in the state's Agro-ecological zone-I, which is the North-West alluvial plains. Samastipur is well-known for its rich alluvial soil and Rabi crops. The soil is clay loam with a relatively high organic matter content, making it ideal for growing vegetables and spices. The pH of the soil ranges between 5.8 to 8.0. They have a light texture with free $CaCO_3$ levels ranging from 3 to 10%. Rice, wheat, and maize are the most important crops in this region, followed by sugarcane and potatoes.

GLDAS Noah land surface temperature data characteristics: Global Land Data Assimilation System (GLDAS) Noah land surface temperature data product (GLDAS-2.1) Noah0.25° monthly dataset was downloaded (https://daac.gsfc.nasa.gov/) from the years 2000 to 2020 (Wan Z 2006) and processed in ArcGIS for land surface temperature extraction over the study area.

Climatic variables observed at meteorological station: The climatic variables such as daily rainfall and temperature (maximum and minimum) and sunshine hour data were collected from the meteorological station (MS) of RPCAU, Pusa for the 21 years from 2000 to 2021. These daily data were processed and converted into monthly scale for validating the satellite based LST extracted from GLDAS (Phan and Kappas 2018).

Data Analysis

ArcGIS: The Environmental Systems Research Institute developed ArcGIS (V 10.7.1) software, a geographic information system (GIS) for working with maps and geographic data was used to, compile, analyse geographic data, and prepare thematic maps. The monthly land surface temperature of 21 years (2000 to 2020) were extracted from

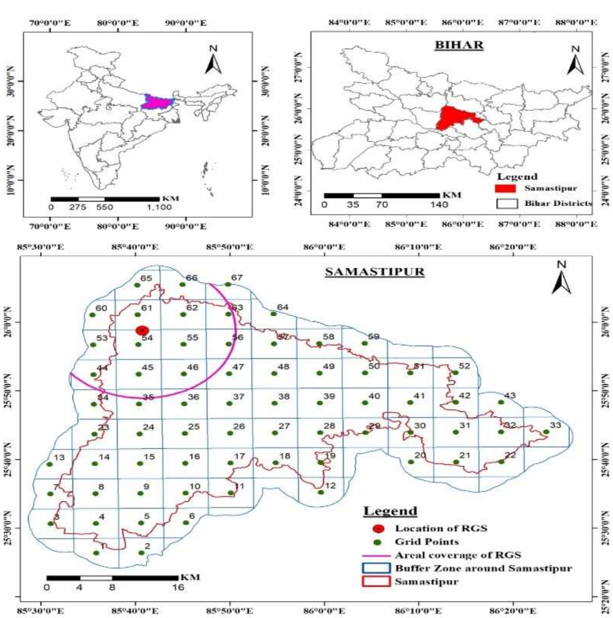


Fig. 1. Location of the study area

GLDAS 2.1 product with the help of a model developed in model builder tool of ArcGIS.

Extraction of climatic variables: Monthly GLDAS land surface temperature was extracted in ArcGIS for each grid point over the study area using a technique of which the flow chart is mentioned below (Fig. 2).

Comparison and validation using statistical approach: LST extracted from GLDAS LST 2.1 products were analysed and validated with the temperature measured at the meteorological station (MS), Pusa using statistical techniques. Various commonly used statistical measures such as Pearson correlation coefficient (PCC), mean error (ME), root mean square error (RMSE), bias (B), and percent bias (PB) were used to test the closeness between the climatic variables measured at MS, Pusa and satellite-based climatic variables. (Prasad et al 2012, Prasad and Kumar 2013, Ahmed et al 2015, Parinussa et al 2016, Bayissa et al 2017 and Singh et al 2017). Bias in extracted climatic variables was identified using statistical analysis and was corrected using linear scaling.

Spatio-temporal analysis: 21 years (2000 to 2020) monthly mean LST for all grid point over the study area were estimated and spatio temporal distribution maps were developed using inverse distance weighted interpolation technique of ArcGIS (Yang et al 2004 and Mayer et al 2016).

RESULTS AND DISCUSSION

The study region, Samastipur district of Bihar, was divided into 67 numbers of square grids of 8 km × 8 km spatial resolution using the Geographic Information System (ArcGIS) software version 10.7.1 (Fig. 2). The mean monthly land surface temperature over the study area was extracted from GLDAS LST products for each grid points created in the region using the algorithm and compared with ground base rainfall and air temperature recorded at meteorological station (MS), Pusa. Due to poor network of meteorological stations in the district, one available in the premises of Dr. Rajendra Prasad Central Agricultural University, Samastipur, Pusa was selected for comparison and validation. Following the suggestion of Subramanya, (2006) the observed and satellite-based rainfall and temperature over the selected grid points like GP-44, GP-45, GP 46, GP-47, GP-53, GP-54, GP-55, GP-56, GP-60, GP-61, GP-62, GP-63, GP-65 and GP-66 which are under the circumferential coverage of 3000 km^2 in flat area from MS, Pusa considering as center was considered for comparison and validation.

The basic statistics of air temperature recorded at MS, Pusa and land surface temperature extracted from GLDAS LST and bias corrected land surface temperature were determined (Table 1). The long term (from 2000 to 2020) mean, standard deviation (SD) and coefficient of variation (CV) of observed air temperature were 24.95ºC, 5.63ºC and 0.226 over the grid points GP-44, followed by GP-45, GP 46, GP-47, GP-53, while the mean, SD, and CV of land surface temperature extracted from GLDAS LST were observed to be 25.94 ºC, 7.03 ºC and 0.271 over the grid points.

After applying the linear scaling to land surface temperature extracted from GLDAS LST using equation Eq. 3.5, the mean, SD, and CV of bias free land surface temperature was 24.95 ºC, 5.68 ºC and 0.228 over the grid points GP-44, GP-45, GP 46, GP-47, GP-53, GP-54, GP-55, GP-56, GP-60, GP-61, GP-62, GP-63, GP-65 and GP-66 (Table 1).

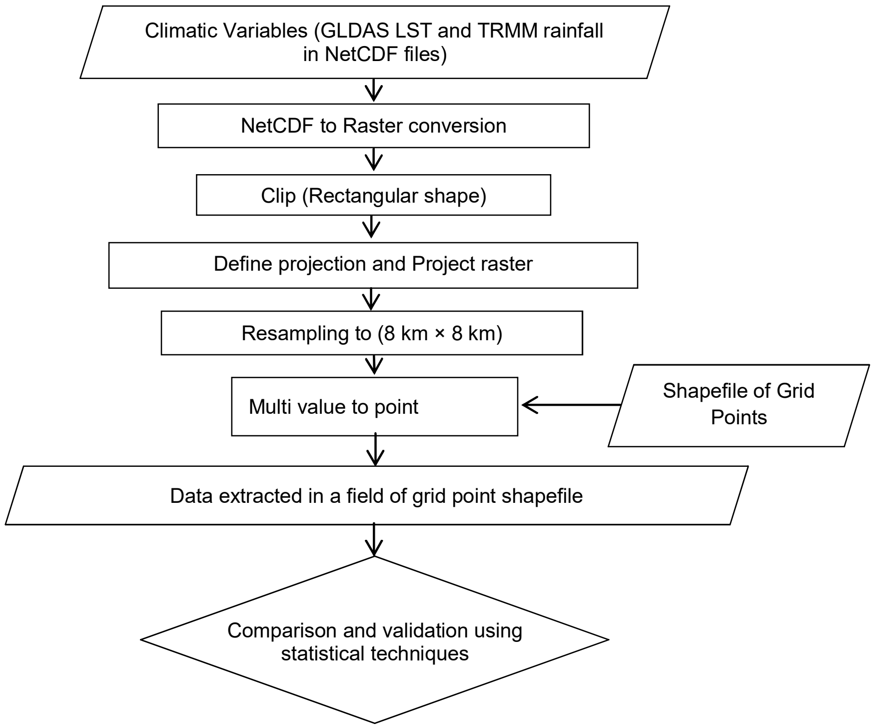


Fig. 2. Flow chart for extraction of climatic variables from satellite over the study area

Table 1. Basic statistics of observed air temperature, extracted and bias free GLDAS land surface temperature over Samastipur district of Bihar

Grid points	Observed air temperature			Extracted GLDAS LST			Bias corrected GLDAS LST		
	Mean (ºC)	SD (ºC)	CV	Mean (ºC)	SD (ºC)	CV	Mean (ºC)	SD (ºC)	CV
GP-44	24.95	5.63	0.23	25.94	7.03	0.27	24.95	5.68	0.23
GP-45	24.95	5.63	0.23	25.90	7.01	0.27	24.95	5.68	0.23
GP-46	24.95	5.63	0.23	25.86	6.97	0.27	24.95	5.68	0.23
GP-47	24.95	5.63	0.23	25.82	6.94	0.27	24.95	5.68	0.23
GP-53	24.95	5.63	0.23	25.83	7.00	0.27	24.95	5.68	0.23
GP-54	24.95	5.63	0.23	25.80	6.97	0.27	24.95	5.68	0.23
GP-55	24.95	5.63	0.23	25.76	6.94	0.27	24.95	5.68	0.23
GP-56	24.95	5.63	0.23	25.73	6.90	0.27	24.95	5.68	0.23
GP-60	24.95	5.63	0.23	25.67	7.00	0.27	24.95	5.68	0.23
GP-61	24.95	5.63	0.23	25.64	6.98	0.27	24.95	5.68	0.23
GP-62	24.95	5.63	0.23	25.61	6.94	0.27	24.95	5.68	0.23
GP-63	24.95	5.63	0.23	25.59	6.89	0.27	24.95	5.68	0.23
GP-65	24.95	5.63	0.23	25.48	6.98	0.27	24.95	5.68	0.23
GP-66	24.95	5.63	0.23	25.46	6.94	0.27	24.95	5.68	0.23

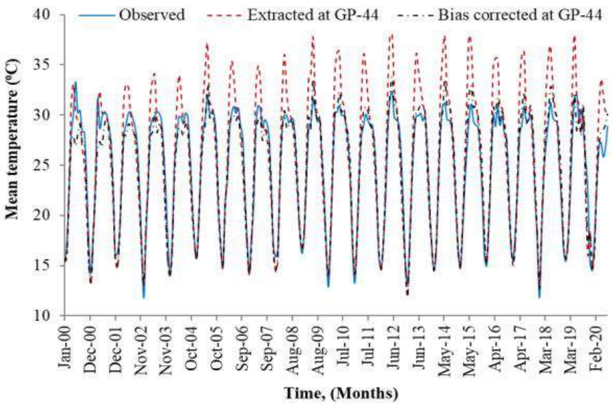
Graphical comparison: The monthly time series of mean air temperature observed at MS, Pusa, land surface temperature extracted from GLDAS LST, and bias free land surface temperature for grid points from GP-44 followed by GP-45, GP 46, GP-47 (Fig. 3). Similar patterns between observed air temperature and land surface temperature extracted from GLDAS LST were observed baring some extreme values in the figures of each grid points in the study area (Fig. 3). After applying linear scaling, extreme values of land surface temperature extracted from GLDAS LST were adjusted and overlying pattern between the near surface air temperature and the bias free land surface temperature extracted from GLDAS LST image were observed (Fig. 3). The land surface temperature extracted from the satellite for each grid points under the study area were compared with the respective air temperature measured at MS, Pusa. The root mean square error (RMSE), bias (B), Pearson correlation coefficient (PCC) and mean error (ME) between the land surface temperature extracted from the satellite and the air temperature measured at the meteorological station for each grid points under the study area were computed (Table 2).

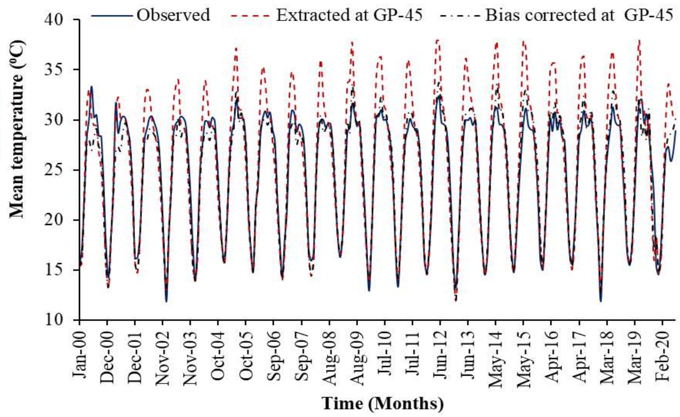
The scatter plots between the near surface air temperature observed at MS, Pusa and the land surface temperature extracted from GLDAS LST over grid points from GP-44, GP-45, GP 46, GP-47, GP-53, GP-54, GP-55, GP-56, GP-60, GP-61, GP-62, GP-63, GP-65 and GP-66 (Fig. 4). These graphs clearly showed the over estimation of land surface temperature over the near surface air temperature observed at MS, Pusa. The extremely high values of land surface temperature extracted from GLDAS LST can easily be seen from the figures. The slope and the value of R^2 of fitted line of linear regression between the near surface air temperature observed at MS, Pusa and the land surface temperature extracted from GLDAS LST were in the range of 1.163 (GP-66) to 1.177 (GP-44) and 0.887 (GP-44 and GP-47) to 0.892 (GP-65), respectively (Table 2). The multiplying factors over the selected grid points were determined and the bias free monthly series of land surface temperature was obtained (Deo and Sahin 2017). The scatter plots between the near surface air temperature observed at MS, Pusa and the bias free land surface temperature over grid points from GP-44 to 47, 53 to 56,60 to 63, 65 and 66 (Fig. 5). These regression line fitted between the near surface air temperature observed at MS, Pusa and the bias free (corrected) land surface temperature lie over the line of best fit. The slope and the value of R^2 of linear regression between the mean air temperature observed and the bias free land surface temperature were greatly improved and was 0.987 and more than 0.955, respectively for all grid points over MS, Pusa (Table 2).

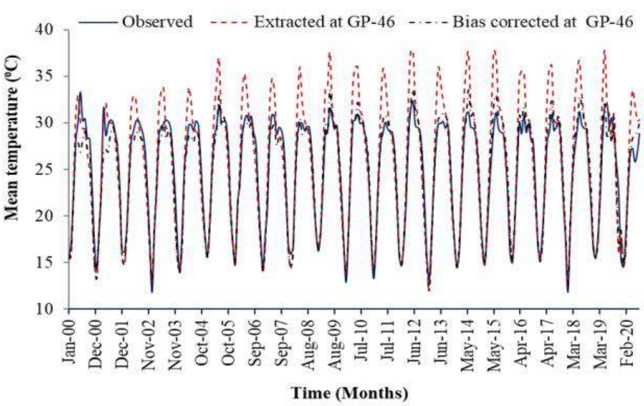
The average multiplying factors (AMF) of linear scaling for each month (January to December) were obtained by taking the average values of multiplying factors determined for each of the grid points mentioned above and were varied from 1.0086 (January) to 1.0141(December). Thus, the bias free

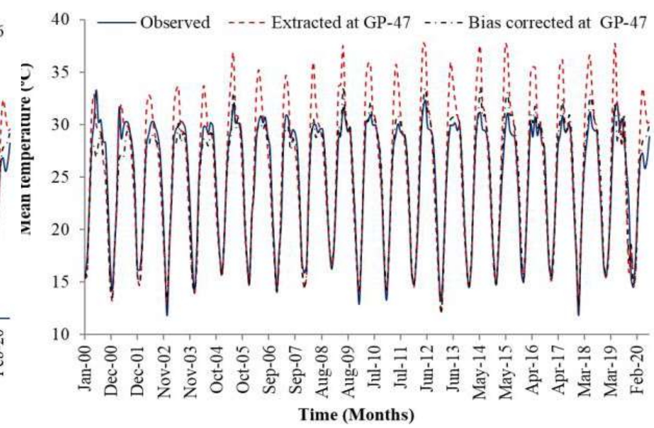
Table 2. Statistics of comparison between observed air temperature and land surface temperature over Samastipur district of Bihar

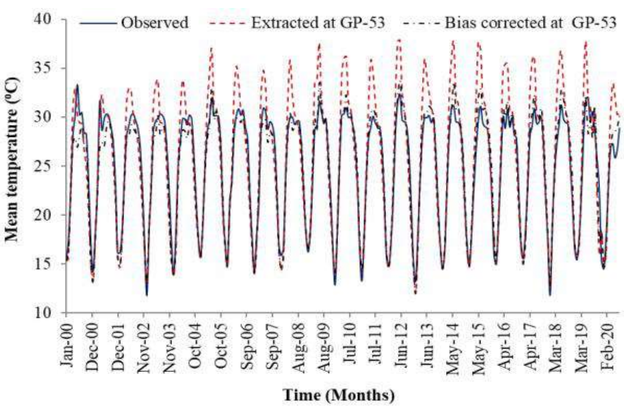
Grid points	Before Bias Correction of LST						After Bias Correction of LST					
	PCC	Bias	ME (ºC)	RMSE (ºC)	Linear Regression		PCC	Bias	ME (ºC)	RMSE (ºC)	Linear Regression	
					Slope	R^2					Slope	R^2
GP-44	0.940	1.040	0.990	2.740	1.177	0.887	0.980	1.000	0.000	1.200	0.987	0.955
GP-45	0.940	1.040	0.950	2.710	1.173	0.888	0.980	1.000	0.000	1.200	0.987	0.955
GP-46	0.940	1.040	0.910	2.680	1.167	0.888	0.980	1.000	0.000	1.200	0.987	0.956
GP-47	0.940	1.030	0.870	2.640	1.161	0.887	0.980	1.000	0.000	1.200	0.987	0.956
GP-53	0.940	1.040	0.880	2.670	1.172	0.889	0.980	1.000	0.000	1.190	0.987	0.956
GP-54	0.940	1.030	0.850	2.640	1.169	0.889	0.980	1.000	0.000	1.190	0.987	0.956
GP-55	0.940	1.030	0.810	2.610	1.162	0.889	0.980	1.000	0.000	1.190	0.987	0.956
GP-56	0.940	1.030	0.780	2.580	1.155	0.888	0.980	1.000	0.000	1.190	0.987	0.956
GP-60	0.940	1.030	0.720	2.610	1.174	0.890	0.980	1.000	0.000	1.190	0.987	0.956
GP-61	0.940	1.030	0.690	2.590	1.170	0.891	0.980	1.000	0.000	1.190	0.987	0.956
GP-62	0.940	1.030	0.660	2.560	1.162	0.890	0.980	1.000	0.000	1.180	0.987	0.957
GP-63	0.940	1.030	0.630	2.540	1.155	0.889	0.980	1.000	0.000	1.180	0.987	0.957
GP-65	0.940	1.020	0.530	2.540	1.172	0.892	0.980	1.000	0.000	1.180	0.987	0.957
GP-66	0.940	1.020	0.510	2.520	1.163	0.891	0.980	1.000	0.000	1.180	0.987	0.957

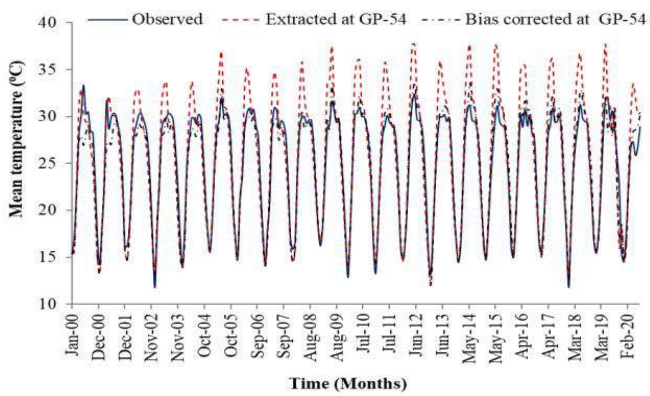

Observed
Extracted at GP-44
Bias corrected at GP-44
Mean temperature (ºC)
Time, (Months)

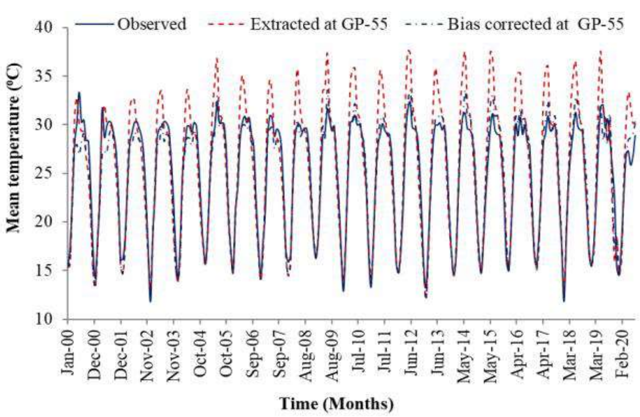

Observed
Extracted at GP-45
Bias corrected at GP-45
Mean temperature (ºC)
Time (Months)

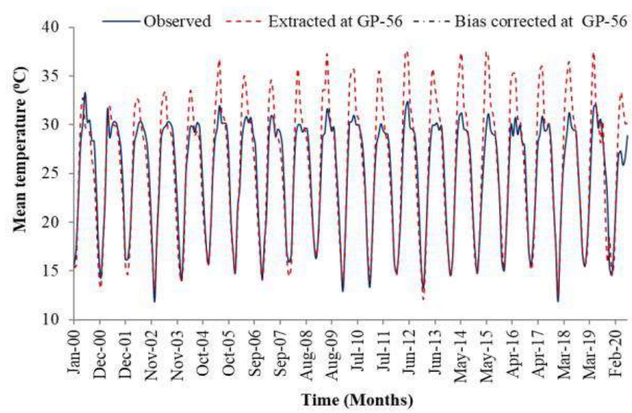

Observed
Extracted at GP-46
Bias corrected at GP-46
Mean temperature (ºC)
Time (Months)


Observed
Extracted at GP-47
Bias corrected at GP-47
Mean temperature (ºC)
Time (Months)


Observed
Extracted at GP-53
Bias corrected at GP-53
Mean temperature (ºC)
Time (Months)


Observed
Extracted at GP-54
Bias corrected at GP-54
Mean temperature (ºC)
Time (Months)


Observed
Extracted at GP-55
Bias corrected at GP-55
Mean temperature (ºC)
Time (Months)


Observed
Extracted at GP-56
Bias corrected at GP-56
Mean temperature (ºC)
Time (Months)

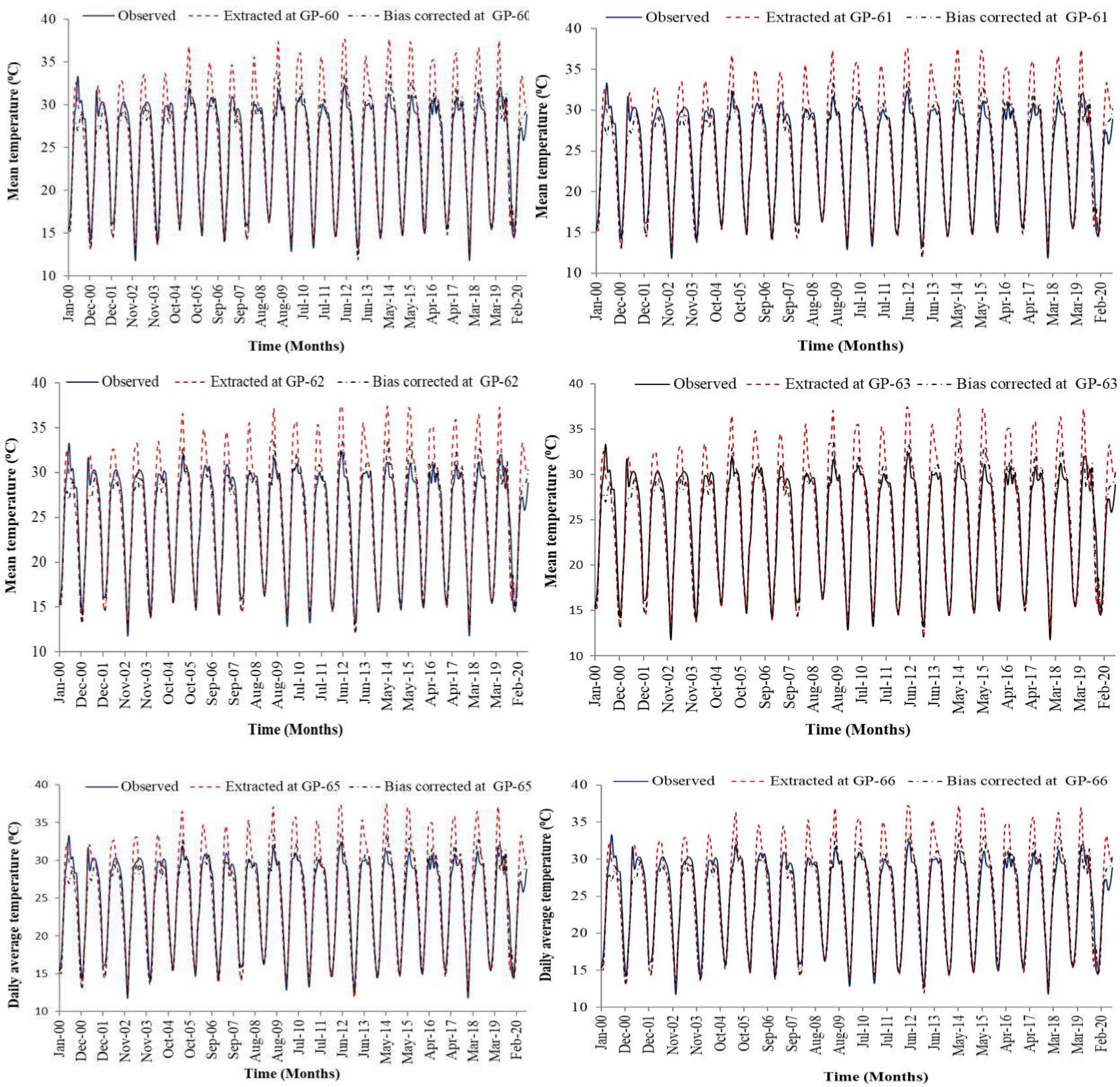
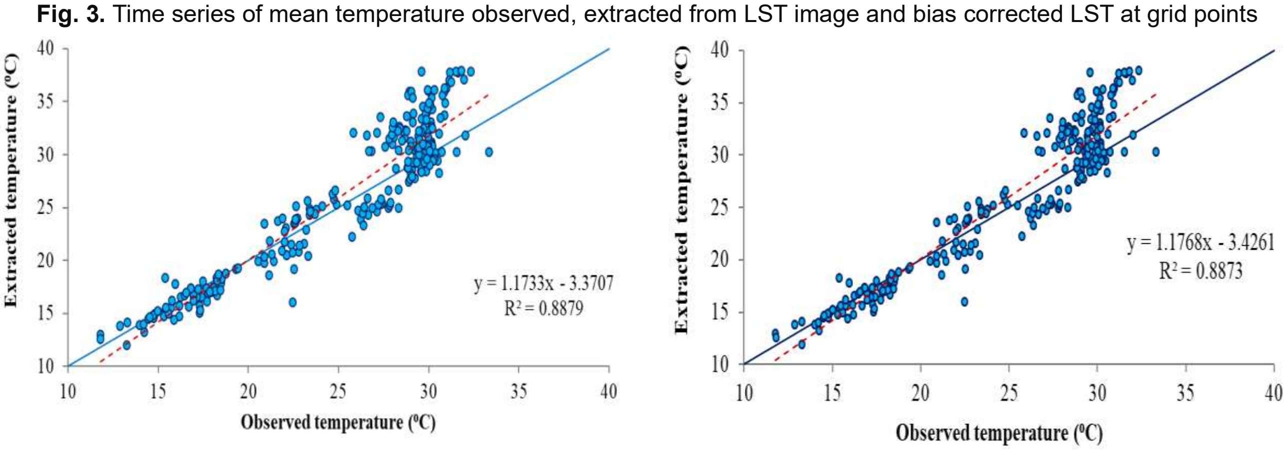
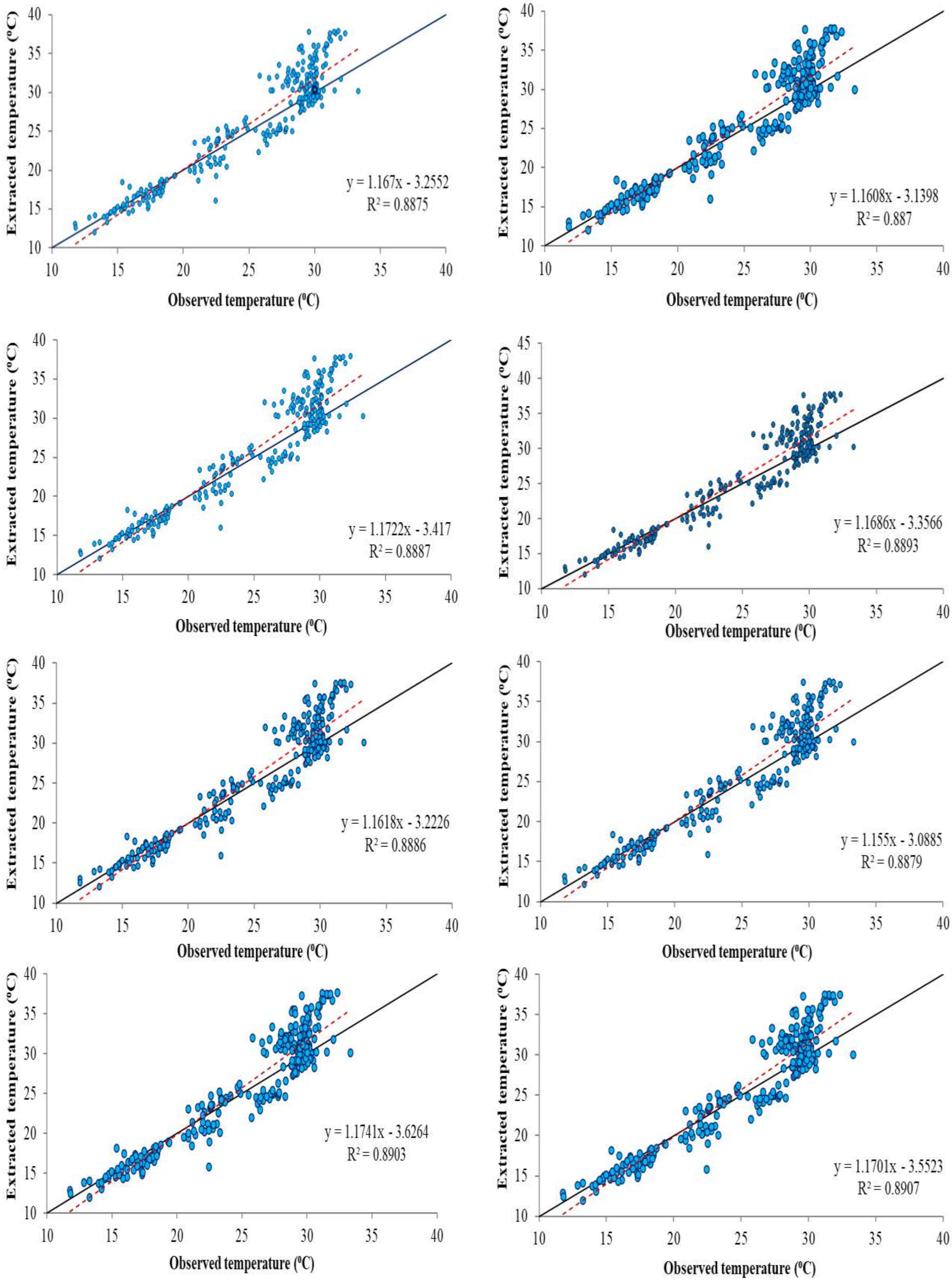


Fig. 3. Time series of mean temperature observed, extracted from LST image and bias corrected LST at grid points




Extracted temperature (ºC)
Observed temperature (ºC)
y = 1.167x - 3.2552
R² = 0.8875
y = 1.1608x - 3.1398
R² = 0.887
y = 1.1722x - 3.417
R² = 0.8887
y = 1.1686x - 3.3566
R² = 0.8893
y = 1.1618x - 3.2226
R² = 0.8886
y = 1.155x - 3.0885
R² = 0.8879
y = 1.1741x - 3.6264
R² = 0.8903
y = 1.1701x - 3.5523
R² = 0.8907

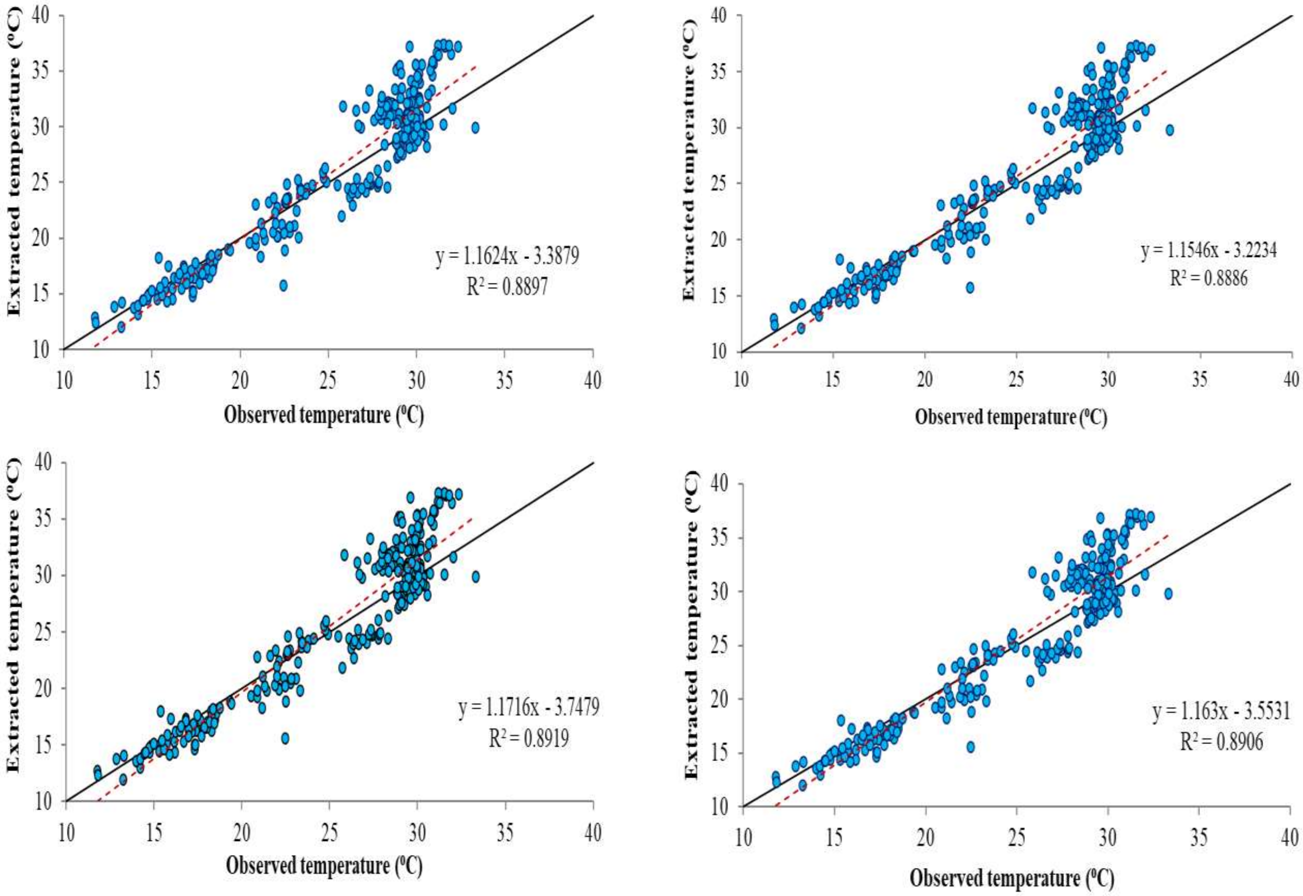
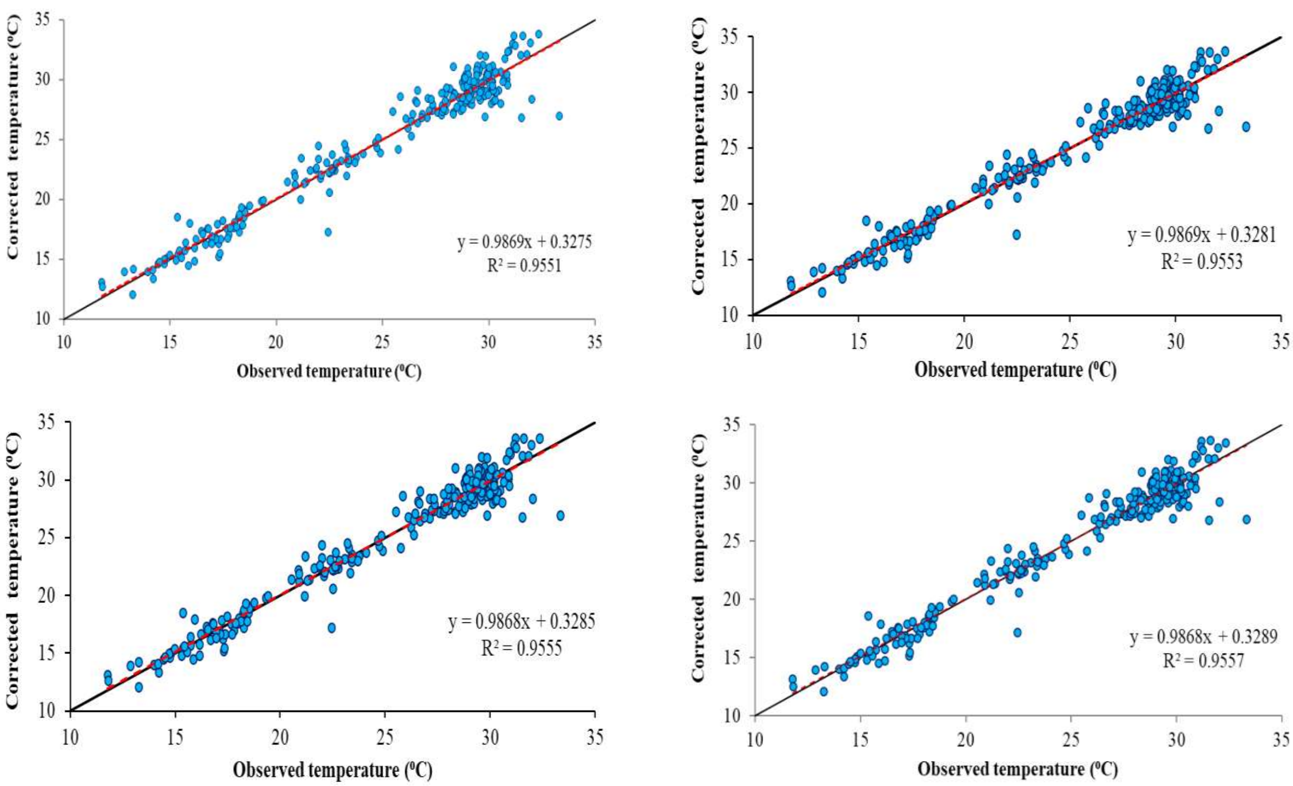
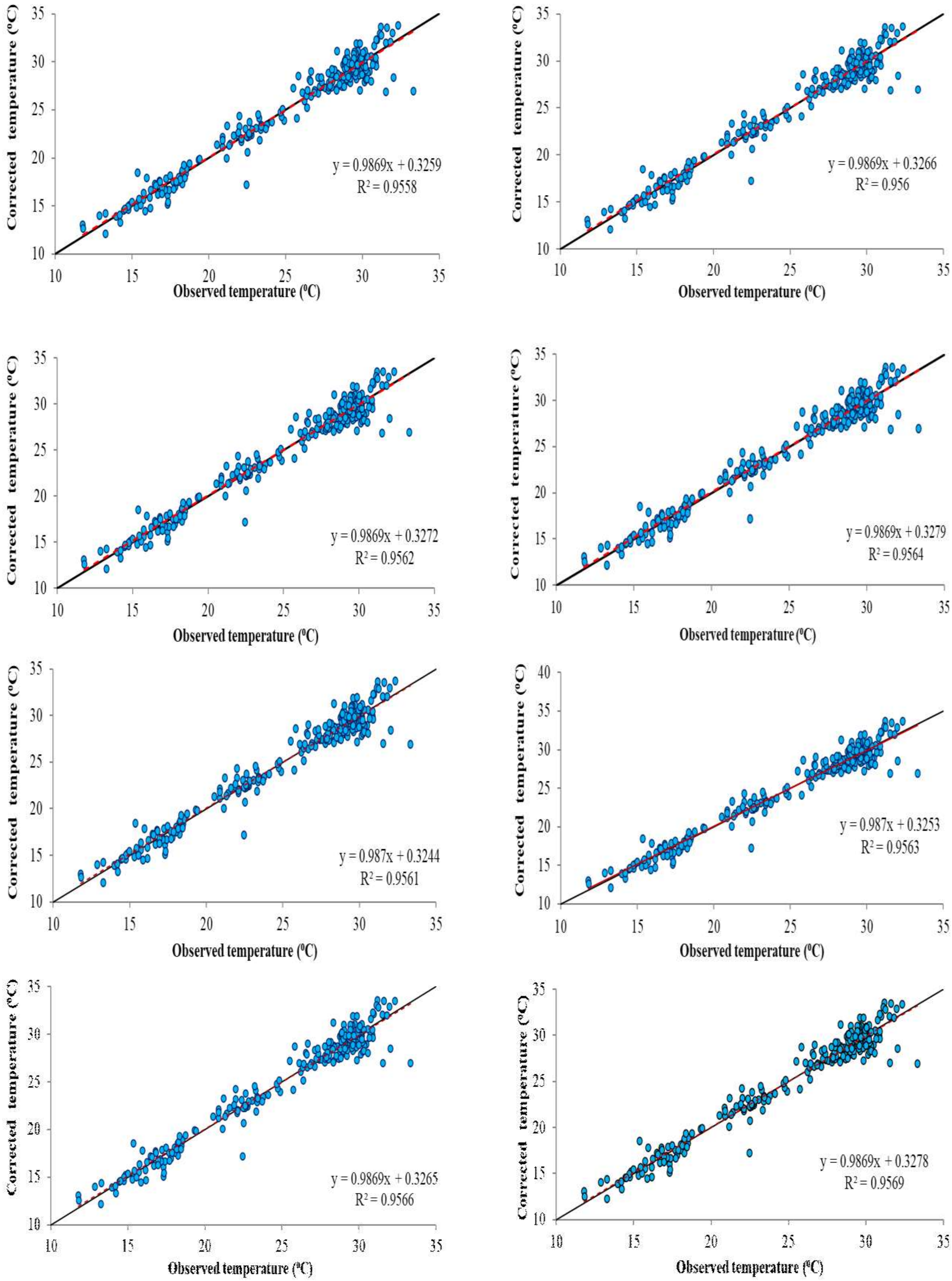


Fig. 4. Scatter plot between the observed mean temperature and that extracted from LST image at grid points




Corrected temperature (°C)
Observed temperature (°C)
y = 0.9869x + 0.3259
R² = 0.9558
y = 0.9869x + 0.3266
R² = 0.956
y = 0.9869x + 0.3272
R² = 0.9562
y = 0.9869x + 0.3279
R² = 0.9564
y = 0.987x + 0.3244
R² = 0.9561
y = 0.987x + 0.3253
R² = 0.9563
y = 0.9869x + 0.3265
R² = 0.9566
y = 0.9869x + 0.3278
R² = 0.9569

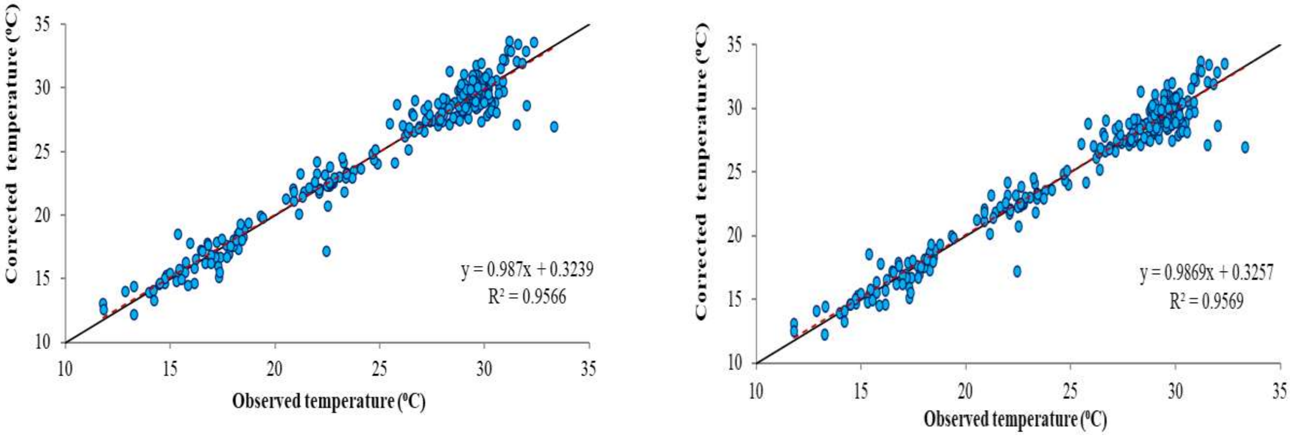


Fig. 5. Scatter plot between the observed and bias corrected mean temperature extracted from LST image at grid points

Table 3. Twenty years monthly average LST over study area

Month	LST (°C)	Month	LST (°C)	Month	LST (°C)
January	14.39	May	29.94	September	29.25
February	18.38	June	30.75	October	27.1
March	23.56	July	29.62	November	22.2
April	28.66	August	29.76	December	16.9

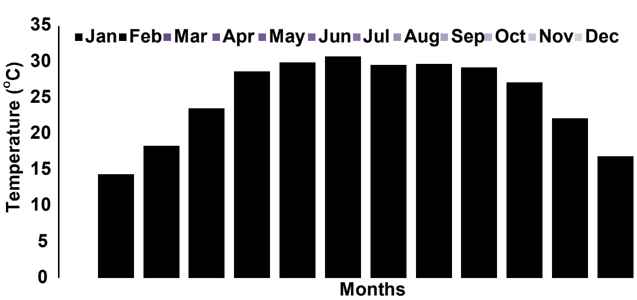


Fig. 6. Variation of temperature in the study area

land surface temperature over the study area was obtained by multiplying the AMFs to the land surface temperature extracted from GLDAS LST for each grid points and used to determine water surplus and deficit in the study area.

LST variation over study area presented in. The LST were maximum in the month of June (30.75°C) and minimum in January (14.39 °C) (Fig. 6 and Table 1). From January to July gradually increased and followed by decreasing trend from July to December (Fig. 7).

CONCLUSION

The monthly mean temperature estimated from the monthly dataset of Noah land surface temperature of Global Land Data Acquisition System (GLDAS) products of 0.25° × 0.25° grid size for the period of 2000 to 2020 using Arc Tool. The monthly air temperature for the months of January to December can be obtained by linear scaling of GLDAS LST product by multiplying the specific multiplying factors for each month. The statistical analysis advocates the use of satellites based GLDAS LST product for air temperature over the district however, application of statistical correction method like Linear-Scaling method of bias correction was found to be extremely suitable and reliable. The estimated LST was highest in the month of June (30.75 °C) and lowest in the month of January (14.39 °C) and from January to July, gradually increased and followed by decreasing trend from July to December. Future research must delve into seasonal temperature shifts, understanding causes and implications like the rise from January to July, followed by a decline to December. This analysis aids agricultural planning, water management, and climate adaptation. Extending studies beyond 2020 reveals long-term trends using high resolution temperature products is vital for assessing climate change impacts on local ecosystems, agriculture, and infrastructure.

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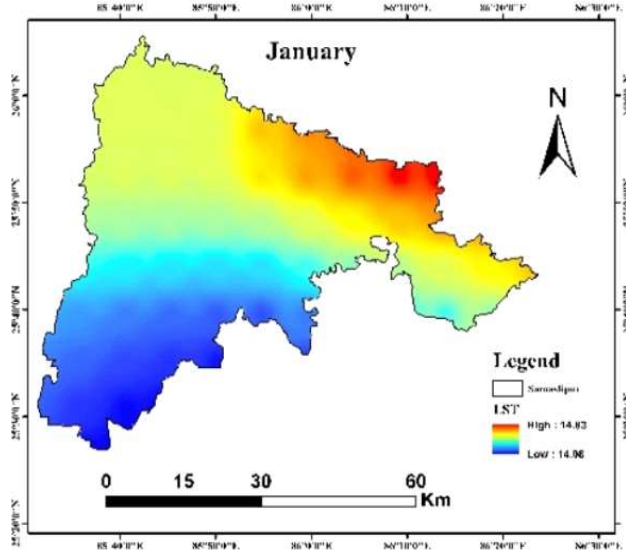
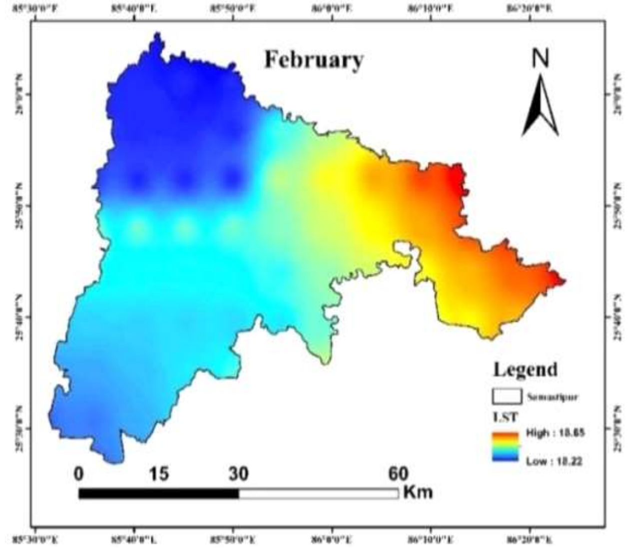

January
N
Legend
LST
0 15 30 60
Km


February
N
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LST
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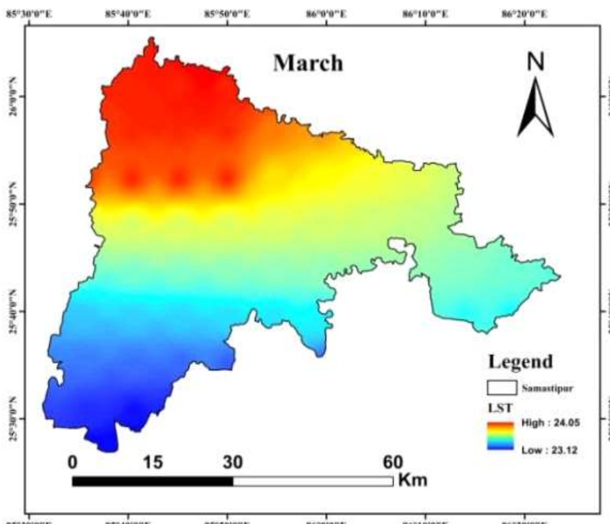
Low : 18.22
0 15 30 60
Km


March
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Samastipur
LST
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Low : 23.12
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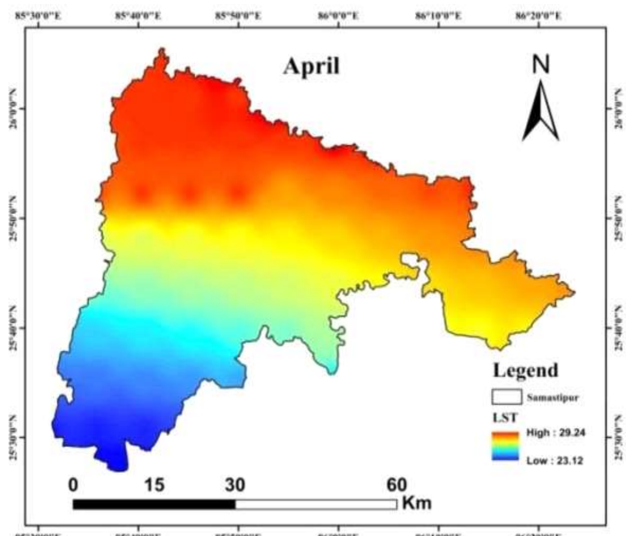
April
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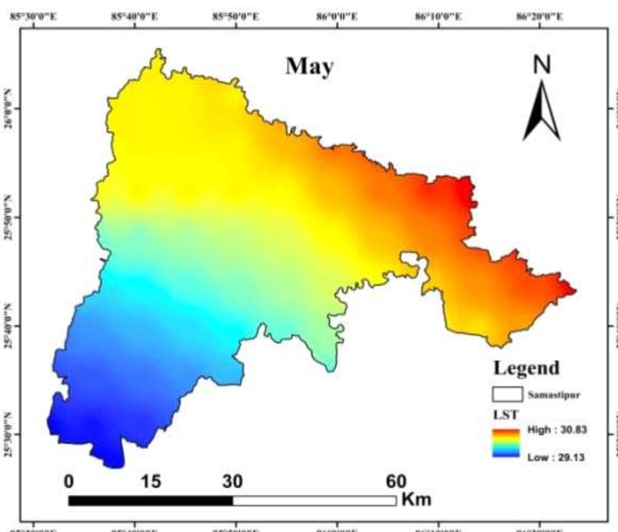
Legend
Samastipur
LST
High : 29.24
Low : 23.12
0 15 30 60
Km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Legend
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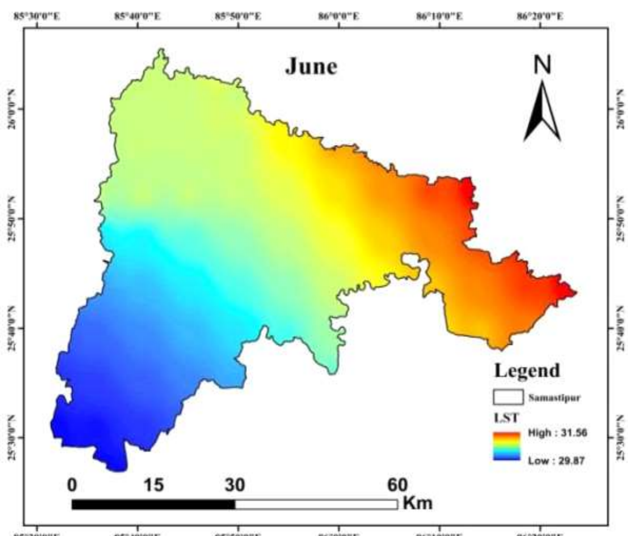
Km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Legend
Samastipur
LST
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0 15 30 60
Km

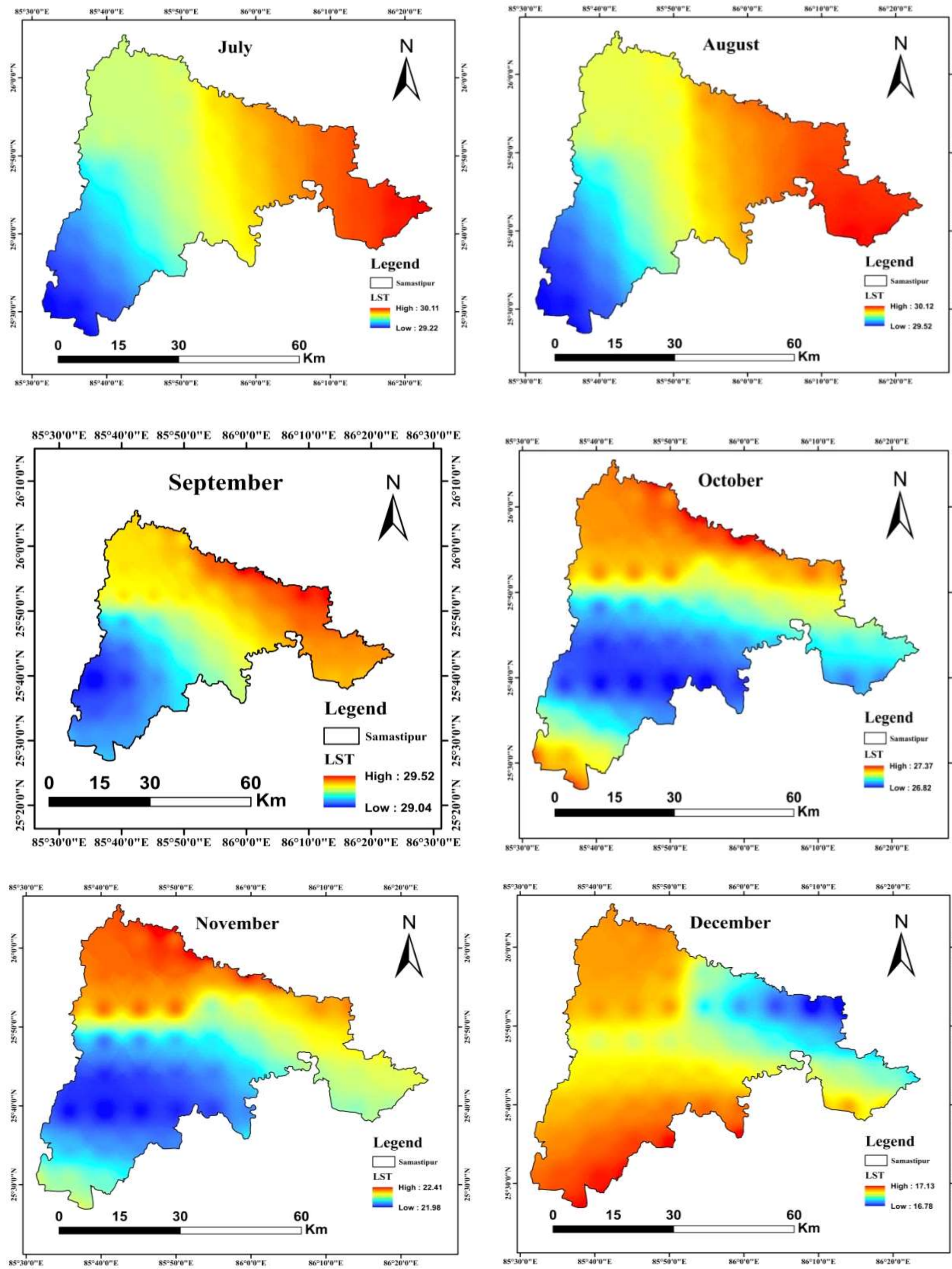

Fig. 7. Spatial distribution of 20 years average LST over the study area

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Artificial Recharge Structures for Heggada Devana Kote Taluk in Southern tip of Karnataka, India using Geospatial Tools

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***Abstract*:** Global warming, climate change, deforestation, rise in water demand for industrial uses rather than domestic purposes has posed serious threats to surface and subsurface water resources. Karnataka is one of the agrarian states in India where groundwater dependency showed always high. The present study involved the artificial techniques in groundwater augmentation analysis by modifying surface runoff in GIS environment with AHP (Analytical Hierarchy Process) methods. Important thematic maps are generated using toposheets, satellite data by GIS insights. Suitable sites for Artificial Recharge Structures (ARS) are derived through AHP by assigning specific weightages depending upon features priority. The results enumerate geospatial technology and AHP tools in achieving best suitable sites for ARS.

***Keywords*:** ARS, Geospatial tools, AHP, Heggada Devana Kote

Scarcity of water and its crisis still rising even though the annual average rainfall of 1100mm is recorded recently in our country. Karnataka State records over-exploited class for groundwater is 26%; whereas other blocks are observed under critical class. Groundwater is the vital component of irrigation and domestic activities in Heggada Devana (H.D) Kote taluk, however the increasing demand of water resources and its over-withdrawal with gradual rise in population impacts the aquifer equilibrium and ecological imbalance (Manjunatha et al 2019). High intensity of rainwater run-off on hill slope regions loses sufficient amount of water to other lands without much infiltration (Manjunatha et al 2019). Groundwater dependency may rise in near future by both manmade and natural processes. In hard rock terrains, ARS sites need detailed assessment of lithology, geomorphology, lineaments that are controlled by climate, weathering grade, drainage pattern, landforms, slope, permeability, fracture extent, and land use patterns (Fateme Falah et al 2016).

The present study aims in identifying suitable ARS sites for H.D kote taluk in an effort to maintain the aquifer equilibrium and store sufficient amount of water for summer seasons (Manjunatha et al 2019). AHP methods are analyzed in order to find best ARS sites by opting specific priorities within the best options (Thomas Saaty 1980). Pair-wise comparison are interpreted in assigning specific weights through Saaty's continuous rating scale of AHP through GIS.

MATERIAL AND METHODS

Site description: The study taluk falls under $11^0$44' to $12^0$17' N latitudes and $76^0$06' to $76^0$33' E longitudes with an area of 1611.29 km^2 (Manjunatha and Basavarajappa 2021) (Fig. 1). The plain regions elevated at 660 mts above MSL, whereas higher elevation ranged at 960 mts above MSL observed in southern parts. H.D kote taluk lies at southern tip of Karnataka that connects to Kerala state through Yerahalli village main road (Manjunatha and Basavarajappa 2021). Annual average rainfall recorded is 832 mm with temperature ranges from 21^0 to 31^0C (CGWB 2012). It is a part of Southern Transition Zone of hilly regions showing cool and moist weather along with sub-humid to semiarid tropical type conditions (CGWB 2012). About 67% of irrigated land is dependent on bore wells and hardly any dug wells (CGWB 2012). Paddy, Maize, Ragi, Sugarcane, Tobacco, Oilseeds and vegetables were grown extensively in the taluk (CGWB 2022). Gneisses and schistose are well exposed major rock groups in hilly terrains along with residual and transported soils.

Data Used: Toposheets (57A/1, 5, 6, 9; 57D/4, 7, 8, 11, 12) of 1:50,000 scale are collected from Bengaluru-Survey of India (SoI) office and digitized as the base maps for taluk boundary extraction (Manjunatha and Basavarajappa 2021). IRS-1D, LISS-III (Nov-2001 & Jan-2002) is collected from ISRO-NRSC, Hyderabad with 23.5 mts and PAN of 5.8 mts; whereas DEM satellite data is downloaded freely from USGS-earthexplorer (Fig. 2a) (Manjunatha et al 2019). Both Digital Image Processing (DIP) and Visual Image Interpretation Technique (VIIT) are applied on LISS-III image in extraction of thematic layers (Fig. 2a to 2l) along with limited field survey using Garmin eTrex-10 GPS (Manjunatha and Basavarajappa 2021).

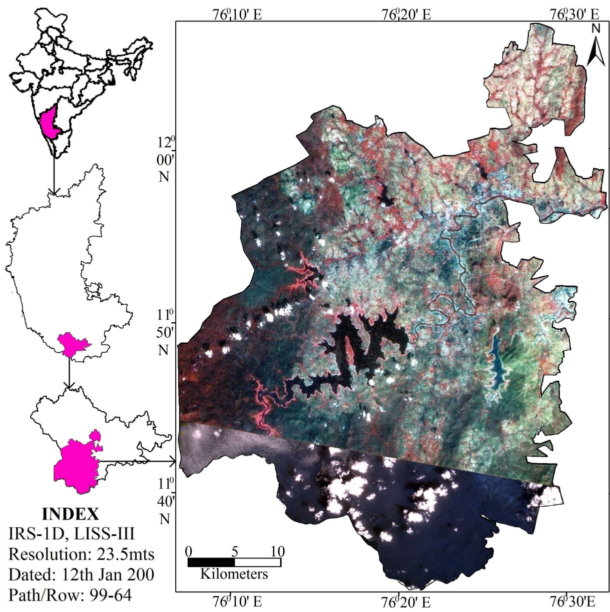

Fig. 1. IRS-LISS-III Satellite data of H.D kote taluk

Data analysis: GSI Quadrangle maps 57D and 58A of 1:250,000 scale are utilized in generating the lithology map; while geomorphology layer is digitized using 1:250,000 scale of geomorphological map of Karnataka (Manjunatha et al 2019). DEM data of 30m resolution is overlaid on SoI topo map in extraction of drainage patterns (Fig. 2d) and (Manjunatha et al 2019). Land use/ land cover categories and lineaments are extracted from PAN+LISS-III image of 5.8m resolution (Fig. 1) (Manjunatha et al 2019); whereas slope map is digitally extracted from DEM data (Manjunatha et al 2019). All seven layers of H.D kote taluk have been overlaid by pair-wise comparison using weighted method and ARS best sites are portrayed in Fig.3 (Table 1, 2, 3).

RESULTS AND DISCUSSION

Lithology: Weathered zones of granitic-gneisses and alluvium of shallow aquifers are observed along the stream courses in NNE parts of the taluk (CGWB 2012). The hard rock terrain of taluk consists of migmatites, amphibolites,

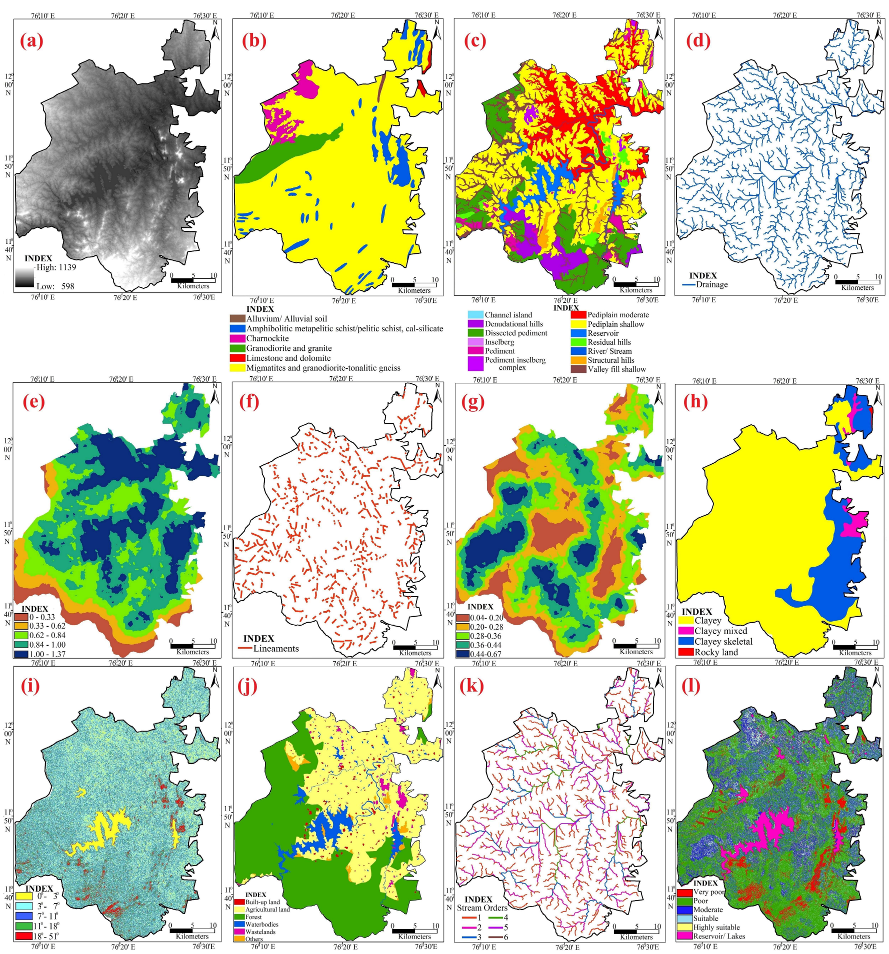

Fig. 2. (a) DEM (b) Lithology (c) Geomorphology (d) Drainage (e) Drainage Density (f) Lineament (g) Lineament Density (h) Soil map (i) Slope map (j) LU/LC (k) Stream Order and (l) Overlay weightage map of H.D Kote taluk

charnockite, limestone and dolomite (Fig. 2b). Tonalitic gneisses granodiorite, migmatites are observed extensively; whereas charnockites are restricted to NW parts following this amphibolites with pelitic/ metapelitic schist noticed at many locations. Weathered granitic-gneisses are noticeably seen along discontinuities and caused complex weathering profiles. The hard bedrock of kote taluk reveal little groundwater infiltration rates and percolations that need ARS to arrest surface water runoff through artificial methods of infiltration.

Geomorphology: Geomorphic units of kote taluk are delineated as dissected pediment, denudational hills, channel island, pediment, inselberg, pediment inselberg complex, pediplain shallow, pediplain moderate, river/stream, residual hills, structural hill, reservoir, and valley fill shallow (Manjunatha et al 2019) based on NRIS classification system (Fig. 2c). Pediplain moderate and valley fill shallow features showed excellent for groundwater potential areas while pediplain shallow features exhibits good to moderate; pediment and pediment inselberg complex features reveal moderate to poor; inselbergs, residual hills, and denudational hills indicate poor to very poor potential areas for kote taluk (Srinivasa et al 2005). Granitic-gneisses and charnockite rocks exhibits continuous range of hard surfaces that perform high runoff. Priorities based weightages are considered for each geomorphological features that help in better ARS site suitability except for river/ streams, reservoir and hills (Table 3).

Drainage & its density (Dd): Dd forms vital component for ARS sites. It's a computation of sum of the channel lengths per unit area along with relief and slope gradient. High Dd indicate channel closeness exhibiting impermeable or feeble subsurface; while low Dd reveal permissible soil or highly resistant material, low relief with thick vegetation cover in kote. Coarser drainage texture showed mountainous relief, scanty greenery type; while finer drainage texture convey high and closeness of drainage patterns. Higher runoff are more common in higher Dd areas that are not suitable for ARS, whereas little runoff in low Dd areas implies highly suitable (Fig. 2e).

Lineament & its density: Groundwater occurrences and its distribution are controlled by fractures, lineaments direction & joints and bore wells yield high water located on these zones. Lineaments/ faults filled with clay and silt of impermeable material will arrest further flow of groundwater. Eminent lineaments of kote observed along directions of NW-SE and NNE-SSW and strongly influence static water levels, boreholes yields, groundwater distribution & occurrences (CGWB 2012) (Fig. 2f). Rocks of kote taluk are hard and compact that imply higher runoff with low infiltration rates observed along fractures, seepages, weak planes, dykes and hence higher Lineament density (Ld) is essential to determine. Ld are digitally generated using Line Density tool on IRS-LISS-III data. Very high, high, moderate, low, and very low classes (Anirudh Datta et al 2020) are showed through lineament density layer (Fig. 2g) and their weightages for ARS sites are shown in Table 3. Higher Ld indicates more suitability for ARS with higher groundwater recharge potential zones.

Table 1. Continuous rating scale of Saaty's analytical hierarchy process

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very Strongly	Extremely
Less Important				Equal	More Important			

Source: Saaty (1980)
Note: 1/8, 1/6, 1/4, 1/2, 2, 4, 6, 8 can also be used if more number of classes exists

Table 2. Percentage of influencing factors based on Saaty's Analytical Hierarchy Process (AHP)

Influencing factor	Saaty's scale (in fraction)	Saaty's scale (in decimal)	Percentage influence = (Saaty's Scale/sum * 100)	Relative influencing factor
Lithology	1	1	38.71	39
Geomorphology	1/2	0.5	19.35	19
Drainage Density	1/3	0.33	12.77	13
Lineament Density	1/4	0.25	9.67	10
Soil types	1/5	0.20	7.74	8
Slope categories	1/6	0.16	6.19	6
LU/LC	1/7	0.14	5.42	5
		Sum = 2.583		

Table 3. Assigned weight according to Saaty's analytical hierarchy process

Influencing factor	Class intervals or features	Saaty's scale (Fraction)	Saaty's scale (Decimal)	Percentage Influence = (Saaty's scale/ sum) * 100	Relative influencing factor
Lithology	Limestone & Dolomite	1	1	48.07	48
	Migmatite and Granodiorite	1/2	0.5	24.03	24
	Amphibolite /Metapelitic Schist	1/3	0.33	15.86	16
	Charnockite	1/4	0.25	12.01	12
			Sum=2.08		
Geomorphology	Pediplain	1	1	40.98	41
	Pediment	1/2	0.5	20.49	20
	Pediment inselberg complex	1/3	0.33	13.52	14
	Reservoir	1/4	0.25	10.24	10
	River/ Streams	1/5	0.20	8.19	8
	Hills	1/6	0.16	6.55	7
			Sum=2.44		
Drainage density (m/m^2)	0.99 – 1.32	1	1	43.85	44
	0.82 – 0.99	1/2	0.5	21.92	22
	0.60 – 0.82	1/3	0.33	14.47	14
	0.31 – 0.60	1/4	0.25	10.96	11
	0 – 0.31	1/5	0.20	8.77	9
			Sum=2.28		
Lineament density (m/m^2)	0.38 – 0.64	1	1	43.85	44
	0.29 – 0.38	1/2	0.5	21.92	22
	0.19 – 0.29	1/3	0.33	14.47	14
	0.09 – 0.19	1/4	0.25	10.96	11
	0 – 0.09	1/5	0.20	8.77	9
			Sum=2.28		
Soil types	Clayey-skeletal	1	1	54.64	55
	Clayey	1/2	0.5	27.32	27
	Rocky land	1/3	0.33	18.03	18
			Sum=1.83		
Slope categories	0 – 3 degree	1	1	43.85	44
	3 – 7 degree	1/2	0.5	21.92	22
	7 - 11 degree	1/3	0.33	14.47	14
	11 – 18 degree	1/4	0.25	10.96	11
	18 – 51 degree	1/5	0.20	8.77	9
			Sum=2.28		
Land use/ land cover	Wastelands	1	1	43.85	44
	Agricultural land	1/2	0.5	21.92	22
	Forest cover	1/3	0.33	14.47	14
	Water bodies	1/4	0.25	10.96	11
	Built-up land	1/5	0.20	8.77	9
			Sum=2.28		

Soil: Soil highly influences the groundwater infiltration in ARS site suitability analysis. Surface water flow and infiltration rates are controlled by permeability and porosity of various soil types. Charnockite and granitic-gneisses are the parent rocks of soil types observed in kote taluk (Fig. 2h). Deeply well drained and slight salinity are shown by clayey soils; whereas moderately well drained with and slight salinity are observed by clayey-mixed soils (CGWB 2012, Basavarajappa et al 2013). Very deep, well-drained with slight erosion are noticed by clayey-skeletal soils in association with gravelly clay soils of shallow to excessively drain and moderately eroded (CGWB 2012). Deep to moderately drain on gently sloping areas with modest eroded particles are noticed from rocky land soils (Basavarajappa et al 2013). Basic intrusions in contact with schist rocks showed mixed soil types localized at certain junctions of kote taluk. The soil textures and types of various infiltration capacity are analyzed to determine best sites for ARS with specific weightages (Table 3).

Slope: Surface water runoff and infiltration capacity are determined by slope classes. Slopes are classified into five categories and proper (Fig. 2i, Table 3). Flat to gentler slope zones imply low runoff and longer water residing time for higher infiltration rates that are benefitted for ARS sites; whereas moderate to greater slopes increase surface runoff making unsatisfactory for ARS. Nearly flat terrain (0-3 degree) is most acceptable lands for 'Very Good' ARS category with higher infiltration capacity. Gentler to slightly undulating lands (3-7 degree) are moderately acceptable as 'Good' ARS category which accepts some amount of runoff. Moderate slopes of 7-11 degree exhibit little infiltration capacity due to higher surface runoff; whereas moderately steep slopes (11-18 degree) represents much higher runoff. Steeper slopes (18-51 degree) imply highest runoff with negligible infiltration capacity.

Land use/ land cover: Built-up, waterbodies, forest, agricultural land, wastelands, and other features are successfully digitized in ArcGIS platform (Fig. 2j) (Manjunatha and Basavarajappa 2021). The agricultural practices of H.D kote taluk are regularly impacted by the surface and sub-surface hydrologic factors of surface flow, evaporation, catchment area, infiltration capacity and interception. Manmade land patterns are assigned with least weight, since this affects recharge. Appropriate weightages are provided based on various land patterns and their specific utilization that may influence ARS sites (Table 3).

Stream Order (Sμ): Identification of stream orders is an essential part in the interpretation of drainage basin. Lithology, morphology and precipitation influences the variation of total stream number and its length in the terrain (Basavarajappa et al 2014). The kote taluk denotes medium precipitation and nearly flat to steeper sloppy areas. Greater discharge are recorded from higher stream orders. Six number of streams are extracted from DEM image for the present study and denoted as 1st to 6th (Fig.2k). Gentler slope lands in association with the stream orders of 2nd, 3rd or 4th are satisfactorily acceptable for ARS percolation tank and other storage tanks (Table 2, 3).

Analytical Hierarchy Process (AHP)

Weighted overlay method: Each thematic layers are assigned proper weightages in accordance with their respective contribution towards the best ARS results for H.D kote taluk. All layers are transformed into raster format using ArcGIS and later the pair-wise interpretation was analyzed in computing the overall score of each criteria. Highly suitable, suitable, moderate, poor, and very poor categories are obtained by using standard deviation classification scheme. Settlements, temples, telephone lines, power lines, taluk & state roads, and other features are ruled out while mapping ARS best site (Fig. 3). Considering the respective significance among the factors portray the real ground conditions.

Need for artificial recharge structures: The effective improvement of groundwater recharge is required for strengthen of major/ minor irrigation and balances between demand-supply equilibrium to all water requiring sectors in H.D kote taluk. ARS is a vital components and major strategies in groundwater management planning for natural

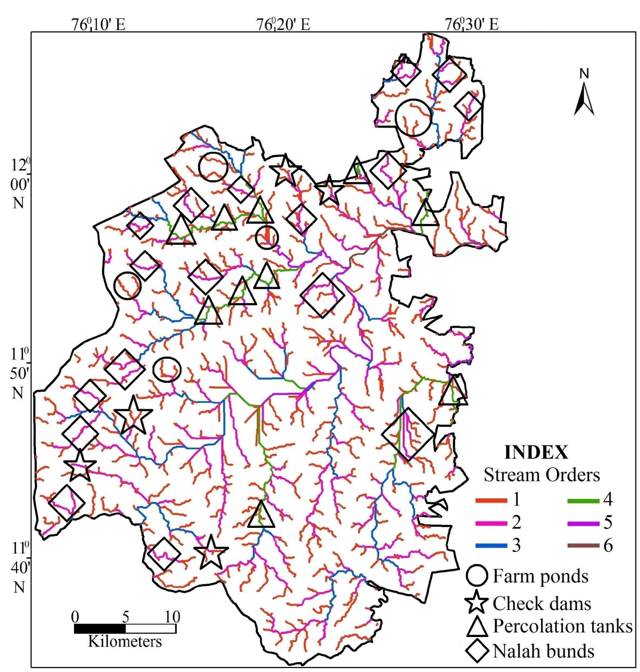

Fig. 3. Final output map to implement ARS for H.D Kote taluk

supply of groundwater. Farm ponds, check-dams, percolation tanks, nalah bunds, barrages are the efficient storage methods of rain water especially for agricultural practices in the taluk which is majorly rainfall dependent. This acts as a sustainable strategy in groundwater augmentation especially in lean seasons.

Farm ponds are compact sized and rectangular shaped trenches that receive surface run-off water over agricultural lands by a narrow stream having 10% ground slope on either sides (Fig. 3). Shrub/ barren types with moderate infiltration capacity of soils are acceptable land to build farm ponds (Manjunatha et al 2019). The elevation of these ponds must be higher than any irrigated lands where it can deliver prime goal for irrigation (Manjunatha et al 2019). These ponds receives the groundwater recharge from post-monsoon periods also. The groundwater contaminations are diluted by interconnecting nearby farm ponds for effective recharge of better quality water. Both soil erosion and conservation of water are addressed by series of check dams that harness water over larger areas. These dams must be built near the crop types of higher potential for better allocation of harvested water. The gentler slopes of 1st and 2nd stream orders are most appropriate for these structures (Fig.3). They store runoff water most of confined type to stream course with less than 2m height from ground level.

Best conventional method of groundwater recharge especially in India is Percolation tanks in case of both hard rock terrains as well as alluvial such as H.D kote taluk (ARS Guide 2000). These are artificially managed surface water on permeable lands observed parallel to the streams in such a way that it can achieve maximum percolation with least evaporation lose. Small streams with gentler slopes of 3-7 degree are most satisfactory for these tanks (Fig. 3) that stores monsoon runoff over larger lands of soil types having moderate to higher pores/ voids. Nalah bunds are small earthen dams of 2 to 3 m high, 1 to 3 m wide and, 10 to 15 m long which normally acts as mini percolation tank (Manjunatha and Basavarajappa 2021). These are best suited across bigger streams of gentler slopes and contour/ graded bunding lands of having lower annual rainfall of 1000mm and should vulnerable to water logging (Fig.3) (ARS Manual 2007, CGWB 2012). Taluk show plain regions in central and northern parts; whereas hilly area are restricted to southern region. The elevation difference had modified the irregular patterns of groundwater flow that falls under Kapila river basin. Principal aquifers of H.D kote taluk are schist & gneisses and hence the circulation of groundwater is controlled by secondary porosity caused by weathering and fracturing of hard rocks. Lineaments trending NE-SW and NW-SE are expected to yield greater. The taluk was categorized under safe zone with groundwater exploration of 47% (CGWB 2022). However ARS is essential especially during extreme summer conditions where sufficient amount of water cannot be supplied for paddy, sugarcane and tobacco which are high water intensive crops.

Nalah bunds (17), percolation tanks (10), farm ponds (5) and check dams (5) are identified to implement best ARS sites for H.D kote taluk using AHP in GIS platform. Southern and eastern parts of H.D kote taluk shows hilly and rugged topography where nalah bunds are appropriate to build; whereas on flat to nearly gentler areas are suitable for percolation tanks (Fig. 3). These structures also helpful to reduce future water crisis that may occur due to global warming, industrial and agricultural water demands. The infiltration rates are noticed to be high near waterbodies, croplands and floodplains that exhibits best ARS sites; whereas low infiltration rate lands show least suitability.

CONCLUSION

Check dams and nalah bunds are suited as a management method to tackle over-withdrawal of water and to avoid fall in groundwater table. AHP and WOM are the excellent approach for ARS sites in ArcGIS insights that significantly enhance the crop yield, irrigation capacity, and sustainability of water sources for demographic growth and demands. Geospatial technology proved to be a policy making in controlling surface water runoff and larger recharge to deep aquifers through cost effective techniques. AHP is the best site suitable analysis in assigning priority based weightages for arresting subsurface flows and groundwater augmentation.

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Cassava for Food Security, Poverty Reduction and Climate Resilience: A Review

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***Abstract*:** Cassava plays a significant role in the food security of the rural poor and marginal farmers and is also recognized as an important industrial crop. Among the crops, cassava is the third largest source of carbohydrates in the tropical region after rice and maize. It is a major staple food in the developing world, which has the capacity to provide a basic diet for over half a billion people. The worldwide production of cassava amounted to 315 million metric tons in 2021, out of which Africa's share was about 65%. According to FAO projections, by 2025, about 62% of global cassava production will come from sub-Saharan Africa. Cassava is a crop that can be considered a poverty reduction crop as it is climate resilient and can be grown in marginal, less fertile soil with less-inputs. Its tuberous root contains 30-40% dry matter and 25-30% starch. Nutritionally, cassava contains potassium, iron, calcium, vitamin A, folic acid, sodium, vitamin C, vitamin B-6, and protein. It is a climate resilient and insurance crop that helps rural people tide over the famine caused by natural calamities and other disasters. Cassava is a crop that is considered as a poor man's saviour crop which helps them to sustain their livelihood in times of natural disturbances. Cassava is a best crop which contributes for rural development, poverty reduction, economic growth and food security. The present review gives comprehensive information about the cassava crop and its role in food security, poverty reduction and income generation for farmers.

***Keywords*:** Cassava, Food security, Poverty, Climate resilience

Cassava is an important staple food crop for more than 500 million people worldwide due to its high carbohydrate content (Blagbrough et al 2010) and is an essential crop in developing countries. Cassava is considered as the third most important crop in India with high productivity. Cassava originated in South America and was distributed to tropical and subtropical regions of Africa and Asia (Blagbrough et al 2010). A recent report from the Consultative Group on International Agricultural Research (CGIAR) noted that 'root crops will be many things to many people by 2020' (Scott et al 2000). The worldwide production of cassava amounted to 315 million metric tons in 2021, out of which Africa's share was about 65%. According to FAO projections, by 2025, about 62% of global cassava production will come from sub-Saharan Africa (FAOSTAT 2020). Cassava is mainly cultivated in the southern parts, particularly in Kerala and Tamil Nadu, which contribute over 92 per cent of the total cassava production in India (GoI 2018). Cassava is a tropical root crop that needs at least 8 months of warm temperature to establish and grow. Cassava does not tolerate freezing conditions. It tolerates a wide range of soil pH from 4.0 to 8.0 and is most productive in full sun and is a hardy crop that produces tuber under marginal conditions, e.g., drought or depleted soils (Iyer et al 2010). Its tuberous root contains 30-40% dry matter and 25-30% starch. Nutritionally, cassava contains potassium, iron, calcium, vitamin A, folic acid, sodium, vitamin C, vitamin B-6, and protein (Montagnac et al 2009a). Cassava roots and leaves are good sources of carbohydrates, protein, vitamins, and minerals (Bayatagna 2019). The cassava tubers are also used as raw materials in the garment, bakery, food, and pharmaceutical industries. Cassava is a crop that is considered as a poor man's saviour crop which helps them to sustain their livelihood in times of natural disturbances. Among the crops, cassava is the third largest source of carbohydrates in the tropical region after rice and maize. It is a major staple food in the developing world, which has the capacity to provide a basic diet for over half a billion people. Cassava is a crop that can be considered a poverty reduction crop as it is climate resilient and can be grown in marginal, less fertile soil with less-inputs. Owing to the role of cassava in the African feeding pattern, it is often referred to as the "hunger crop" (Wigg 1993). Though relatively new in African agriculture, it has become very popular because of its ease of cultivation and adaptability to a wide variety of soils even the marginal ones (Hahn 1994).

Status of cassava cultivation globally: Globally cassava is grown in an area of 29.65 million ha producing 314.80 million tons with an average yield of 10.62 tons/ha. It is grown in 94 countries and these countries are in Africa, America, Asia and Oceania continents. Among the continents, African continent occupied the first position in terms of area (80.34%) and production (64.67%) of cassava with a yield of 8.55 t/ha followed by Asian continent contributing 12.79% of the cassava area with production share of 26.76%. The Americas continent occupied third position accounted 6.80% of the cassava area with a production share of 8.49% of the world production. Among the countries, Nigeria had the largest area under cassava (30.64%) with an annual output of 20.02% followed by Democratic Republic of the Congo (18.90% area and 14.51% production) and Thailand (4.94 % area and 9.56% production). Thailand, Indonesia, Vietnam, China mainland, Cambodia, Philippines and India are the major cassava producing countries in Asia continent (Table 1).

Status of cassava cultivation in India: During 2017-2018, area (51.85%) and production (57.83%) of cassava was highest in Tamil Nadu followed by Kerala (31.67% and 34.87%) and Andhra Pradesh (7.34% and 3.88%). Approximately 97% of the nation's total cassava production was produced in these three states. Tamil Nadu alone contributed about 58 percent of the total cassava production. In addition to the South Indian states, the North-Eastern states of Nagaland (1.60%), Assam (0.58%), and Meghalaya (0.73%) also contributed significantly to the total production of cassava (Table 2).

Cassava as a food security and poverty reduction crop: Cassava crop is known for its wide ecological adaptability and always perform relatively well where other crops fail to

Table 1. World cassava producing regions and countries, 2021

Continent	Country	Area (Million ha)	% to total	Production (Million tons)	% to total	Yield (Tons/ha)
World	Total world	29.652	100	314.807	100	10.62
Africa	Total	23.822	80.34	203.573	64.67	8.55
	Angola	1.017	3.43	9.867	3.13	9.70
	Benin	0.362	1.22	4.219	1.34	11.65
	Burundi	0.321	1.08	2.528	0.80	7.88
	Cameroon	0.395	1.33	4.994	1.59	12.63
	CÃ´te d'Ivoire	1.093	3.69	6.962	2.21	6.37
	DR of the Congo	5.605	18.90	45.673	14.51	8.15
	Ghana	1.010	3.41	22.682	7.20	22.46
	Guinea	0.301	1.02	2.743	0.87	9.10
	Madagascar	0.306	1.03	2.440	0.77	7.97
	Mozambique	0.569	1.92	5.598	1.78	9.84
	Nigeria	9.086	30.64	63.031	20.02	6.94
	Togo	0.322	1.09	1.178	0.37	3.66
	Uganda	0.878	2.96	2.679	0.85	3.05
	UR of Tanzania	0.987	3.33	6.126	1.95	6.21
Americas	Total	2.015	6.80	26.715	8.49	13.26
	Brazil	1.206	4.07	18.098	5.75	15.01
	Paraguay	0.188	0.63	3.384	1.07	18.00
Asia	Total	3.793	12.79	84.252	26.76	22.21
	Cambodia	0.282	0.95	7.722	2.45	27.41
	China, mainland	0.303	1.02	4.954	1.57	16.36
	India	0.183	0.62	6.941	2.20	37.93
	Indonesia	0.666	2.25	17.749	5.64	26.64
	Philippines	0.216	0.73	2.560	0.81	11.84
	Thailand	1.466	4.94	30.108	9.56	20.54
	Viet Nam	0.525	1.77	10.566	3.36	20.14
Oceania	Total	0.022	0.07	0.266	0.08	12.00
	Papua New Guinea	0.016	0.05	0.156	0.05	9.81
	Fiji	0.004	0.01	0.086	0.03	20.00

Source: Authors computation from FAOSTAT, 2021 produce reasonable yield (Otekunrin and Sawicka 2019). This attribute confers on cassava a reliable food security for farming households in the tropics (Ikuemonisan et al 2020) in addition to providing dietary energy for close to a billion people and livelihood for millions of farmers/processors and traders worldwide (FAO, 2018; Ikuemonisan et al 2020). Cassava is recognized as a subsistence crop to overcome food insecurity for the fast-growing population in areas prone to important climatic changes (Chavez et al 2005, Lobell et al 2008, Burns et al 2010). Cassava is a choice crop for rural development, poverty alleviation, economic growth and ultimately, food security (FAO 2018) and is tolerant to drought and its roots can maintain their nutritional value for a longer time without water and thus, it may represent the future of food security in some developing countries (Elsharwey et al 2003). Few cassava varieties are promoted in food insecure northern areas of Ethiopia. Sheela Immanuel et al (2019) reported that cassava is highly suitable for intercropping/farming systems in Kerala and Tamil Nadu for ensuring livelihood and food security of the farmers.

Cassava is by far the most important root crop grown in the tropics and it forms a dietary staple in many African countries. In the early 1970s the cassava mealybug, *Phenacoccus manihoti,* thrived as it had no enemies in nature and by the late 1970s the pest started damaging as much as 80% of the cassava crop in some areas and it was dispersing rapidly leading to extensive famine and economic and environmental calamity. The 1995 World Food Prize was awarded to Dr. Hans R. Herren, a Swiss-born entomologist made a dramatic and highly successful effort to rescue one of Africa's most important food crops the cassava plant which is a key source of the food consumed by 200 million people from a pest that threatened its total destruction, and in the process averted extensive famine otherwise which would have cost 200 million of Africans lives. (Food and nutrition bulletin, 1996). In the Southern Ethiopia, particularly in Amaro-Kello area, cassava is used as a staple food. In Wolayta and Sidama Zone, cassava roots are widely consumed after boiling or in the form of bread or “injera” (Ethiopia staple food) after mixing its flour with that of some cereal crops such as maize, wheat, sorghum, or teff. Preliminary reports from the southern region of the country suggest that cassava is consumed more frequently in low-income households, and fills the food shortage periods of the year, when supplies of cereal crops such as maize and teff are short (Haile 2015, Balta et al 2015, Legesse and Geta 2015). Cassava is a crop which does not fail and whose food quality is generally improved through processing (Falade and Akingbala 2010). In developing countries, cassava root is a valuable food and energy source and optimum post-harvest handling, processing and storage techniques alleviate some concerns of food insecurity (Uchechukwa-Agua et al 2015). Roots and leaves, which constitute 50 to 60% of the mature cassava plant, respectively, are the nutritionally valuable parts of cassava (Tewe and Lutaladio 2004). The edible green leaves of cassava are a good source of protein, vitamins and minerals and are often used to augment the rural diet (Bradbury and Holloway 1988). The root is a physiological energy reserve with high carbohydrate which ranges from 32 to 35% on a fresh weight (FW) basis, and from 80 to 90% on a dry matter (DM) basis (Julie et al 2009). Cassava (*Manihot esculenta* Crantz.) is considered as the future food security crop because of its biological efficiency coupled with ability to sustain climate change. The calcium content is relatively high compared to that of other staple crops and ranges between 15 and 35 mg/100 g edible portion. The vitamin C (ascorbic acid) content is also high and between 15 to 45 mg/100 g edible portions (Charles et al 2004). Raw cassava root has more carbohydrate than potatoes and less carbohydrate than wheat, rice, yellow corn,

Table 2. State-wise area, production and productivity of cassava in India during 2017-18

States/UTs	Area ('000 ha)	Production ('000 t)	Productivity (t/ha)	% share of area	% share of production
Tamil Nadu	89.61	2862.14	31.94	51.85	57.83
Kerala	54.73	1725.98	31.54	31.67	34.87
Andhra Pradesh	12.68	192.15	15.15	7.34	3.88
Nagaland	5.47	79.32	14.50	3.17	1.60
Assam	3.12	28.87	9.25	1.81	0.58
Meghalaya	5.49	36.24	6.60	3.18	0.73
Karnataka	1.08	13.99	12.95	0.62	0.28
Madhya Pradesh	0.28	4.29	15.32	0.16	0.09
Other states	0.37	6.65	13.13	0.21	0.13
India	172.82	4949.62	28.64	100	100

Source: Prakash et al 2020

and sorghum on a 100 g basis (Montagnac et al 2009b). Cassava root is an energy dense food and it produces about 250,000 calories/hectare/day, which ranks it before maize, rice, sorghum, and wheat (Okigbo 1980). Roots contain small quantities of sucrose, glucose, fructose, and maltose (Tewe and Lutaladio 2004).

In the tropical regions, cassava is the most important root crop and, as a source of energy, the calorific value of cassava is high, compared to most starchy crops. The starch content of fresh cassava root is about 30% and gives the highest yield of starch per unit area. The protein content ranges between 1-3% but contains significant amounts of iron, phosphorus and calcium and is relatively rich in vitamin C (Enidiok et al 2008). Cassava flour is highly recommended in the diet of celiac patients who require strictly gluten free food products (Briani et al 2008). Cassava is the fourth most important source of calories in Africa (FAO, 2020). For some countries of Africa, approximately 25 % of the daily calorie intake is provided by cassava (De Souza et al 2016). However, cassava has been less well studied compared to other crops despite its importance as a food in many of the developing countries (Leal et al 2014, Varshney et al 2010).

Cassava produces more food energy per unit of cultivated land than any other staple crop in sub-Saharan Africa (De Bruijn and Fresco, 1989; Plucknett et al 2000). Cassava has remained a vital crop for food security and income generation in the country contributing about 25% of cash income in many households (COSCA Tanzania 1996). Cassava is widely used for staple foods, livestock feeds, processed foods, and starch production, mainly in tropical Asia and Africa (FAO 2013). Cassava has achieved considerable agricultural importance as a staple food for more than 500 million people, especially in the tropics (Egan et al 1998). Cassava withstands difficult growing conditions and long storability underground makes it a resilient crop, contributing to food security (Amelework et al 2021). Low input requirements, tolerance to drought, the capacity to grow in marginal soils and long-term storability of the roots in the ground make cassava a resilient crop for food and nutritional security (Jarvis et al 2012). Cassava production and the demand are expected to grow largely because of the crop's ability to withstand drought and provide yields on marginal and low-fertility soil conditions. Many countries in the world have realized the economic potential of the crop as a food, feed, and industrial crop. In Africa, the demand for cassava production has been mostly driven by its food applications, but in Asia the demand was mainly for industrial applications for starch, livestock feed and biofuel production. (Amelework et al 2021).

Presently, Nigeria grows more cassava more than any other country in the world. Production is driven primarily by the demand for food for its nearly 130 million inhabitants and the rest very little is used for feed and industry. Cassava is the most widely cultivated crop in the country and it has a major role in the food security of the rural economy because of its ability to yield under marginal soil conditions and its tolerance to drought. Agro-processing and value addition are the platform for employment and wealth creation in the cassava sub-sector. The conversion of cassava into various forms for food, feed, and industrial raw material has the potential to help Nigeria to improve its food security situation, diversify its manufacturing base, generate income and employment and achieve a favourable balance of trade (Ezedinma et al 2007). Cassava provides livelihood security to about 10 lakh farm families in India (Ana Raj et al. 2022).

The relative importance of these crops is evident in their annual global production, which is approximately 836 million tonnes (FAO 2013). Tubers are known as functional foods and possess nutraceutical ingredients that have a major role in disease reduction and wellness (Chandrasekara and Kumar 2016). The contribution of roots and tubers to the energy supply in different populations varies with the country. Cassava is a low-cost source of calories accessible to humans and animals (Tolukari 2004). In Africa, nearly 88 % of cassava produced is used for human consumption, and the remaining 12 % is used as feed for animals and starch-based products (Henry et al 1998). Cassava serves as a source of income for rural people. The inherent characteristics of cassava make it attractive to small farmers. As cassava is a carbohydrate-rich crop, it provides dietary energy to humans. The tubers are processed into various granules, pastes, and flours, consumed in boiled forms or raw (Nweke et al 1998). Tropical tuber crops supply food of 28.5 kg/head/year and 75 kcal energy/head/day (Nayar 2014). The energy content and nutritional values reveal the importance of cassava to readdress the issues like 'food insecurity' and 'malnutrition', especially with climate change (Nedunchezhian et al 2016). Cassava production has significantly increased in the Sub Saharan Africa agri-food systems as a rural food staple, source of cash income, famine reserve crop, and urban food staple, and with increased interest in its potential for animal feed in processed form, industrial uses, and a source of foreign exchange (Spencer and Ezedinma 2017). Once the cassava roots attain maturity, they can be stored in underground conditions for two years and harvested as per the food need of the households (Sanchez et al 2013).

In Nigeria, over 70% of the cassava yield is processed into Gari (Sanni and Olubamiwa 2004). Gari is a creamy white, starchy, pre-cooked grit produced by fermenting the peeled, washed, and mashed cassava roots dehydrated, sieved, and roasted (Onyekwere 1989). Gari is the most commercial and useful product of cassava processing. It is creamy white, pregelatinized, granular and calorie rich food with bit sour taste (Falade and Akingbala 2010). As cassava is an important food and source of energy, better postharvest handling, processing, and storage methods can reduce food insecurity to a certain extent (Uchechukwa-Agua et al 2015). Cassava also addresses the issue of poverty by providing food security to the marginal people who are devoid of fertile land for cultivation. The cost of production may be reduced if family labour is deployed and little attention is given in the initial stages of crop growth.

Biofortification has the potential to improve the nutritional status and health of poor populations in rural and urban areas in developing countries (Saltzman 2013). Katz et al (2013) stated that cassava holds great potential for pro vitamin A bio fortification. Randomised control trial conducted in Kenya with children aged 5-13 years old revealed that a small improvement in the vitamin A status of children fed provitamin A-biofortified cassava (test group), was significant compared to children who were fed non-biofortified cassava (control group) as reported by Talsma et al 2014. Developing biofortified cassava varieties may address the hidden hunger problem in developing countries and it helps in improving the food and nutritional status of the targeted poor population. Nutritional education combined with health programmes will improve the consumption of the biofortified crops.

Cassava as an income and employment generation crop: The roots are rich in energy, starch and soluble carbohydrates, but poor in protein. It is important not only as a food crop, but also as a source of income for rural households (Awotona and Oladimeji 2020). Intercropping of root and tuber crops with plantation crops is common in Andaman and Nicobar islands, especially in small and medium-sized land holdings, to augment the net income and employment opportunities. In such farms, the produce from the perennials generates cash income, while the starchy root and tubers partially meet the farm family's food requirements and farm animals' feed needs (Sankaran et al 2014). Using cassava would break the vicious cyclic effect associated with its production, increase stakeholders' income, create more jobs, solve some health problems, and reduce dependence on wheat as a staple crop (Kaur and Ahluwalia 2017). Cassava also has the potential to increase farm income, reduce rural and urban poverty and help close the food gap (Nwakor and Nwakor 2012). Although cassava plays an important role as a food security crop in sub-Saharan Africa, it is also used as a cash crop in various cassava-growing regions (Spencer and Ezedinma 2017, Munganyinka et al 2018). Cassava is important, not as a food crop alone but even as a major source of income for rural households. Due to its inherent characteristics, it is more attractive, especially to the smaller farmers. It is rich in carbohydrates and provides a basic daily source of dietary energy. Roots are processed into a wide variety of granules, pastes, flours, or consumed freshly boiled or raw (COSCA Tanzania 1996). Cassava roots serve as an efficient source of carbohydrate food energy, cultivated widely for its ability to withstand harsh environmental and agronomic conditions as well as to its utilization as raw material for many uses and food products (Akoroda 1995).

Cassava is now one of the priority crops to be used as a means to wriggle out of the menace of unemployment in the country (Olukunle 2013). Legesse (2013) concluded that in one of the districts (Amaro), in the southern region, the households that were involved in cassava production were better off regarding calorie intake and income than the households which did not cultivate cassava. Cassava is an important food and cash crop for many rural households in Imo State. As a cash crop, cassava generates cash income for a greater number of households when compared to other staples (Adeniji et al 2000). Cassava is a source of income for farmers with small holdings and is also used as raw materials for industrial purposes (Onabola and Bokanga 1998, Sanni et al 1998).

Cassava processing was a profitable business and could be a source of livelihood for most rural dwellers, particularly women (Ojo et al 2015). Among all the cash crops in Nigeria, cassava production plays a significant role in securing the livelihood of the rural poor and providing a sustainable avenue for value chain actors to create advantage (Ho et al 2019). Women play a central role in Nigerian cassava production, processing and marketing (Enete et al 2002), and provide much of the labour associated with cassava production. In particular women perform the majority of cassava processing in Nigeria (Curran et al 2009, Walker et al 2014). Even women's participation is more in cassava cultivation in states like Kerala and Tamil Nadu in India which supports women to earn their income and maintain their families. Cassava products namely gari, cassava flour (lafun), fufu and starch were the major products from cassava processing and that it provided full employment for 81% of the cassava processors. Cassava processing was a source of employment for majority of the processors and also had ability of alleviating poverty among the rural folks (Ojo et al 2015) and are often considered as an entry point for targeting market interventions to the rural poor, particularly women (Forsythe et al 2015). The vast majority of cassava roots are processed at the village by small-scale methods into many different products that cater for local preferences.

Small-scale processing machines namely graters, mills and press are available in the cassava producing zones of Nigeria (Nweke 1994, Ezedinma and Oti 2001).

Value-added traits for developing new products and new markets could offer a huge potential for promoting cassava production of amylose-free (waxy) cassava which has multiple food and industrial applications; varieties with small granule starch which is used in rapid hydrolysis for the ethanol industry; varieties with high beta-carotene content to aid vitamin-A deficit areas; and forage varieties which could provide a strategic animal component into small-holder systems (American Conference 2014). Cassava production in Kogi State, Southern Guinea Savannah Region of Nigeria was subsistent about two decades ago, but now it has become a cash crop, providing food, employment and income in a sustainable manner to millions of people in the State. The cassava value chain has been able to meet the challenges of the nation through job creation, wealth generation and industrialization. Gari processing factory was the highest employer of labour, while cassava production employed the least number (Alhassan 2020). Cassava cultivation also serves as an important source of employment and income in rural, and often marginal areas, and especially for women (Muimba-Kangolongo 2018). Women play a major role in most processing operations (peeling, sieving, toasting, fermenting, cooking, pounding and wrapping of pounded cassava), while men dominate in grating and dewatering because they work with the machineries (Amadi and Ezeh 2018). Polthanee et al (2016b) reported that roots yielded 24 t/ha by crops sampled in the 4th year of intercropping cassava with rubber in the farmer field, and providing cash income about 763 US$/ha/year. Cassava is widely cultivated in tropical regions by small-scale resource-limited farmers, who cannot afford to buy agro-chemicals or install irrigation systems (Costa and Delgado 2019).

Cassava contributes to household food and nutritional security and also ensures the economic security of the farmers with an array of value-added products and plays an inevitable role in fulfilling numerous needs of the people, and thereby significantly contributing to attaining the Sustainable Development Goals (SDGs). Cassava is an established commercial crop as its roots are utilized in an array of products for human food as fresh or processed roots, starch and flour for food and industry, and animal feed. In China, cassava meets the basic needs of food security and income generation, while animal feed in Vietnam. Root and tuber crops are preferential crops over cereals by the farming community and the end consumers, and it forms a major part of programmes, policies, and strategies that are devised to enhance the economic upliftment of the rural population (NRC 2006).

Laode Geo (2020) showed that the average amount of cassava farm production is 1.14 kg per farmer. The average income received by each farmer is Rp. 6,115,969. The efficiency level of 6.10 means that cassava farming is efficient and feasible to be developed. The prospects of cassava for cash were further enhanced with the development and diffusion of improved, small-scale processing equipment (Oppong-Apane 2013, Spencer and Ezedinma 2017). Utilization of about 30 to 40% of leaves from castor and tapioca plantations for Eri culture without affecting the seed/tuber production can fetch the farmers' substantial additional income apart from the regular earnings to the poor dry land cultivators besides providing gainful employment to the women. It is established that about 25% of leaf plucking in tapioca would not affect the average tuber yield (Bhat et al 1991).

Cassava as famine saviour and insurance crop: Cassava has been called “the drought, war, and famine crop” because it can be grown in challenging conditions and it can be harvested when needed providing a reserve of food in times of war and famine (Burns et al 2010) and has a role as a famine-reserve crop since it has the ability to withstand infertile soils, drought, and uncertain rainfall, and it can have delayed harvest of tubers until needed (James and David 2021). Ambayeba (2018) also stated that it is cultivated as a famine reserve crop, it is flexible for cultivation under a mixed-farming system, contributing to food diversification over a long period of time and providing food at the critical moment of the hungriest seasons, thus mitigating the effect of shortfall of other crop cereals. In areas where cassava is a main staple, people process them into storable products such as tapioca starch, dough and gari. It plays a major role in efforts to alleviate the African food crisis because of its efficient production of food, year-round availability and tolerance to extreme stress conditions. Cassava roots can be stored underground for nearly 24 months after maturity, and it can be harvested at any time when a household needs food (Sanchez et *al* 2013).

The cassava crop saved the people of the erstwhile Travancore province from famine during World War II (1939-45). During this period, the import of rice from Burma (Myanmar) came to a halt, and cassava also saved the people during subsequent times whenever food was scarce and was primarily used as a substitute for rice (staple) by the people of low-income strata (Edison et al 2006). Due to its inherent tolerance to stressful environments, where other food crops fail, it is often considered a food-security source against famine, requiring minimal care (Kamaljit and Preethi

2017). Many developing countries referred tuber crops as the 'drought, war, and famine crop' due to their versatile nature (Pearce 2007). Tuberous roots can be made to remain in the soil for up to three years during agricultural and social instability periods (Lebot 2009). This provides 'insurance' against social disruption, prolonged droughts, or other periods of stress and unrest. Tuber crops are 'famine-secure, drought-tolerant, grows well on poor soil, relative insect and pest resistance, produces high carbohydrate per hectare compared to other crops, remain in the ground for a more extended period before harvesting'. These characteristics are the major factors that make these crops acceptable to small farmers (Nweke et al 2002, Roza 2011). The cassava transformation encompasses four stages that indicate specific importance: famine-reserve, a rural food staple, livestock and industrial materials, and urban food staple (Umeh 2013).

In African, Caribbean and Pacific (ACP) countries, root and tuber crops contribute to the income and nutrition of a large majority of the population, especially the resource-poor rural farmers and village processors. Root and tuber crops act as insurance crops and provide safety shields for hunger and natural disaster. For instance, in Sierra Leone, when it was safe to return to the villages during the devastating war, Sierra Leoneans did not find cereals but found cassava waiting for them. Such stories are repeated everywhere in ACP, especially by countries seeking economic drivers. The Caribbean found the best utilization of RTCs in the diversification programmes as an option for food and nutrition security (Chandra 2010). Burns et al (2010) stated that cassava is essential for small and big-scale plantations as it needs low nutrients and can tolerate dry conditions with less cost involved in its propagation. It is sometimes referred to as the 'drought, war, and famine crop of the developing world' and reliance upon this crop is expected to increase in the coming years as the global climate change.

Cassava as a climate-resilient crop for livelihood security of farmers: Climate change poses many challenges to humanity in the present scenario. The IPCC (2007) defines climate change as 'a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and the variability of its properties, and that persists for an extended period, typically decades or longer'. Adaptation is expecting the undesirable effects of climate change and taking proper steps to prevent or mitigate the damage caused or encashing the opportunities it may cause (IPCC 2007). Farmers always decide what they should produce and how to maximize their economic returns. Cassava is a drought tolerant crop and has a great ability to survive under uncertain rainfall patterns (El-sharkawy 1993). In addition, cassava is tolerant to acidic soil conditions and it can grow on poor soils (De Tafur et al 1997, FAO 2010, FAO, 2013). Cassava can withstand significant periods of drought stress. Mechanisms of drought tolerance in cassava is due to the partial stomatal closure to reduce transpiration (El-sharkawy and Cock 1984, Alves and Setter 2000), reduction in leaf canopy (Connor and Cock 1981, Ike and Thurtell 1981, Polthanee et al 2016a) and extensive root systems (El-sharkawy 2007). Cassava is resistant to adverse environments (El-Sharkawy 2003). It has also been suggested that cassava could be more resilient to climate change than other staple crops (Jarvis et al 2012). Cassava, the crop itself, has few mechanisms to tolerate stress. To adapt to climate change, farmers can cultivate cassava in their fields to reduce crop loss and get returns for their livelihood.

Chitiyo and Kasele (2004) stated that the climate-resilient approach can be implemented not only through crop diversification but also by growing low-input crops like cassava (*Manihot esculenta* Crantz), known to tolerate drought, acidity, and low soil fertility (Asher et al 1980, Challinor et al 2007). Cassava is the best alternative crop to combat climate change. Jarvis et al (2012) reported that compared to African staples such as maize, sorghum, and millets, the cassava crop is not affected by the nature of soil and changes in weather conditions. The adaptation strategies of small farmers are conservation agriculture and the production of drought-tolerant crops that thrive in all soils (Herrera Campo et al 2011). Studies indicated that cassava cultivation has the least impact on environmental parameters compared to the other major food crops, such as rice, maize, and sorghum (Reynolds et al 2015). Studies highly recommend the adaptability of cassava in regions with higher temperatures, and it can tolerate up to 40 °C (El-Sharkawy et al 1984). Cassava can be grown even in low fertile soil without many inputs, and it can be harvested after the growth period so that the farmers can harvest it as per their requirements. Thus, the cassava crop support the farmers to cope with the climate vagaries and provide them with livelihood security.

CONCLUSION

Cassava is an important crop to reduce poverty throughout the world because of its climate-resilient nature; and also, it grows in marginal soil, and it is less capital intensive. It forms a staple food in many countries, and it forms the primary source of carbohydrates for people. The tubers can be termed insurance crops as they can be stored in the soil by using appropriate methods to be used when there is a need. In Tamil Nadu and Kerala, many farmers earn their livelihood through cassava farming. These crops should be propagated in non-traditional areas to increase the area and production. Cassava can be grown as intercrops, which suits the integrated farming system well and fetches additional revenue for the farmers, and the field can be used efficiently. There is ample scope of tuber crops-based cropping/farming system to serve as a livelihood activity. It may be adopted on a larger scale as it contributes to livelihood. Sequential cassava cropping with paddy and pulses may be adopted to maintain soil fertility, which will help food and nutritional security. Moreover, the crop has good potential for value addition in food products, which is an added advantage where it can support the establishment of small village-based production units with the support of the Government and other funding agencies. Under ICAR-CTCRI NEH programme, it was observed that even modest postharvest value addition interventions such as cassava slicers, chipping machines, and graters could bring desirable changes among farmers in their postharvest management. When coupled with adopting new cassava varieties, appropriate value chain interventions can play a significant role in the livelihood enhancement of farmers.

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Climate Change Impacts on Rainfall Extremes and Historical Rainfall Trends Over Upper Krishna River Basin, Maharashtra, India

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***Abstract*:** The present study was an attempt to examine the spatiotemporal variability of precipitation over a part of the Upper Krishna River Basin confined in Maharashtra state having a geographical area of 15,190 km^2. Daily rainfall data of 15 stations located in the study area for the period of 52 years from 1970 to 2021 were analysed using Man-Kendall's test and Sen's slope estimator test. Almost all stations showed a non-significant rising trend in monsoon rainfall out of which four stations viz. Shahuwadi (12.53 mm/year), Sangli (2.27 mm/year), Karad (3.51 mm/year), and Wai (4.83 mm/year) showed a significant rising trend in monsoon rainfall. Islampur and Tasgaon stations located in Sangli district showed non-significant falling trend. For the decade 2010-2020 all stations showed rising trend in annual rainfall. Six stations in Kolhapur and Satara districts of Maharashtra viz. Kolhapur, Hatkalangale, Shahuwadi, Panhala, Satara, Mahabaleshwar, Wai, and Koregaon showed the presence of extreme rainfall events in the last three decades. Also, many stations observed a rise in the total number of heavy rainfall days for the last decade.

***Keywords*:** Trend analysis, Man-Kendall's test, Extreme event analysis, Upper Krishna River Basin

Water is one of the most important factors influencing the agricultural production. In India precipitation is majorly in the form of rainfall. The annual rainfall is the important factor for determining the availability of water for agriculture and other usages. The changes in the pattern of rainfall affect the availability of water as well as increases the danger of frequent draughts and floods. It is therefore essential to study trends in rainfall. Indian monsoon rainfall as a whole does not show any specific trend, but over some specific areas of country significant trends were observed in the annual rainfall. As an influence of changing climate, a decreasing trend in the all-India annual, as well as summer monsoon mean rainfall during 1951-2015, was observed over the Indo-Gangetic Plains and the Western Ghats with the increase in the frequency of localized heavy rain occurrences over India (Kulkarni et al 2020). Consequently, regional trends in rainfall patterns need to be studied carefully.

In the present study a part of the Upper Krishna sub-basin contributing runoff up to Kurundwad (located in Kolhapur district) was selected to observe rainfall trends. Krishna river basin is the second largest river basin (22.6 % of the geographical area) of Maharashtra. Out of seven sub-basins of Krishna, a part of Upper Krishna, Upper Bhima, and a small part of Lower Bhima falls in Maharashtra (Sharma and Paithankar 2014).

Studies on variability in the rainfall patterns over the Krishna River basin and its sub-basins for analysing trends of drought events, occurrences of rainfall extremes, and spatiotemporal rainfall variability (using IMD gridded rainfall dataset) have been reported by various workers (Mahajan and Dodamani 2015, Tirupathi et al 2018, Harshavardhan et al 2020).

Harshavardhan et al (2020) found significant trends in annual and seasonal rainfall over the Krishna River Basin based on IMD gridded rainfall datasets. In the present study, an attempt has been made to perform the station-based rainfall variability analysis for the upper Krishna River basin.

MATERIAL AND METHODS

Study area: The Krishna is the second largest eastward draining interstate river basin in peninsular India. The basin is situated between the Deccan Plateau covering large areas of the states of Maharashtra, Karnataka, Andhra, and Telangana. Krishna River drains an area of 2,58,948 km^2. The overall basin area comprises 7 sub-basins. The area selected for the current study is located in the upper Krishna basin partly in the Satara, Sangali, and Kolhapur districts of Maharashtra state having a geographical area of 15,190 km^2. The study area is confined between 73^{0}34'38'' E to 74^{0}50'30'' E and 16^{0}18'50'' N to 18^{0}03'07'' N. Average annual rainfall over the region varied from 636 to 5870 mm over the study period.

Data used: Daily rainfall data of 15 rain gauge stations located in the study area were obtained from India Meteorological Department data portal (Table 1). Daily rainfall data for the period from 1970 to 2021 were summed up to prepare annual, monthly, seasonal (winter (December to February), summer (March-May), monsoon (June-September), and post-monsoon (October-November)) data series. For missing data estimation, three methods viz. normal ratio method, modified normal ratio method, and inverse distance method (Subramanya 1994) were tried for each station with missing data. Station-wise suitable method based on root mean square error and the correlation coefficient was decided and missing data were estimated.

Trend analysis: The presence of a monotonic increasing or decreasing trend was tested using the non-parametric Mann-Kendall test (Mann 1945, Kendall 1995). The magnitude of change was estimated using Sen's slope test (Sen 1968). The significance of the results was tested at 90, 95 and 99 % confidence levels.

Mann-Kendall Test:

The Mann-Kendall statistic S is given as;

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(x_j - x_i) \ldots (1)$$

The test is being applied to sequential time series 'x_i' and 'x_j' with 'n' number of observations.

Where;

$$\mathrm{sgn}\,(x_j - x_i) = \begin{cases} +1, & (x_j - x_i) > 0 \\ 0, & (x_j - x_i) = 0 \\ -1, & (x_j - x_i) < 0 \end{cases} \qquad \ldots (2)$$

the variance statistic;

$$\mathrm{var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18} \qquad \ldots (3)$$

In which, t_i = number of ties up to sample i.

Statistic Z is given as;

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{var}\,(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S-1}{\sqrt{\mathrm{var}\,(S)}}, & S < 0 \end{cases} \qquad \ldots (4)$$

A positive or negative value of 'Z' indicates upward or downward trend, respectively. The significance of the results was tested at 90, 95 and 99 % confidence levels.

Sen's slope estimator test:

Slope (T_j) of the trend line is computed as;

$$T_j = \frac{x_j - x_k}{j - k} \qquad \ldots (5)$$

Where;

Table 1. Data used for analysis

Name of location	Latitude (N) (degrees)	Longitude (E) (degrees)	Period
Kolhapur	16.70	74.23	1970-2021
Shirol	16.73	74.60	1970-2021
Hatkalangale	16.75	74.41	1970-2021
Shahuwadi	16.83	73.95	1970-2021
Panhala	16.83	74.11	1970-2021
Sangli	16.85	74.60	1970-2021
Shirala	16.96	74.15	1970-2020
Islampur	17.05	74.26	1970-2021
Tasgaon	17.03	74.60	1970-2021
Karad	17.28	74.18	1970-2021
Vaduj	17.60	75.45	1970-2020
Satara	17.68	73.98	1970-2020
Mahabaleshwar	17.93	73.66	1970-2021
Wai	17.93	73.90	1970-2021
Koregoan	17.70	74.16	1970-2020

x_j and x_k are data values at time 'j' and 'k' (j>k), respectively. Sen's estimator of slope is given as:

$$Q_i = \begin{cases} T_{\frac{N+1}{2}} & N \text{ is odd} \\ \frac{1}{2}\left(T_{N/2} + T_{\frac{N+2}{2}}\right) & N \text{ is even} \end{cases} \qquad \ldots (6)$$

At the end slope magnitude is calculated by two-sided test at 100(1-α) % confidence level and true slope is obtained by non-parametric test. Positive value of 'Q_i' indicates an increasing trend while negative value gives decreasing trend in the time series.

Extreme event analysis: The entire study period was divided into five decades and the number of events in the category of severe draught, moderate draught, excess rainfall, and extreme rainfall was computed as 'extreme events' for each station. Rainfall events were classified as (Thirupathia et al 2018);

Severe draught: Deficiency of ISMR >50 %

Moderate draught: Deficiency of ISMR between 26-50 %

Dry year: Deficiency of ISMR between 15-25 %

Normal year: ISMR between +15 to-15 %

Wet year: Excess of ISMR between 15-25 %

Excess rainfall: Excess of ISMR between 26-50 %

Extreme rainfall: Excess of ISMR >50 %

Heavy rainfall days: A day is called 'heavy rainfall day' if the rainfall of that day is 64.5 mm or more according to India Meteorological Department. This includes very heavy (i.e., 124.5–244.5 mm) and extremely heavy rainfall (i.e., >244.5 mm) (Guhathakurta et al 2011). Station-wise heavy rainfall days were counted and summed up on a decade basis (Table 6).

RESULTS AND DISCUSSION

Statistical properties of annual and seasonal rainfall: Annual and seasonal rainfall of all stations of Upper Krishna River Basin for the study period 1970-2021 were analyzed using basic statistical indices (Table 2). Annual mean ranged from 557.6 mm to 5870.08 mm. Seasonal mean rainfall varied from 395.72 mm to 5467.22 mm. Overall all stations showed variable deviations in annual and monsoon rainfall from the mean.

Trends in annual and monsoon rainfall: It is essential to analyse trends in precipitation and their spatial and temporal variability in order to identify climate-related changes and recommend suitable water resource management methods for the future. In the study area, trends in monthly, annual, and seasonal, time scales were examined. Station-wise details of trend statistic for annual and seasonal rainfall (Q is mm/year) in UKRB was estimated (Table 3). Almost all stations showed a non-significant rising trend in monsoon rainfall out of which four stations viz. Shahuwadi (12.53 mm/year), Sangli (2.27 mm/year), Karad (3.51 mm/year), and Wai (4.83 mm/year) showed a significant rising trend in monsoon (JJAS) rainfall of variable magnitudes over last 52 years. For, Islampur and Tasgaon stations non-significant downward trend was observed over a study period of 1970-2021 (Fig. 1).

In the case of annual total rainfall; a significant decreasing trend was observed at Tasgaon station (4.23 mm/year) and a significant rising trend was for Shahuwadi (12.71 mm/year) and Sangli station (2.97 mm/year). Out of the remaining

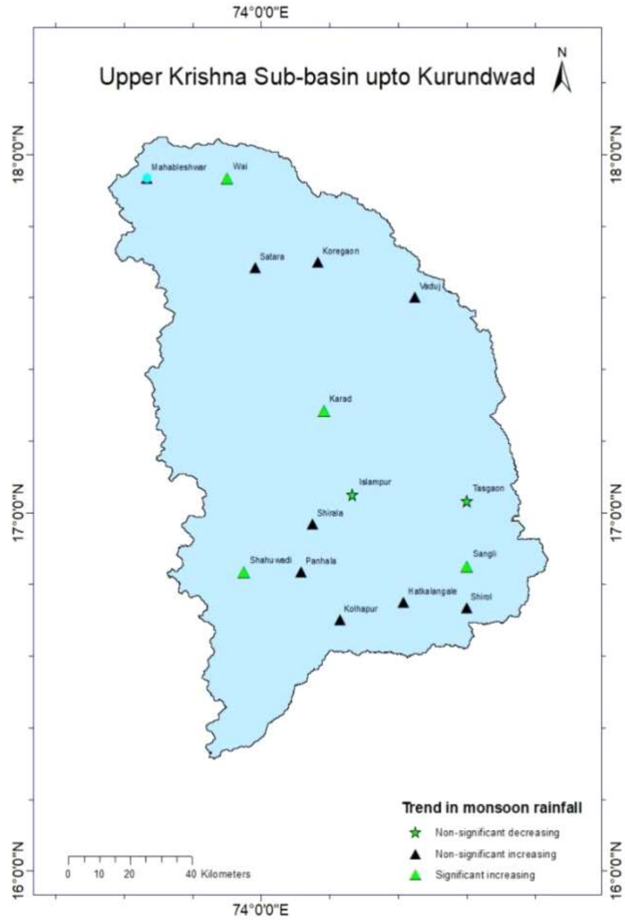

Fig. 1. Location of rain gauge stations and nature of trend for monsoon rainfall

Table 2. Station wise statistical properties of annual and monsoon rainfall

Station	Annual rainfall (mm)		Mean (mm)		Standard deviation (mm)		Coefficient of variation (%)	
	Minimum	Maximum	Annual	Monsoon	Annual	Monsoon	Annual	Monsoon
Kolhapur	568.80	1954.90	1074.89	838.76	284.26	259.92	26.45	30.99
Shirol	193.50	1192.70	636.27	433.65	238.47	168.76	37.48	38.92
Hatkalangale	317.90	1609.60	787.55	555.88	239.00	191.78	30.35	34.50
Shahuwadi	1082.00	3450.50	2070.24	1751.54	518.81	504.49	25.06	28.80
Panhala	918.70	2735.00	1703.80	1464.96	446.46	427.28	26.20	29.17
Sangli	255.20	1690.43	674.33	433.72	230.09	155.71	34.12	35.90
Shirala	481.80	1838.30	1093.19	906.73	282.06	284.07	25.80	31.33
Islampur	291.00	1412.60	734.63	541.71	259.12	213.09	35.27	39.34
Tasgaon	186.60	1142.70	596.47	426.37	213.69	154.45	35.83	36.22
Karad	368.20	1328.00	780.73	594.16	203.23	195.01	26.03	32.82
Vaduj	153.80	1006.10	557.60	395.72	194.68	157.25	34.91	39.74
Satara	583.70	1849.10	1039.56	855.69	279.25	284.42	26.86	33.24
Mahabaleshwar	3514.00	8841.10	5870.08	5467.22	1191.36	1199.08	20.30	21.93
Wai	395.70	1574.30	961.52	702.28	264.74	246.04	27.53	35.03
Koregoan	318.80	1435.50	765.73	586.33	248.11	217.42	32.40	37.08

stations' a non-significant rising trend in annual total rainfall was observed for Kolhapur, Shirol, Hatkalangale, Panhala, Shirala, Karad, Vaduj, Mahabaleshwar, and Wai stations. The rising trend magnitude was of order 0.18 to 12.71 mm/year. Islampur, Satara and Koregaon stations showed a non-significant falling trend.

An entire study period was divided into five decades and trends in annual rainfall magnitudes were also studied on a decadal basis. Mann-Kendall's trend statistic and magnitudes of the trend for the decade 2010-2020 were estimated by Sen's slope estimator method (Table 4). Almost all stations showed a rising trend in the annual rainfall of which, Kolhapur and Shirala stations showed a significant increasing trend in annual rainfall over the last decade (2010-2020). The magnitude of a positive trend was found to be 62.15 mm /year for Kolhapur and 49.78 mm/year for Shirala. Although, statistically non-significant but Mahabaleshwar station showed a rising trend in the annual rainfall of magnitude 150 mm/year over the last decade. For Hatkalangale and Wai non-significant negative trend in annual rainfall was observed over the last decade.

In general, all stations in the Upper Krishna River Basin showed a rising trend in the annual rainfall except four stations viz. Islampur, Tasgaon, Satara, and Koregaon showed decreasing trend in annual rainfall. Therefore, it was concluded that the overall basin was subjected to a rise in monsoon rainfall (Fig. 2).

Extreme rainfall events and heavy rainfall days: Extreme

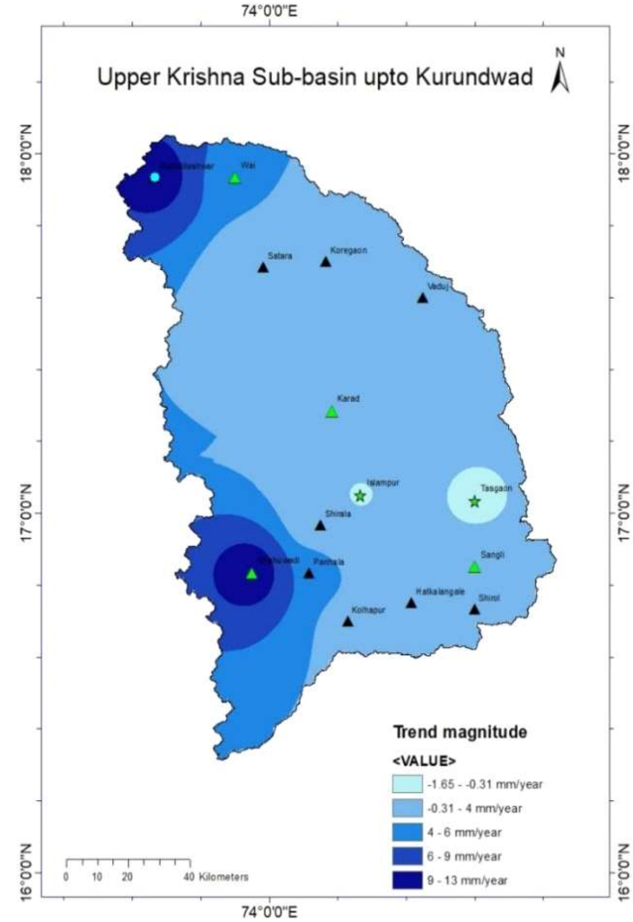

Fig. 2. Magnitude of trend (mm/year) in monsoon rainfall

Table 3. Station wise details of trend statistic (Z) for annual and seasonal rainfall (Q is mm/year) in UKRB

Location	AAR	Annual		Winter		Summer		Monsoon		Post- monsoon	
		Z	Q	Z	Q	Z	Q	Z	Q	Z	Q
Kolhapur	1074.9	0.67	1.63	0.24	0.00	-1.68^{+}	-0.65	1.37	3.12	0.17	0.15
Shirol	636.3	0.08	0.18	0.51	0.00	-1.52	-0.52	0.45	0.92	0.41	0.28
Hatkalangale	787.5	0.84	1.74	0.88	0.00	-2.50*	-0.89	1.43	2.13	1.33	1.00
Shahuwadi	2070.2	2.79**	12.71	0.65	0.00	-0.72	-0.13	2.83**	12.53	-0.18	-0.19
Panhala	1703.8	1.19	5.56	0.50	0.00	-2.01	-0.57	1.51	5.95	0.42	0.35
Sangli	674.3	1.79^{+}	2.97	1.00	0.00	-0.02	0	1.95*	2.27	1.86^{+}	1.40
Shirala	1093.2	0.15	0.40	0.15	0.00	-1.14	-0.38	0.33	1.26	-0.51	-0.40
Islampur	734.6	-0.51	-1.69	0.99	0.00	-2.27*	-0.54	-0.44	-0.71	0.71	0.60
Tasgaon	596.5	-1.93^{+}	-4.23	0.14	0.00	-3.18*	-1.17	-0.86	-1.66	-0.73	-0.53
Karad	780.7	1.45	2.64	-0.31	0.00	-2.21*	-0.64	2.56*	3.51	-0.09	-0.09
Vaduj	557.6	0.79	-1.47	-0.28	0.00	-1.96	-0.39	1.62	2.88	-0.18	-0.14
Satara	1039.6	-0.08	-0.20	0.44	0.00	-1.96	-0.64	0.47	1.17	0.16	0.10
Mahabaleshwar	5870.1	1.19	12.57	1.19	0.00	0.06	0.07	1.05	11.03	0.59	0.66
Wai	961.5	1.60	3.55	-0.36	0.00	-1.92^{+}	4.83	2.11*	4.83	-0.20	-0.21
Koregoan	765.7	-0.52	-1.36	-0.38	0.00	-2.18*	-0.63	0.21	0.39	-0.63	-0.48

+ Significant at 90 % confidence interval; * Significant at 95 % confidence interval, ** Significant at 99 % confidence interval

Table 4. Trend in annual rainfall during period 2010-2020

Station	Trend statistic (Q) & magnitude of trend (Z, mm/year)	
Kolhapur	Z	2.40
	Q	62.15
Shirol	Z	1.03
	Q	20.23
Hatkalangale	Z	-0.34
	Q	-4.14
Shahuwadi	Z	0.75
	Q	15.92
Panhala	Z	1.30
	Q	78.23
Sangli	Z	1.58
	Q	29.92
Shirala	Z	2.02
	Q	49.78
Islampur	Z	0.00
	Q	-2.09
Tasgaon	Z	0.89
	Q	27.64
Karad	Z	1.44
	Q	16.95
Vaduj	Z	1.56
	Q	48.63
Satara	Z	0.62
	Q	24.23
Mahabaleshwar	Z	1.44
	Q	150.55
Wai	Z	-0.34
	Q	-14.69
Koregaon	Z	0.47
	Q	13.60

rainfall events represent the years with an excess of ISMR by 50 % or more. Six stations in Kolhapur and Satara districts of Maharashtra viz. Kolhapur, Hatkalangale, Shahuwadi, Panhala, Satara, Mahabaleshwar, Wai, and Koregaon showed the extreme rainfall events in the last three decades (Table 5). Whereas, for the rest of the stations' the number of extreme rainfall events was more or less the same throughout the study period. Six stations Kolhapur, Shahuwadi, Pahnala, Karad, Mahabaleshwar, and Wai were observed with rise in the total number of heavy rainfall days for the last decade (Table 6).

CONCLUSION

Analysis of the trend in annual and seasonal rainfall over the Upper Krishna River Basin was performed using observed daily rainfall data from 1970 through 2021. The entire Upper Krishna River Basin was observed with a positive trend in annual and monsoon rainfall. An increase in the occurrence of extreme rainfall events was observed in many parts of the basin in Satara and Kolhapur districts of Maharashtra. Occurrences of heavy rainfall days in many stations of the basin in Satara and Kolhapur districts particularly during 1990 -2020 (last 3 decades) from a total study period of 52 years were also observed. This indicated that, rainfall over a part of the Upper Krishna River Basin in Maharashtra had been significantly altered due to the effects of climate change. This analysis may be supportive in the planning of mitigation measures for controlling future extremes.

Table 5. Station wise number of extreme rainfall events

Name of location	Number of extreme rainfall events (excess of ISMR>50 %)				
	1970-1979	1980-1989	1990-1999	2000-2009	2010-2021
Kolhapur	0	0	0	2	1
Shirol	0	2	1	2	1
Hatkalangale	0	0	1	3	2
Shahuwadi	0	0	0	2	1
Panhala	0	0	0	3	1
Sangli	0	0	1	2	0
Shirala	0	1	0	1	2
Islampur	1	0	1	2	1
Tasgaon	1	2	1	1	1
Karad	1	0	1	3	1
Vaduj	0	1	0	2	2
Satara	0	0	0	2	1
Mahabaleshwar	0	0	0	2	1
Wai	0	0	1	2	1
Koregoan	0	0	0	3	1

Table 6. Station wise number of heavy rainfall days

Name of location	Number of heavy rainfall days (daily rainfall > 64.3 mm)					
	1970-1979	1980-1989	1990-1999	2000-2009	2010-2021	Percent rise /fall
Kolhapur	12	12	12	11	22	100.0 (In last decade)
Shirol	10	5	9	8	4	random pattern
Hatkalangale	3	5	6	11	8	100.0 (In last 3 decades)
Shahuwadi	41	38	68	77	72	28.5 (In last 3 decades)
Panhala	32	23	58	49	54	52.0 (In last 3 decades)
Sangli	5	10	8	14	6	random pattern
Shirala	20	14	18	13	19	random pattern
Islampur	9	8	10	10	1	-89.2 (In last decade)
Tasgaon	9	9	9	2	3	-72.2 (In last 2 decades)
Karad	7	5	12	13	10	83.3 (In last 3 decades)
Vaduj	10	6	4	6	7	random pattern
Satara	21	16	16	22	20	random pattern
Mahabaleshwar	291	248	309	298	362	26.6 (In last decade)
Wai	12	12	23	21	16	66.7 (In last 3 decades)
Koregoan	6	6	8	16	5	random pattern

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Evaluation of Soil and Water Conservation Interventions Impact on Water, Crop and Economic Resources Development: A Case Study of Karma Micro-Watershed in Eastern Plateau of India

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***Abstract*:** Strategic management of soil and water conservation measures for water resources generation through small farm pond reservoirs to harvest rainfall-runoff from agricultural land for crop irrigation are the focal points for enhancing agricultural productivity and economic profitability in semiarid Karma micro-watershed of Bankura, West Bengal, India under IWMP were evaluated for impact of technological interventions on improvement of water, crop and economic resources. The increased pond-water availability augmented irrigated areas by 40.23-46.94% in kharif, 30.53-38.46% in rabi and 23.08-33.33% in summer season after the programme, which encouraged the beneficiary farmers to grow diversified crops across the year. In lowland ecosystem with sporadic stressed water regime, imposition of conservation tillage, stubble mulching, draught-resistant varieties use and low-water consuming short duration crops were advocated. The marginal increase in productivity for Aman paddy (1.75%) and a greater increase for maize (14.16%) after programme were observed. Net income and BCR for Aman paddy increased from ₹ 6165/ha and 1.23 during pre-programme to ₹ 40124/ha and 2.41 during post-programme, respectively due to adoption of specific soil and water conservation technologies.

Keywords: Micro-watershed, Soil and water conservation, Rainwater harvesting, Crop productivity index, Benefit-cost ratio

A micro-watershed is a natural geo-hydrological unit encompassing less than 400 ha area that drains the rainfall-runoff flow to a common outlet. The area with undulating topography causes different degrees of land degradation in terms of severe soil erosion, fertility depletion and water scarcity due to indiscriminate anthropogenic and hostile natural activities along with increasing climate variability that have deleterious effects on agricultural productivity, food and nutritional security and environmental quality (Manivannan et al 2017, Dimtsu et al 2018, Demelash and Stahr 2020, Tilahun and Desta 2021). Rapid deterioration of soil health and water resources is a growing concern in arid and semiarid regions of the world. About 146.8 Mha out of 329 Mha geographical area are degraded in different extents in India by various factors, where water erosion is the most threatening one and accelerates topsoil loss, fertility depletion and land deformation (Bhattacharyya et al 2015, Manivannan et al 2017).The lack of technical knowledge and skills, non-availability of site-specific management interventions and poor resource base of farmers are the key inhibitors for adoption of appropriate remedial measures to restraint such adverse conditions. The suitable watershed management strategy can provide an improved technological support to conserve the precious soil and water resources and its maximum economic utilization for resilience of agriculture, besides strengthening the food and livelihood security to the farming community (Palanisami and Suresh Kumar 2009, Rathod and Rathod 2017, Khan 2018). The tapping and storage of excess rainfall-runoff flow through appropriate rainwater harvesting structures during wet season and its reuse for supplemental irrigation during lean dry season in a planned way is a cost-effective small-scale irrigation strategy to mitigate the worst surface and groundwater conditions and enhance the productivity in rainfed areas (Fazlul et al 2009, Nagaraj et al 2011, Khajuria et al 2014, Kashiwar et al 2016). The integrated watershed management is eco-friendly and climate adaptation strategy for sustaining ecosystem and environment, restoring natural resources, improving agricultural productivity and upscaling the income and livelihoods of the rural people (Pathak et al 2013, Gwozdziej-Mazur et al 2022).

Karma micro-watershed in Purulia district of West Bengal in eastern plateau of India is a draught prone semi-arid area, where agricultural activity is risky and at subsistence level due to acute irrigation water constraints and land degradation. An Integrated Watershed Management Programme (IWMP) with recommended soil and water conservation techniques was launched during 2010-11 and continued its operation up to

2015-16 for conservation and management of precious natural resources for sustainable agricultural development. The watershed technological approaches, specifically the construction or renovation of farm pond structures, were more focused for in-situ harvesting and storage of excess rainfall-runoff water to guarantee assured irrigation facility for crop production over the year. But till date, no comprehensive data based scientific literatures is available on the integrated effects of watershed technologies on changing agricultural production scenario in the area. In these perspectives, the present survey-based investigation was carried out to evaluate the impacts of soil and water conservation measures on the availability of irrigation water resources, crop productivity enhancement and economic elevation in the Karma micro-watershed areas.

MATERIAL AND METHODS

Study area: The field survey was conducted in Karma micro-watershed of Balarampur block in Purulia district of West Bengal in the eastern plateau of India during 2017-18. The site is located between 23°5'51.009" to 23°11'12.411" N latitudes and 86°7'45.398"E to 86°13'40.139" E longitudes and the altitude ranges between 165 to 280 m above mean sea level. The watershed covers a geographical area of 813 ha and is characterized by the problems of undulating topography, soil erosion hazards, severe water scarcity and marginal crop productivity. It represents a typical semiarid climate with a hot and dry summer and a cold winter. The variations in Climatological parameters of the study area before and after IWMP are depicted in Figure 1. The area has 1268 mm mean annual rainfall, the most of which is received during June-September. The mean monthly maximum temperature was noticed in May (40.3°C) and mean monthly minimum temperature in December (14.2°C). The mean relative humidity across the year was 46-84%. The soils are mostly red lateritic and sandy loam in texture with high soil porosity and low water holding capacity. Three major soil orders in the site are Alfisols, Entisols and Inceptisols. The farmers are largely small and marginal with poor socio-economic condition. Rainfed agriculture is the main livelihoods of rural people. The farming system is traditional, subsistence and unrewarding. The chances of crop damage or even failure is common in the area due to uncertain or erratic rainfall.

Soil and water conservation practices: The different adaptable soil and water conservation interventions under IWMP such as conservation tillage, stubble mulching, soil and stone bunds, terraces along the contour, grass stripped drainage lines, grassland and farm forestry management and construction or renovation of rainwater harvesting structures (farm ponds, dug wells) for tapping rainfall-runoff flow and recharging shallow aquifers, along with seasonal training programmes for the farmers and other stakeholders were implemented over the five years' period to solve the problems and develop the study area from low-productive to high-productive one with active participation and involvement of the beneficiary farmers.

Construction and renovation of water harvesting structures: The new farm ponds were built-up by excavation in the target area and storage capacity of the existing farm ponds were improved by desilting for harvesting the surplus runoff flown over the micro-watershed areas while IWMP in operational stage. This reservoir water was mainly used for

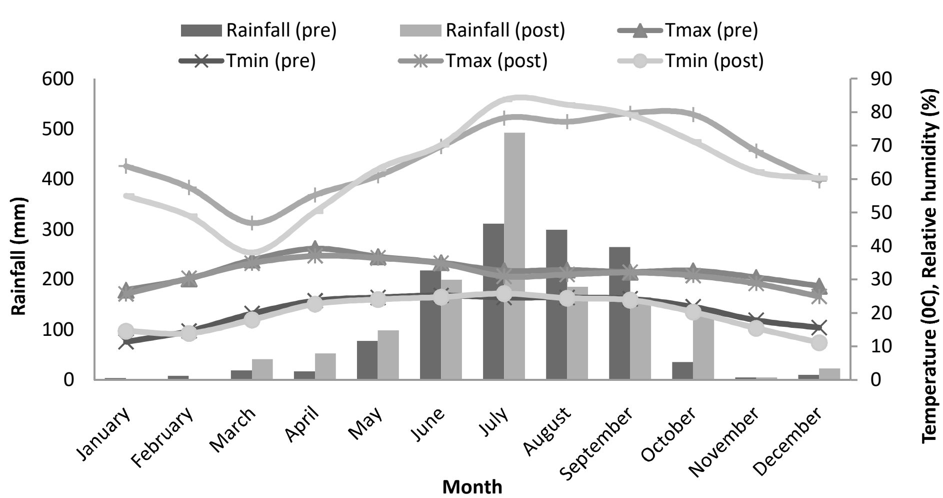
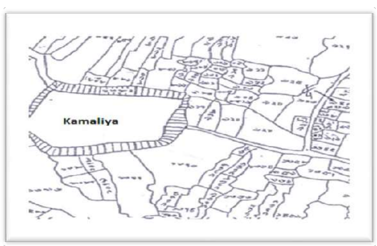


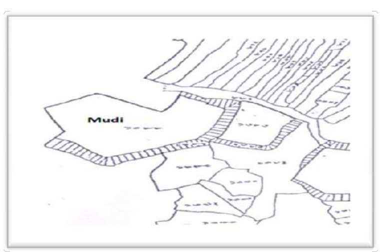
Fig. 1. Mean monthly rainfall, maximum and minimum air temperature (T) and relative humidity (RH) during pre-project (2009-11) and post-project (2017-18) period of IWMP in the study area (Source: Forest office, Balarampur, Bankura, West Bengal)

providing supplemental irrigation during the period of water scarcity (winter and summer crops). Three different sized farm ponds in diverse topographical situations such as pond-1 (Kamaliya village) from low land, pond-2 (Mudi village) from medium land and pond-3 (Charkannya village) from upland of the watershed areas were randomly selected for our investigation (Fig. 2). The configuration of each farm pond was irregular in shape and pond area was calculated by triangular method using Heron's formula (Dunham 1990). The depth of pond water was measured by placing seven bamboo sticks from center to periphery of each pond at equal distance and depth of water was recorded with a measuring tape. The volume of water stored in each pond was calculated by multiplying pond area with average depth of pond water. The data was recorded at monthly interval over a period of two years for each pond. The month-wise volumetric water storage in each farm pond was partitioned into kharif (June-September), rabi (October-January) and summer (February-May) growing seasons.

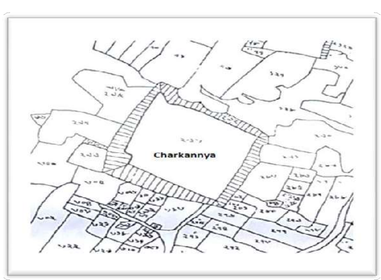
Collection and computation of climatic variables: The secondary sources of month-wise data on climatological parameters such as total rainfall, temperature and potential evapotranspiration (PET) during pre-project (2010-11) and post-project (2017-18) period of IWMP in the watershed area were collected from the forest office, Balarampur, Bankura and their monthly average values were calculated.



Pond-1 (Kamaliya village)
Location: 23.158690 N latitude, 86.205832 E longitude
Pond area: 1.05 ha
Land situation: low



Pond-2 (Mudi village)
Location: 23.159444 N latitude, 86.203056 E longitude
Pond area: 1.26 ha
Land situation: medium



Pond-3 (Charkannya village)
Location: 23.162778 N latitude, 86.198611 E longitude
Pond area: 1.61 ha
Land situation: upland

Source: mouza map of Karma village in Bankura district of West Bengal, India

Fig. 2. Location of small ponds in the Karma micro-watershed

Farmers' households sample survey: The IWMP was started functioning during 2010-11 and continued up to 2015-16 in the Karma micro-watershed. About 315 farmers' households of the area were involved in watershed management activities. One-fifth of the households (61) were randomly selected and the head of each household was contacted personally and direct interview with him was conducted. The primary data before and after IWMP implementation was documented through a set of questionnaires containing the specific information related to the surface water resources induced physical (irrigated area), biological (crop productivity) and economics (net income, BCR) improvement of agriculture due to the adoption of soil and water conservation (SWC) interventions in the area. Based on the highest irrigated area and crop production in *kharif* season under pond-2 ecosystem, the major crops of aman paddy and maize were selected for evaluation of crop productivity index in the micro-watershed area. Accordingly, 27 beneficiary farmers of pond-2 command area were interviewed. The base year for the study was 2010-11 and the assessment year was 2017-18.

Crop productivity index: Crop productivity index (CPI) was determined by the relationship given by Enyedi (1964) as,

$$CPI \quad \frac{\frac{Y}{Yn}}{\frac{T}{Tn}} *100$$

where, Y= production of selected crop in unit area, Yn = total production of same crop in the region, T = area of selected crop in unit area, Tn = area under the same crop in the region.

Economics of aman paddy cultivation: Aman paddy is the main staple crop with highest cultivated area in the area, which was selected for calculation of various costs following the recommendations of Commission for Agricultural Costs and Prices, Ministry of Agriculture, Government of India (CACP, 1965). The different cost concepts used are given below:

Cost A_1= Value of hired human labour, hired bullock labour, owned bullock labour, hired machine labour, seeds (both farm produce and purchase), insecticides and pesticides, manures (owned and purchased), fertilizers, depreciation on implements and farm buildings, irrigation charges, land revenue and other taxes, interest of working capital and other expenses.

Cost A_2 = Cost A_1 + Rent paid for leased in land

Cost B_1= Cost A_1 + Interest on value of owned fixed capital assets (excluding land)

Cost B_2= Cost B_1 + Rental value of owned land and rent paid for leased in land

Cost C_1= Cost B_1 + Imputed value of family labour

Cost C_2= Cost B_2 + Imputed value of family labour

Cost C_3= Cost C_2 + Value of management input at 10% of cost C_2.

The various profitability was determined by using the following economic formula:

Gross income = Main product × Price per unit + By product × Price per unit

Net income = Gross income – Cost C_3

Farm business income = Gross income – Cost A_1

Family labour income = Gross income – Cost B_2

Farm investment income = Net Income + Rental of owned land + Interest on fixed capital

Benefit-cost ratio (BCR) = Gross income / Cost C_3

Cost of production = (Total cost – Value of by product) / Yield of main product

Statistical analysis: The secondary data for the dependent variable of mean monthly variations in depth of water in each pond with the specific values of the independent variables of mean monthly rainfall, temperature and potential evapotranspiration, before and after the IWMP programme, were subjected to the bivariate and multivariate linear regression analysis using software MS excel and SPSS 12.0 version.

RESULTS AND DISCUSSION

Impact of SWC measures on water resources in pond-1: The multiple regression of mean monthly total rainfall (MMTR), mean monthly temperature (MMT) and mean monthly potential evapotranspiration (MMPET) with mean monthly water depth of pond-1 (MMDP-1) for pre-programme had coefficient of determination (R^2) value of 0.37 which appeared to be very low and non-significant in influencing MMDP-1 (Table 1).This also indicates that only 37% of total variation in dependent variable (MMDP-1) is explained by the linear function of independent variables of MMTR, MMT and MMPET. The relationships of MMDP-1 with MMTR, MMT and MMPET were statistically non-significant. In contrast, the multiple regression of MMTR, MMT and MMPET with MMDP-1 for post-programme showed R^2 value as 0.54, indicating 54% of total variation in MMDP-1 could be determined by independent variables of MMTR, MMT and MMPET. MMDP-1 had highly significant relation with MMTR.

Impact of SWC measures on water resources in pond-2: The multiple regression of MMTR, MMT and MMPET with MMDP-2 for pre-programme showed R^2 as 0.63 (Table 1), suggesting 63% of total variation in dependent variable MMDP-2 could be described by the independent variables of MMTR, MMT and MMPET. The association of MMDP-2 with overall dependent parameters was significant, whilst with MMTR was highly significant. In post-programme, R^2 value

Table 1. Coefficients of regression (R^2) and P values before and after IWMP

Pond 1 (MMDP1)						
Variables	Before programme			After programme		
	R^2	Overall P	P	R^2	Overall P	P
MMTR	0.37	0.267	0.098	0.54	0.001**	0.0003**
MMT			0.577			0.702
MMPET			0.932			0.709
Pond 2 (MMDP2)						
Variables	Before programme			After programme		
	R^2	Overall P	P	R^2	Overall P	P
MMTR	0.63	0.036*	0.008**	0.58	0.0004**	0.0002**
MMT			0.957			0.555
MMPET			0.426			0.640
Pond 3 (MMDP3)						
Variables	Before programme			After programme		
	R^2	Overall P	P	R^2	Overall P	P
MMTR	0.56	0.070	0.018*	0.50	0.002**	0.0007**
MMT			0.652			0.399
MMPET			0.828			0.417

*Significant at 0.05 level of probability, **Significant at 0.01 level of probability was recorded as 0.58 which elucidated 58% of total variation in MMDP-2 by the independent variables of MMTR, MMT and MMPET. The relationship of MMDP-2 with overall independent components as well as MMTR was highly significant.

Impact of SWC measures on water resources in pond-3: Multiple regression exhibited R^2 value of 0.56 and 0.50 implying 56% and 50% of total variation in MMDP-3 could be described by independent variables of MMTR, MMT and MMPET for pre- and post-programme, respectively (Table 1). The mutual relation of MMDP-2 with MMTR for both programmes was significant, while it showed highly significant association only with overall independent variables for post-programme. The results indicated that among three climatic variables studied, monthly rainfall produced a significant impact on water resources augmentation in all the three ponds and the relative effect was less pronounced before than after IWMP implementation. Similarly, among the three ponds studied, the impact of monthly rainfall on enhancing water reserves was appreciably higher in pond-2 as compared with two other ponds. These variations were attributed to adoption level of soil and water conservation measures during IWMP, pond topographical situations, extents of rainwater harvesting by small ponds and magnitudes of groundwater replenishment.

Impact of SWC measures on irrigated area expansion: Highest seasonal mean volume of water was found in pond-2 lying in medium land and lowest in pond-1 in lowland over the years (Table 2). The plausible reasons were the accumulation of relatively higher amounts of rainfall-runoff in all the three growing seasons, especially during the monsoon season and the greater possibility of significant amounts of groundwater contribution during summer season due to the adoption of soil and water conservation measures effectively in the form of re-excavation of pond while IWMP was in operational stage. This development of assured surface water resources facility through rainwater-runoff harvesting in pond reservoirs could help the farmers of the area to grow diversified crops round the year under irrigated environment, as evidenced from the primary data from the households' survey report. The results also indicated that irrespective of ponds, highest positive change in irrigated area in *kharif* season (June-September) after programme were 46.94% for pond-2 (Mudi village), 44.29% for pond-1 (Kamaliya village) and 40.23% for pond-3 (Charkannya village). For rabi season (October-January), highest positive change in irrigated area after programme was in pond-1 (38.46%) followed by pond-3 and pond-2. Likewise, the change in irrigated area after programme for summer season (February-May) was highest in pond-2 (33.33%) followed by pond-3 and pond-1.

Table 2. Change of irrigated area during *kharif, rabi* and summer cropping with seasonal mean volume of water stored in different three ponds before and after IWMP

Season	Volume of water (m^3) stored during 2017-18	Irrigated area (ha)		Change in irrigated area (%)
		Before programme	After programme	
Pond 1				
Kharif	13796	7	10.1	44.29
Rabi	11812	5.2	7.2	38.46
Summer	11321	3.9	4.8	23.08
Pond 2				
Kharif	19431	9.8	14.4	46.94
Rabi	16733	9.5	12.4	30.53
Summer	17000	4.2	5.6	33.33
Pond 3				
Kharif	18146	8.7	12.2	40.23
Rabi	15327	6.1	8.2	34.43
Summer	13078	4.8	6.2	29.17

Source: Primary data from survey

These results amply indicated that on utilizing the additional water sources created, the beneficiary farmers could put their unirrigated lands under surface irrigation network for enhancing production and productivity of diverse crops and increasing cropping intensity with higher economic returns. The pond-1 lying in lower topographical situation recorded lowest water storage and hence, there was a possibility of water shortage for dry season crops. In this adverse situation, the beneficiary farmers could employ the soil and water conservation measures appropriate to their field conditions like mulching practice, growing of draught resistant crops and cultivars and low-water requiring short duration crop, particularly during summer season and paddy cultivation during *kharif* season. The pond-3 in upland situation was found to store voluminous amounts of water as compared with pond-1. In this favorable water available condition, the beneficiary farmers could easily take up different crops through the seasons of the year. They could opt for paddy or maize or groundnut in kharif; wheat, potato and vegetables in winter and mustard, green gram and black gram in summer season. The farmers in pond-2 ecosystem could safely grow all types of field crops with assured irrigation facility.

Crop productivity index: The major irrigated cereal crops of kharif paddy and maize grown in pond-2 command was selected for evaluation of crop productivity index (CPI). It is evident that CPI for paddy increased marginally from 96.79% before the programme to 98.54% after the programme (Table 3). In contrast, CPI for maize increased substantially from 80.61% before the programme to 94.77 after the programme. This was attributed to the adoption of soil and water conservation interventions, particularly the re-excavation and renovation work in pond-2 command, which eventually caused guaranteed availability of plentiful irrigation water after programme that helped the farmers for irrigating crops as per necessity or under conditions of low and uncertain rainfall occurrence.

Cost of cultivation of aman paddy: Aman paddy cultivation in pond-2 command under different watershed technological interventions was selected for economic appraisal (Table 4-6). Total cost of cultivation was ₹25976/ha during pre-project and ₹27490/ha during post-project, where per unit cost of production was increased by ₹1514 during post-project as compared to pre-project period. Variable cost and fixed cost of aman paddy during pre-project period were ₹13592/ha and₹10023/ha, whereas the corresponding figures during post-project period were ₹14837/ha and ₹10154/ha, respectively. Aman paddy cultivators invested less expenses on irrigation charges and more on other agricultural inputs during post-project as compared to pre-project, because of higher quantity of easily accessible water for irrigation during post-project period due to increased capacity of the reservoir to store surplus rainfall-runoff water as a result of re-excavated and renovated works under IWMP activities. The productivity of aman paddy during post-project period (3705 kg/ha) was much higher than that of pre-project period (2300

Table 3. Crop productivity index of aman paddy and maize before and after IWMP

Crop	Crop productivity index (%)	
	Before programme	After programme
Aman paddy	96.79	98.54
Maize	80.61	94.77

Table 4. Detailed cost of cultivation for aman paddy (₹/ha) in pond-2 command

Particulars	Before programme	After programme
A. Variable cost		
Hired human labour	2178	2506
Family labour	1341	1560
Machine labour	3120	3428
Seed	1680	1838
Fertilizers	2438	2720
Plant protection materials	710	828
Irrigation charges	1564	1338
Interest on working cost @ 7%	561	619
Sub-total	13592	14837
B. Fixed cost		
Land revenue	23	25
Rental value of owned land	8200	8305
Interest on fixed capital	825	842
Depreciation	975	982
Sub-total	10023	10154
C. Managerial cost @ 10% of (A+ B)	2361	2499
D. Total cost of cultivation (A + B + C)	25976	27490

Table 5. Cost of cultivation using cost concept of aman paddy (₹/ha)

Cost concept	Before programme	After programme
Cost A1	14240	15125
Cost A2	14240	15125
Cost B1	15064	15968
Cost B2	23264	24273
Cost C1	16405	17528
Cost C2	24605	25833
Cost C3	27065	28417

Table 6. Economics of aman paddy cultivation in Karma micro-watershed

Particulars	Before programme	After programme
Main product (kg/ha)	2300	3705
Price (₹/kg)	14.10	17.80
Value of main product (₹/ha)	32430	65949
Byproduct (kg/ha)	1000	1800
Price (₹/kg)	0.80	1.44
Value of byproduct (₹/ha)	800	2592
Gross income (₹/ha)	33230	68541
Net income (₹/ha)	6165	40124
Farm business income (₹ha^{-1})	18990	53416
Family labour income (₹/ha)	9966	44268
Farm investment income (₹/ha)	15189	49272
Benefit-cost ratio (BCR)	1.23:1	2.41:1
Cost of production (₹/kg)	10.95	6.72

kg/ha). Straw productivity followed the same trend (Table 10). Based on the various cost involvements in aman paddy cultivation (Table 9), gross income, net income, farm business income, family labour income and farm investment income were substantially higher in post-project than pre-project period. Besides, the cost per unit of grain production was considerably decreased in post-project as compared with pre-project period. Benefit-cost ratio (BCR) for aman paddy was 1.23 during pre-programme which increased almost twice to reach 2.41 during post-programme, which means that aman paddy cultivators could obtain ₹1.23 for one rupee investment before programme, but they could gain ₹2.41 per rupee investment after programme. This indicates that aman paddy cultivation was more profitable after project as compared with pre-project period.

CONCLUSIONS

The strategic adoption of soil and water conservation measures with greater emphasis on the water resources development through water harvesting pond structures have a significant impact on agricultural and socio-economic scenario in arid Karma micro-watershed in Bankura district of West Bengal in the eastern plateau of India. Increasing availability of pond water resources substantially augmented the irrigated areas which enabled the beneficiary farmers to grow more diversified throughout the year. In water-stressed low land especially during summer, the practices of conservation tillage, stubble mulching, use of draught resistant crops and cultivars and low-water demanding short duration crops are advocated. Crop productivity index increased marginally for aman paddy and markedly for maize during post-project period, preferably in pond-2 command. Net income and benefit-cost were increased manifolds for aman paddy during post-project period.

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Ethnobotanical Survey of Medicinal Plants used by Native Inhabitants of Protected Area of District Solan, Himachal Pradesh

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Abstract: Medicinal plants of Majathal Wildlife Sanctuary (a protected area) of district Solan, Himachal Pradesh were used to treat various ailments. Consequently, extensive field work was conducted to record the traditional use of ethno-medicinal plants and survey was conducted in 2021-2022 to understand the importance of ethnomedicinal plants for their health care. The total of 53 informants, 33 male and 20 female were randomly selected for interviews. The total of 67 plants species belonging to the 63 genera, and 38 families were found to cure many disease. The shrubs were most dominated habit (34%) and most frequently plant part used was leaves (37%). The family Fabaceae, Moraceae and Rosaceae had the most ethnomedicinal plants, with five species. On the basis of use value (UV) the most important medicinal plants were *Tinospora cardifolia* (UV=0.97). The medicinal plants *Achyranthus aspera, Ajuga integrifolia, Adhatoda vasica, Asparagus racemosus, Bauhinia acuminata, Cannabis sativa* were used for the treatment of various diseases namely arthritis, asthma, skin disorders, fungal infections, eye infection, dysentery, malaria, constipation.

Keywords: Ethnomedicine, Traditional knowledge, Use value, Majathal Wildlife Sanctuary, *Tinospora cardifolia*

India is one of the world's top 17 mega-diverse countries with a total area of 32, 87,263 km^2, of which 4.9 percent comes under protected areas. Protected area (PA) referred to geographic area that has been acknowledged, dedicated to, and managed-either legally or by other efficient means-in order to accomplish the long-term protection of nature and the related ecological services and cultural values (IUCN 2008). In India, a network of 668 PAs has been built, including 102 National Parks, 515 Wildlife Sanctuaries, 47 Conservation Reserves, and four Community Reserves (MoEF, 2016). From ancient time, the locally available plant species used for curing human diseases by utilizing the traditionally accepted remedies (Sharma *et* al 2015). All over the world, 10 to 18% of wild plant species are used for medicinal purpose (Kunwar and Bussmann 2008). India is one of the 12 super biodiversity hotspots, with 45000 plant species spread across 16 agro-climatic regions, 15 biotic provinces, and 10 vegetative zones. Around 15000 medicinal plant species have been listed in country, with 7000 plants used in Ayurveda, 700 in Unani, 600 in Siddha, 450 in Homeopathy, and 30 in modern medicine (Siwach et al 2013).

The Indian Himalayan Region is known for its diverse plant species, some of which are widely used by indigenous communities for medicine, fruit, fodder, and wood, religious, and other purposes. Around 279 fodder species, including trees, shrubs, and herbs, have been recorded from the Western Himalayan area in previous studies (Samant et al 2006). India is rich in ethnic diversity and it resulted in an exceedingly considerable body of ethnobotanical research (Ramya et al 2009, Bahadur et al 2011). Orthodox drugs are now used by 80 percent of people in developed countries for healthcare (Thakur et al 2014). In earlier ethnobotanical studies of all over the world reported that drugs are derived from different plant sources (Mahmood et al 2011). In Himachal Pradesh, about 3,500 plants species are well known in which almost 1,500 species are curative (Bhardwaj and Seth 2017). The rural societies of Himachal Pradesh are using medicinal herbs for the treatment of common health problems like cough, cold and fever, headache, body ache, dysentery, diarrhoea and in some cases they treating serious ailments like fractures and scorpion bites (Sharma et al 2015). This survey on ethnomedicinal plants is a first attempt of study and collection of plants with the assistance of native inhabitants of Majathal Wildlife Sanctuary, district Solan in Himachal Pradesh, India. During survey a great deal of knowledge is recorded by the local villagers about ethnomedicinal plants and their important role for preparation of medicines which helps in various diseases. Aim of this survey is to identify new or lesser known medicinal plant species used by local people for their health care.

MATERIAL AND METHODS

Study Area

Majathal wildlife sanctuary: Majathal wildlife sanctuary is located in altitude ranging is 1310.6m (amsl), latitude 31°27'99''N and longitude 77°10'29''E in the Solan district of

Himachal Pradesh. This Sanctuary covers 30.86 km^2 areas. Sutlej river is the part of the catchment area. Sutluj River covers the sanctuary area from north and mountain ridge bounded from south. The Sanctuary also covers a portion of the southern slopes of the Sutlej Valley with steep land. The Harshang temple is one among the places of worship (Singh et al. 1990). The chir pine (*Pinus roxburghii*) and Ban Oak (*Quercus leucotrichophora*) forests, and subtropical *Euphorbia* are the major vegetation type (Mishra 1996). The slopes are largely covered in grassy tracts and sparingly wooded with chir pine and ban oak, regularly extending continuously from the ridge-tops down to about 1,000 m (Garson 1983). The map of the study site given in (Fig. 1).

Survey and data collection: The current study was done in peripheral villages of Majathal Wildlife Sanctuary. This study was carries out in between 2021-2022 with the help of informants or villagers of surrounding wildlife sanctuary on the bases of interviews and group discussion to know the ethnomedicinal importance of plants. There are 10 peripheral villages in Wildlife Sanctuary enlisted with altitudinal ranges (amsl): Rudal (1197m), Saryali (1327m) Pajina (1175m), Pariab (1634m), Sohra kanaitan (1554m), Daund (1520m), Jandoi (773m), Matrech (1321m), Dhar Parli (1808m), Dhar Warli (1801m). Demographic distribution (age, education, gender) of the participant was recorded. The information collected included local name, part used, mode of administration, Ailments/diseases treated and indigenous medicinal uses (Table 1). Botanical names of plant species were validated from the online website www.theplantlist.org.

Data analysis: The ethnobotanical data collected from Majathal Wildlife Sanctuary, district Solan of Himachal Pradesh, India through interviews and direct observation was analysed by using quantitative methods as given below (Phillips et al., 1994).The relative importance of plants was determined by using the formula below to calculate the use-value (Phillips et al 1994).

$UV = \Sigma U/n$

Where U denotes the number of usage reports listed by each informant for a certain plant species, and n denotes the cumulative number of informants chosen for interviews and community conversation. If the usage values are high, it means the plant is significant, and if they are close to zero (0), it means there are few comments of its use. The usage value makes no distinction between whether a plant is used for several or single uses (Musa et al 2011).

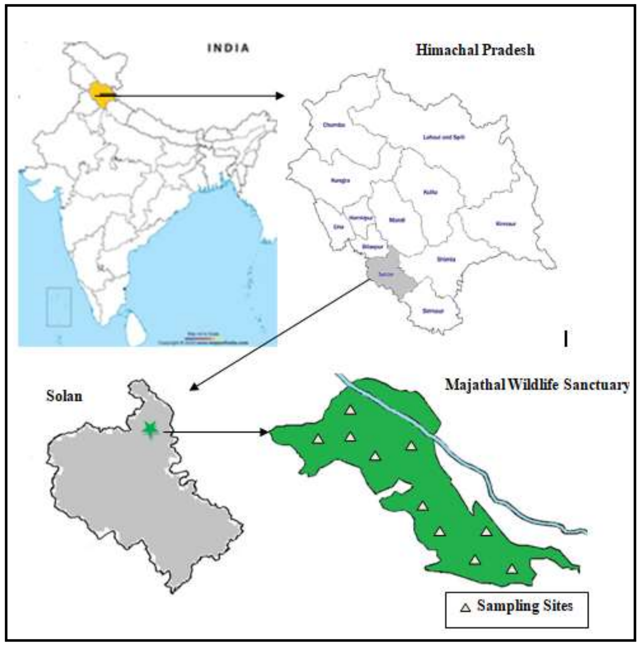

Fig. 1. Google map showing study site in district Solan, Himachal Pradesh, India

Table 1. Demography and literacy among the informants

Age groups	No. of informants
25-35	2
36-50	12
51-60	20
61-70	11
70-75	8

Education and literacy	Age groups				
	25-35	36-50	51-60	61-70	70-75
Never attended school	0	0	0	03	05
Attended school for 1-5 classes (Primary level)	0	0	2	05	02
Attended school for 6-8 classes (Middle level)	0	0	12	03	01
Attended school for 9-10 classes (Metric level)	0	4	04	0	0
Attended school for 11-12 classes	2	8	02	0	0

Table 2. Ethnomedicinal plants studied in Majathal wildlife sanctuary

Plant name	Family	Local name	Habit	Part used	Total citation (ΣU)	UV values	Mode of administration	Ailments/diseases treated
Achyranthus aspera L.	Amaranthaceae	Puthkanda	Herb	Leaves	42	0.73	Oral/Topical	Leaf decoction used for gastric problems and leaf paste is used externally for insect bite.
Adhatoda vasica Nees	Acanthaceae	Bansa, Basuti, Vasaka	Shrub	Whole plant, leaves, root	41	0.78	Oral/Topical	Leaves and root for the treatment of asthma, cough, bronchitis.
Aerva sanguinolenta Blume	Amaranthaceae	Chaya	Herb	Whole plant	23	0.43	Topical	Leaves paste applied on fresh cut for 3 days.
Ageratum conyzoides Linn.	Asteraceae	Buti	Herb	Leaves	32	0.60	Topical	Leave paste applies on cuts to stop bleeding.
Albizia lebbeck (L.) Benth.	Fabaceae	Fuli	Tree	Seeds	21	0.39	Topical	Seed oil used for wound healing.
Ajuga integrifolia Buch.-Ham.	Lamiaceae	Neelkanthi	Herb	Leaves	29	0.54	Topical	Leaves used as diuretic, rheumatism.
Asparagus racemosus Willd	Asparagaceae	Shatavri, Satmuli	Climber	Leaves	33	0.62	Topical	Leaves paste for wound healing.
Bambusa vulgaris Schrad	Poaceae	Bans	Tree	Stem, leaves	41	0.76	Topical	Stems and leaves for piles, kidney disorder, laxative, swelling.
Bauhinia variegata L.	Fabaceae	Kachnar, karale	Tree	Roots, bark, flower, pods	46	0.85	Oral/Topical	Decoction of roots prevents obesity, bark is used as ulcer and leprosy, flower and pods are used as vegetable.
Berberis lycium Royle	Berberidaceae	Kashmal	Shrub	Root	49	0.93	Topical	Root paste for wound healing, diabetes, blood purifier.
Bergenia ciliate (Haw.) Sternb.	Saxifragaceae	Dakachru, pashan-bhed	Rhizomatous herb	Rhizome, Leaves, Flowers.	45	0.85	Topical	Decoction of rhizomes for fever, joint pain, kidney and bladder stone.
Bidens pilosa L.	Asteraceae	Gumber	Herb	Leaves	26	0.49	Oral/Topical	Leaves for malaria, skin infection, stomach, liver disorder.
Boenninghausenia albiflora Hooks	Rutaceae	Pissumar buti	Shrub	Aerial Plant Parts	29	0.53	Topical	Poultice of the aerial plant parts good for healing wounds.
Callistemon viminalis (Sol. Ex Gaertn.) G.Don	Myrtaceae	Cheel	Shrub	Leaves	20	0.36	Topical	Leaves to treat skin infection.
Cannabis sativa L.	Cannabaceae	Bhang	Herb	Whole plant	43	0.81	Oral/Topical	Whole plant for the treatment of depression, sleep disorder, anxiety.
Carissa spinarum L	Apocynaceae	Garna	Shrub	Fruits	39	0.73	Oral	Fruits for the treatment of indigestion, malaria, fever, cough, cold.
Celtis australis Linn.	Ulmaceae	Khidak	Tree	Roots	33	0.62	Topical	Paste of root applied on cuts and wounds.
Centella asiatica (L.) Urb.	Apiaceae	Brahmi	Herb	Whole plant	48	0.89	Oral/Topical	Whole plant for jaundice, asthma, toothache, skin disorder.
Cynodon dactylon (L.) Pers.	Poaceae	Drub	Herb.	Whole plant	44	0.82	Oral/Topical	Decoction of *C. dactylon* treat kidney stone. Leaf paste is applied for wounds, piles and Leaf juice is installed into eyes for catarrhal condition.
Catharanthus roseus Linn.	Apocynaceae	Peri-winkle	Herb,	Roots, Leaves	33	0.62	Topical	Decoction of roots and leaves prescribed against hypertension and diabetes

Cont...

Table 2. Ethnomedicinal plants studied in Majathal wildlife sanctuary

Plant name	Family	Local name	Habit	Part used	Total citation (ΣU)	UV values	Mode of administration	Ailments/diseases treated
Datura stramonium Linn.	Solanaceae	Datura	Herb	Leaves	29	0.53	Topical	Fresh leaves tied on wounds for early cure.
Delphinium denudatum Wall. ex Hook	Ranunculaceae	Nirbisi	Herb	Whole plant	36	0.67	Topical	Plant paste applied on cuts for immediate relief and healing.
Duranta repens Linn.	Verbenaceae	Daranta	Shrub	Leaves	29	0.54	Topical	Paste of fresh leaves mixed with coconut oil applied to cure wounds
Eucalyptus citriodora Hook.	Myrtaceae	Safeda	Tree	Leaves	23	0.43	Topical	Decoction of leaves used to wash wounds and sores.
Euphorbia helioscopia L	Euphorbiaceae	Dudhi	Herb	Whole Plant. Leaves	30	0.56	Oral/Topical	Paste of the plant applied for healing wounds. 5-10ml of leaf juice mixed with honey given for persistent cough.
Ficus auriculata Lour.	Moraceae	Tiamble	Tree	Leaves, Root	23	0.43	Topical	Leaves paste for wounds, diarrhea, dysentery. Latex of root for vomiting, diarrhea, jaundice.
Ficus benghalensis L	Moraceae	Bargad	Tree	Bark, fruit	25	0.47	Oral/Topical	Bark and fruit to control diabetes. Latex for wound, swelling, toothache and skin disorder.
Ficus palmata Forssk	Moraceae	Fagura	Tree	Leaves,fruit	47	0.87	oral	Decoction of leaves to treat gastrointestinal disorders.
Ficus religiosa L.	Moraceae	Pipal	Tree	Leaves, bark,	42	0.78	Oral/Topical	Leaves juice cure diarrhea, asthma, migraine, constipation, toothache. Bark is used for ulcers, wound healing, diarrhea, leucorrhea.
Foeniculum vulgare Gaertn.	Apiaceae	Saunf	Herb	Leaves	44	0.83	Topical	Paste of leaves applied for healing wounds and skin rashes.
Fragaria indica Andr.	Rosaceae	Aakhe	Herb	Fruit	39	0.73	Oral/topical.	A decoction can be used externally (or the fresh leaves and fruit can also be crushed) and be applied as a poultice to treat boils and abscesses, swellings
Fumaria parviflora Lam.	Fumariaceae	Bansulpha	Herb	Whole Plant	29	0.53	Topical	Paste of the plant applied for suppuration of boils and healing cut injuries
Geranium wallichianum Sweet	Geraniaceae	Bhanda	herb	Root	23	0.43	Topical	Decoction of roots taken good for kidney stones.
Hedera helix Linn	Araliaceae	Dakari	Climber	Leaves, Fruits	37	0.68	Oral	Leaves and berries taken orally as an expectorant to treat cough and bronchitis
Hypericum cernuum Roxb.	Hypericaceae	Pinli	Shrub	Seeds	29	0.54	Topical	Seed oil massaged for quick relief of rheumatism.
Indigofera cassioides DC.	Fabaceae	Kathi	Shrub	Leaves	42	0.78	Oral/Topical	Leaves treat arthritis, inflammation, cough and liver problems.
Indigofera heterantha Brandis	Fabaceae	Sakena	Shrub	Leaves	30	0.56	Topical	Juice of leaves applied to treat cuts and wounds
Jacaranda mimosifolia Linn	Bignoniaceae	Jacaranda	Tree	Leaves	24	0.45	Topical	Leaf paste applied for healing wounds
Jasminum grandiflorum Linn.	Oleaceae	Chameli	Shrub	Leaves, flowers	23	0.43	Oral/Topical	Leaves chewed for healing mouth ulcer and gum infection. Oil from flowers used in skin disorders, headache and eye ailments.

Cont...

Table 2. Ethnomedicinal plants studied in Majathal wildlife sanctuary

Plant name	Family	Local name	Habit	Part used	Total citation (ΣU)	UV values	Mode of administration	Ailments/diseases treated
Juglans regia L.	Juglandaceae	Akhrot	Tree	bark, kernel, leaves,fruit.	36	0.67	Oral/topical	Extract of bark treat asthma and skin disorders.
Justicia adhatoda L.	Acanthaceae	Arusa	Shrub	Leaves,roots ,flower,bark	24	0.45	Oral/topical.	Decoction of leaves treat cough, cold.
Leucas mollissima Wall.	Labiatae	Bish-khapru.	Herb	Leaves	37	0.70	Topical	Poultice of fresh leaves applied to cure sores, headache, wounds and bites of poisonous insects.
Morus nigra L.	Moraceae	Tut	Tree	Ripe berry,twigs ,root bark,	28	0.52	Oral/topical	Decoction of root bark for constipation,menopause, runny nose.
Murraya koenigii (L.) Spreng.	Rutaceae	Curry patta	Shrub	Leaves	41	0.77	Oral	Leaves decoction for diarrhea, diabetes, morning sickness and good for eyesight.
Parthenium hysterophorus Linn.	Astraceae	Congress grass	Herb	Root	36	0.67	Oral	Root decoction given to check dysentery.
Phyllanthus emblica L.	Phyllanthaceae	Amla	Tree	Fruit	50	0.93	Oral/topical	Fruit used jaundice, dye hair and to treat diarrhea.
Pinus roxburghii Sarg	Pinaceae	Chir	Tree	Bark extract	34	0.63	Topical	Bark extract for inflammatory disorders.
Prinsepia utilis Royle	Rosaceae	Bhekal	Shrub	Seeds	26	0.49	Topical	Seed oil for massaging rheumatic joints.
Prunus persica (L.) Batsch	Rosaceae	Aru	Tree	Fruits	36	0.67	Oral	Fruits are eaten for constipation
Psidium guajava L.	Myrtaceous	Amrood	Tree	Leaf, fruit	35	0.66	Oral/Topical	Leaves for intestinal conditions fruit is used for high blood pressure.
Punica granatum L.	Lythraceae	Anar	shrub	Fruits	41	0.77	Oral	Powdered rind of fruit (2-3g, 30-45 days) taken with luke warm water empty stomach for diabetes.
Pyrus communis L	Rosaceae	Nashpati	Tree	Leaves,fruit	32	0.59	Oral/topical	The leaves for their antibacterial and antifungal properties, and as contraceptive,
Quercus leucotrichophora A. Camus	Fagaceae	Ban	Tree	Seeds	36	0.67	Oral	Decoction of seeds (10ml, thrice daily) given for checking dysentery and diarrhoea.
Ricinus communis L.	Euphorbiaceae	Arand	Shrub	Leaves, Seeds	09	0.39	Topical	Leaves coater with oil and warmed, are commonly applied over the abdomen to give relief in the flatulence in the children. Poultice of leaves good for healing cuts, bruises and swollen joints. Seed oil taken along with milk to check constipation.
Rubus ellipticus Smith	Rosaceae	Aakhae	Shrub	Leaves,fruits ,roots	32	0.59	Oral/topical	Leaves treat fevers and diarrhea,Young shoots are chewed for treatment of throat infections; a paste of root and leaves is applied for treatment of skin diseases and boils; and the stem is used as toothbrush .

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Table 2. Ethnomedicinal plants studied in Majathal wildlife sanctuary

Plant name	Family	Local name	Habit	Part used	Total citation (ΣU)	UV values	Mode of administration	Ailments/diseases treated
Rumex hastatus D. Don	Polygonaceae	Khati-meethi	Shrub	Leaves	39	0.73	Oral/topical.	Fresh leaves used in the treatment of constipation. A paste of fresh leaves is used against nettle sting
Syzygium cumini (L.) Skeels	Myrtaceae	Jamun	Tree	Leaves,fruits, bark.	43	0.81	Oral/topical.	The bark is acrid, sweet, digestive, astringent to the bowels, anthelmintic and used for the treatment of sore throat
Terminalia arjuna (Roxb. Ex DC.) Wight and Arn	Combretaceae	Arjun	Tree,	Stem Bark,	24	0.45	Oral/topical	The bark of Arjun is astringent, sweet, acrid, cooling, aphrodisiac, urinary astringent, and expectorant
Tinospora cordifolia (Willd.) Miers	Menispermaceae	Giloy	Climber	Stem	51	0.97	Oral	Stem boosts immunity, improve digestion.
Thymus vulgaris Roxb.	Lamiaceae	Ban-ajwain	Shrub	Leaves, Flowers	28	0.51	Oral/Topical	Poultice of leaves and flowers applied to check headache.
Urtica dioica L	Urticaceae	Chee	Herb	Leaf,bark	31	0.57	Topical	The leaf extract of Urtica dioica has been reported to improve glucose homeostasis in vivo.
Viola serpens Wall. ex Ging.	Violaceae	Banafsha	Herb	Leaves, Flowers	38	0.71	Oral/Topical	Flowers eaten as such for irritating throat
Vitex negunda L.	Lamiaceae	Banna, Sambhalo	Shrub	Leaves	40	0.75	Topical	Leaves to relieve muscle aches and joint pains.
Withania somnifera (L.) Dunal	Solanaceae	Ashwagandha	Shrub	Leaves	31	0.58	Topical	A paste of Ashwagandha leaves when applied on a local inflammation acts as anti-inflammatory. Regular use of Ashwagandha helps to reduce blood sugar and cholesterol levels.
Woodfordia fruiticosa (L.) kurz	Lythraceae	Dhawai, Dhaun	Shrub	Flowers	23	0.42	Topical	Dried flowers considered good against piles and dysentery.
Zanthoxylum armatum DC.	Rutaceae	Tirmir	Shrub	Branches	25	0.47	Oral	Branches used for brushing teeth.
Ziziphus nummularia (Burm. f.) Wight and Arn.	Rhamnaceae	Ber	Shrub	Branches, Leaves, Fruits.	24	0.46	Topical	Leaves decoction for cough, cold.

RESULTS AND DISCUSSION

Demography of informants: A total of 53 informants (33 males and 20 females) between age group 25-75 years were interviewed with a questionnaire. The age and educational background of informants were also recorded during the interview. The informants were divided into 5 groups on the basis of their age (Table 2).

The current study is the first systematic record of ethnomedicinal plants (67 species belonging to 63 genera and 38 families) utilised by the local people of peripheral villages surrounding Majathal Wildlife Sanctuary, Solan, Himachal Pradesh. Ethnobotanical data was collected from different age groups between 25 to 75 years. The older informants who were not well educated had a greater understanding of the therapeutic uses of the plants. Medicinal plants and their conventional formulations have long been a part of social life in sanctuary areas, and they've proven to be very effective in treating a number of health problems. The reliance of the people on medicinal plants increased because of a lack of other healthcare resources close to their households. The local people of study area had a strong understanding of ethnomedicinal plants because they used different plant species to treat various diseases. Interviews and direct observation approaches were used to gather ethnobotanical data, which was then analysed using quantitative techniques such as use-value analysis (UV). The plants habits-wise, shrubs were most frequently used. (34%), followed by trees, herbs, climbers and rhizomatous herb (Fig.3). The most dominant plant part used was leaves (37%) followed by fruits, roots and bark, flowers, whole plant (Fig. 4). Depending of the illness, different ways of using these plant parts are used. Dried powder and juice extraction and administrated via orally or topically (Table 3). The family Fabaceae, Moraceae and Rosaceae had the most ethnomedicinal plants, with five species, followed by Myrtaceae, with four. The Asteraceae, Lamiaceae and Rutaceae, contributed three plant species. Eight families contributed two species each. Rest of the documented families contributed one species each (Fig. 2). On the basis of use value (UV) the most important medicinal plant was *Tinospora cardifolia* (UV=0.97), followed by *Berberis lyceum*, *Phyllanthus emblica*, *Centella asiatica*, *Ficus palmate* (Table 3).

In current observations *Tinospora cordifolia* stem extract used for diabetes, fever, upset stomach, peptic ulcer, high cholesterol and strong the immune system and *W. semnifera* leaves are chewed every alternate day to reduce swelling and conjunctivitis. *Asparagus racemosus* roots and leaves extract used for kidney disorders, infertility, fevers, stomach ulcer and diarrhoea and *Vitex negundo* used to cure stomach, swellings and relief from pain. Plants namely *Achyranthus aspera, Ajuga integrifolia, Adhatoda vasica, Asparagus racemosus, Bauhinia acuminata, Cannabis sativa, Carissa spinarum, Delphinium denudatum, Ficus roxburghii, Ficus palmata, Ficus religiosa, Justicia adhatoda, Phyllanthus emblica, Solanum indicum*, *Terminalia chebula, Berberis lyceum*, *Viola canescens*, *Urtica dioca* and *Zanthoxyllum armatum* were used for the treatment of various diseases namely arthritis, asthma, skin disorders, fungal infections, eye infection, dysentery, malaria, constipation, wound healing, cough and cold, liver problems, kidney and bladder stones, mouth ulcers, immunity, sore throat, headache, jaundice, fever, piles, leucorrhoea, tumour ,gastric problems, insects bite, toothache, stomach-ache, diarrhoea etc. Local people have good knowledge for medicinal plants as per used value. These plants are very valuable for human health care system.

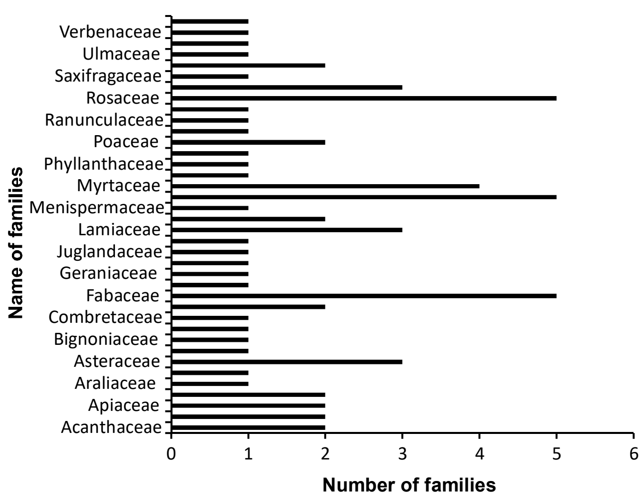

Fig. 2. Representation of the families and number of plants species at study site

Tinospora cordifolia is an important drug of ayurvadic system of remedy for the cure of various diseases such as diabetes, jaundice, fever and skin diseases etc. have been

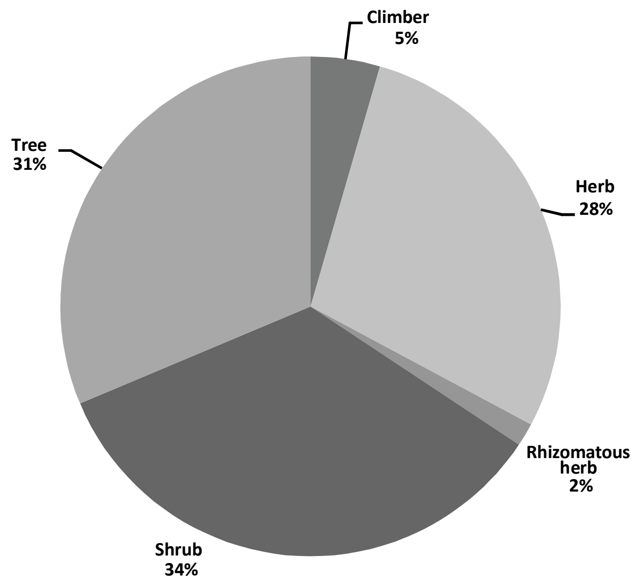

Fig. 3. Utilization pattern of Ethnomedicinal plants used in the Majathal Wildlife Sanctuary, Solan

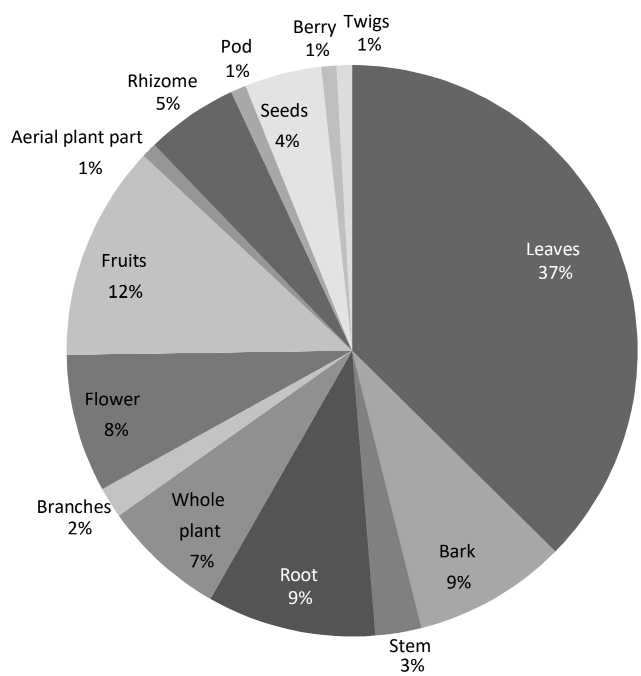

Fig. 4. Utilization pattern of plants parts used in Majathal Wildlife Sanctuary, Solan

reported (Sinha et al 2004). In Ayurveda, *Withania semnifera* (Ashwagandha) is considered one of the best refreshing agents. Ayurvedic and Unani medicines use its seeds, stems, leaves and root for the in the treatment of joint inflammation, rheumatoid arthritis, nervous disorders, and epilepsy. Dried roots are used to treat hiccups, colds, cough, and feminine illnesses, as a sedative, senile debility, ulcers, and other ailments. Carbuncles, inflammation, and swellings may all be treated with the leaves. Asthma is treated with a bark decoction, and is often used to treat bed sores locally. Antioxidant compounds used in this herb help to slow down the ageing process and scavenge free radicals. (Uma devi et al 2012). Seed oil of *Vitex negundo* is a rich source of unsaturated fatty acids such as nervonic acid and used to prevent stroke sequela, cerebral palsy, forgetfulness, Alzheimer's disease, memory loss, insomnia and other brain diseases (Lin et al 2008).

CONCLUSION

The current research indicate that many plants are used by local people to cure different diseases as part of their healthcare system. The use of medicinal plants by villagers has a long history and here we reported 67 medicinal plant species used in needs. Many plants are used for the treatment of fever, pain, diarrhoea, jaundice etc. Villagers have no other source of medicine near their household so that they are depends on plants for their healthcare. People use the plants part for the treatment of disease by two routes one is orally and second is topical. Many new uses of plant species discovered during the survey that have significant medicinal value have never been explored before. In the study location, several new or lesser-known species were discovered. The plant species studied in the chosen research field have a high medicinal value. So, therefore proper documentation of medicinal plants from study area is necessary. This form of research has never been conducted in Majathal Wildlife Sanctuary before, so it will be extremely beneficial for future.

ACKNOWLEDGEMENT

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Pastoralists Dairy Cattle Breeding and Reproductive Performance Evaluation Indigenous Knowledge in West Guji, Ethiopia

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***Abstract*:** Pastoralists practice extensive communal systems of animal husbandry and have their own experiences and knowledge as well as culture about livestock that fit well with their type of livestock husbandry. The objectives of this study were to assess pastoral indigenous knowledge of dairy cattle breeding and reproductive performance evaluation practices in Ethiopia. The study areas and dairy cattle-rearing households were purposively and randomly selected, respectively. The traits pastoralists use for best dairy cattle selection were body conformation, age, and coat color as well as milk yield and pedigree performance. Further, pastoralists use Birth frequency, calf growth rate, and fertility traits for best dairy cattle production. Age at first service, Age at first calving, calving interval, Days open, and Number of services pre-conception number were parameters used for reproductive performance evaluation. In general, the breeding practices and reproductive performance evaluation practiced in the areas depended on indigenous knowledge without performance recording. Therefore, supporting the indigenous knowledge of the pastoralists with science will be the best option for genetic improvement, and increasing the production and productivity of livestock is recommended.

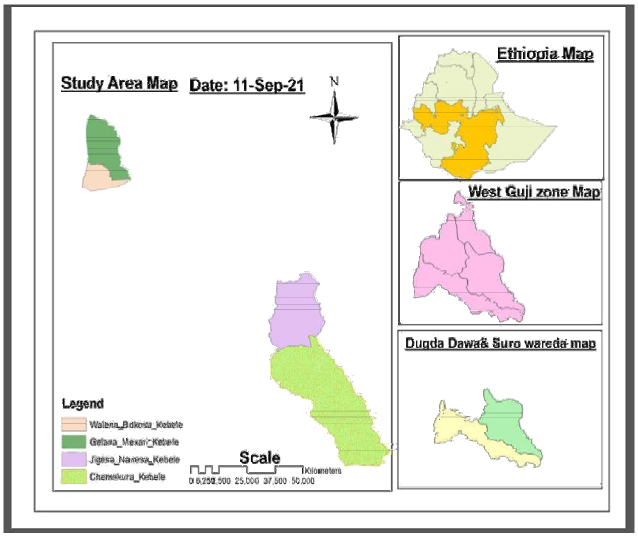
Keywords: Dairy cattle, Breeding practices, Reproduction performance, Evaluation practice

Ethiopia has the largest livestock population in Africa. Livestock is an integral part of agriculture, accounting for about 45 percent of the total value of agricultural production and supporting the livelihoods of a large share of the population around more than 14 million households or 70 percent of the population keep livestock, including many poor (FAO 2019). Cattle are kept for milk, meat, income, and other social functions. However, local cattle are poor in production due to the absence of genetic improvement interventions, low level of inputs, traditional husbandry practices as well as high environmental stress on which they are inhabited (Azage et al 2009; 2010). Nevertheless, the breeds have desirable traits for which they are preferred by the keepers and produce subsistence amounts within the existing challenges that might face pastoralists due to natural, social, economic, and political factors. Pastoralists with their long tradition of animal breeding and daily interaction with their herds, have knowledge of their animals, their needs, and their surroundings and they are privy to important information. They use traditional systems of population classification to know the qualities and the family history of animals in their herd (Ayan et al 2007, Krätli 2008). In modern production systems, ranking and selection of livestock are essential for obtaining animals for breeding but the effects of ranking and selection of livestock in pastoral systems are not well understood (Rege et al 2001). However, Pastoralists rely significantly on indigenous knowledge to memorize events and activities in a sequential way to acknowledge individual animals and ancestors' performance. Hence, pastoralists also use phenotypic traits like coat color, body size, horn shape, and udder size to select dairy cattle which has the best performance without any recorded data. However, pastoralists' indigenous knowledge regarding breeding and reproductive performance evaluation practices of dairy cattle has a scarcity of information on recording and documenting in general. Therefore, this research was designed to assess pastoralists' indigenous knowledge of dairy cattle breeding and reproductive performance evaluation practices at the West Guji zone.

MATERIAL AND METHODS

Study area: The study was conducted at Dugda Dawa and Suro Barguda Districts of West Guji zone, Oromia regional state, Ethiopia. The zone has a total population of 141,579 and is located between 38°-40° East longitude and latitude 4°_5° on the North and the altitude ranges from 500m up to 3500 m.a. s.l. The climatic condition of the West Guji zone is characterized by Dega (33%), Weina Dega (47%), and Kola (20%). The mean annual rainfall of the Zone is about 900mm and the annual temperature of the Zone is 25^0 C (WGLEPO, 2012).

Sampling techniques and sample size: The study employed a cross-sectional research design anda two-stage sampling technique was employed to select sample respondents. The study areas were selected based on accessibility and potential of dairy cattle production and two (2) kebeles /villages from each district were purposively selected. From a total of 50,596 households or dairy producers having lactating cows, 100 households (52 HHs from Dugda Dawa and 48 HHs from Suro Barguda) were selected according to Bowley (1926).



ni = nNi

Where: i= 1, 2, 3, ni represents the sample size of ith strata, n represents the total sample size,

Ni represents the population size of the ith strata and N represents the total population size

The study employed both primary and secondary data. The sample respondents and key informant interviews yielded qualitative and quantitative primary data. Surveys were conducted with 100 cattle pastoralists who had at least four dairy cattle and more than 10 years of cattle husbandry experience from December to February 2021 using a semi-structured questionnaire. The questionnaire was prepared in English and translated to Afan Oromo (Local language) and pretested and administered to address the description of socioeconomic characteristics of pastoral households, herd structures, and other types of livestock kept. A key informant interview (Focal group discussion) with 8-10 members was held at each kebele/village. Focus group discussion (FGD) was focused on the pastoralist's knowledge of reproductive performance evaluation, practices and history of their dairy cows, age at first service, major sources of their income, and reasons for culling breeding bulls, etc. Secondary data was collected from the district office of agriculture, CSA, and other published and unpublished documents.

Data analysis: The data werecollected coded, organized, and entered into Microsoft Excel (2007). The coded and summarized data were later imported into the Statistical Package for Social Sciences (SPSS, version 24). Inferential statistics like the chi-square test and Z test were employed for socio-economic and significance, respectively.

RESULTS AND DISCUSSION

Demographic characteristics of the respondents: The majority (78%) of the respondents were men andwere considered as owners of the resources like livestock and land assets, and responsible for the grazing decisions in the pastoral community (Table 1). This was due to culturally the women were not allowed to own pastoral assets. Therefore, their accessand activities were regulated and controlled by their husbands or fathers. Abraham et al (2022), Blench (2001), and Ngowi et al (2008) reported that pastoral women are forbidden from owning livestock, although they perform routine livestock practices including herding, milking, milk processing and selling of dairy products, calves and small ruminants rearing. Further, the children's duties were not so distinct from those of their parents, especially women; they performed herding/grazing, rearing of calves, and attention to sick animals, and small ruminants. In this regard, the division of labor and allocation of functions were based on age and gender, as previously observed by Blench (2001), Tadesse et al (2015), Homewood (2018) and Abraham et al (2022). Household members are encouraged to marry for the continuity of family lineage and labor, and, as such, about 92.95% of the respondents were married. The overall age of the respondents indicated between 30-45 years old, followed by 46-60 years old. However, the results show a significant difference at age 16-29 and above 60. Blench (2001). Otteand Chilonda (2002) reported that most pastoralists leading herds are strong and very active people. Moreover, the educational statuses of the respondents were literate. With the presence of primary and secondary schools in the village, the respondents were optimistic about improved educational status. Abreham et al (2022) also observed that literacy is usually higher among agropastoral communities than in pastoralist ones. In addition, Ocaido et al (2005) observed a 62.9% literacy level among the agropastoral communities of Serere County in Uganda. Moreover, illiteracy was high among the Maasai pastoralists of RAP land village as the majority of the respondents (54%) had never been to school. This is commonly observed among mobile pastoral communities (Abreham et al 2022).

Livestock holding composition: The pastoralists kept indigenous breeds of cattle, sheep, goats, donkeys, camels, and chickens under extensive systems. The main objectives of multi-species rearing were to produce a range of products (meat, milk), and minimize risks emanating from droughts, famines, and floods, owing to their varying degree of coping with the challenges. Among the livestock species, cattle dominate the proportions. This implies pastoralists are cattle-based. Similarly observed among pastoralists of the Oyo area of Southwest Nigeria (Daodu et al 2009). Pastoralists kept cattle purposely for milk production, essential food, an income source for pastoral households, and herd replacement. Mgongo et al (2014) also observed a similar trend in cattle rearing for the provision of milk for households Iyayi et al (2003), reported that female cattle usually dominate the herd because they are reserved for breeding and milk production with few bulls retained to replace those sold. Small ruminants were also among the livestock species reared by pastoralists. Accordingly, the small ruminant flock size kept per household was 9.9in the study areas. The higher composition of small ruminants is attributed to ease of

Table 1. Socio-economic characteristics of the respondents

Variables	Districts				Overall (N=100)	P-value (*P*<0.05)
	Dugda Dawa (N=52)		Suro Barguda (N=48)			
Sex of the respondents	F	(%)	F	(%)	(%)	
Male	40	78.8	35	77.1	78.0	0.83
Female	12	21.2	13	22.9	22.0	
Average family size		(Mean±SE)		(Mean±SE)	(Mean±SE)	
16-29 years		1.96±0.18		1.29±0.13	1.72±0.12	0.01*
30-45 years		4.43±0.28		4.36±0.22	4.40±0.18	0.86
46- 60 years		2.53±0.20		2.14±0.11	2.34±0.12	0.10
Above 60 years		1.67±0.17		1.00±0.00	1.43±0.14	0.01*
Age of the respondent (Mean ± SE)		47.25±1.89		43.48±1.64	45.44±1.27	0.14
Marital status	F	(%)	F	(%)	(%)	
Single	3	5.8	5	8.3	7.05	0.93
Married	49	94.2	43	91.7	92.95	
Divorced	0	0	0	0	0	
Widowed	0	0	0	0	0	
Educational status						
Illiterate	25	47.8	17	35.4	41.6	0.53
Basic education	5	9.6	7	14.6	12.1	
Grade 1-8	16	41.1	18	37.5	34.30	
Grade 9-12	4	7.7	6	12.5	10.0	
College	2	3.8	0	0.0	2.0	

F**=** frequency of respondents N= number of respondents SE= standard error **= significance (***P***<0.05)

Table 2. Livestock holding of households in the study areas (Mean ± SE)

Species	Districts		Overall	P-value (*p*<0.05)
	Dugda Dawa	Suro Barguda		
Oxen	3.02±0.18	2.82±0.18	2.92±0.13	0.43
Cow	9.25±0.67	5.92±0.47	7.65±0.45	0.00**
Chicken	8.85±0.82	13.0±1.16	11.2±0.8	0.01**
Sheep	2.75±0.48	2.70±0.36	2.71±0.29	0.94
Goat	6.29±0.57	8.05±0.67	7.21±0.45	0.05
Donkey	1.46±0.13	2.16±0.20	1.86±0.14	0.01**
Camels	4.26±0.5	3.45±0.03	3.86±0.27	0.08

management and adaptive nature to bushy vegetation. The pastoralists reared small ruminants for immediate cash income, mutton, as well as cultural ceremonies.

Dairy cattle management: The majority (66.7%) of the pastoralists preferred culling as a stock management system. Pastoralists culled aged dairy cattle, with poor body

Table 3. Dairy cattle culling and housing system in the study areas

Variable	Districts				Overall (N=100)	P-value (P<0.05)
	Dugda Dawa (N=52)		Suro Barguda (N=48)			
Preferring culling for stock management	F	(%)	F	(%)		
Yes	30	57.7	32	66.7	62.2	0.17
No	22	42.3	16	33.3	37.8	
Housing						
Yes	52	100	48	100	100	0.61
No	0.0	0.0		0.0	0.0	
Types of houses						
Open barn	40	76.9	40	83.3	80.1	0.51
beside with family	12	23.1	8	16.7	19.90	
Isolated pen	0.0	0.00		0.00	0.00	

F= frequency of respondents N= number of respondents

Table 4. Dairy cattle diseases and treatment methods

Variable	Districts				Overall (N=100)	P-value (P<0.05)
	Dugda Dawa (N=52)		Suro Barguda (N=48)			
Major dairy cattle disease	F	(%)	F	(%)		
Bacterial diseases						
Anthrax	4	7.6	3	5.1	6.35	0.1
Blackleg	9	16.52	10	20.1	18.31	0.05
Mastitis	10	20.4	8	18.6	19.5	0.12
Brucellosis	2	4.2	4	8.8	6.5	0.06
Contagious bovine pleuropneumonia	19	36.2	14	29.8	33	0.07
Pneumonic Pasteurellosis	8	15.08	9	17.6	16.34	0.2
Viral diseases						
Foot and mouth disease	12	21.7	17	34.2	27.95	0.11
Lumpy skin disease	40	78.3	31	65.8	72.05	0.06
Parasitic Infestation						
Internal Parasites						
Lice and ticks	40	76.2	40	80.3	78.25	0.18
Flea	12	23.8	8	19.7	21.75	0.06
External parasites						
Lungworm	35	66.8	28	58.7	62.75	0.05
liver flukes	17	33.2	20	41.3	37.25	0.10
Treatment methods						
Treat animals at home using traditional medicine	40	76	41	78.2	77.1	0.14
Burning external parts of livestock		20.8		18.2	19.5	0.21
Using herbal remedies		55.2		60.0	57.6	0.13
Taking the animal to the veterinary clinic	12	24	7	21.8	22.9	0.07

F= frequency of respondents N= number of respondents

condition, lower milk yield, and poor fertility. All the respondents provide different types of shelter for their dairy cattle. The 80.1 and 19.90% of respondents mentioned they use open barns and beside family houses, respectively. Moreover, pastoralists housed dairy beside families when animals aged and unhealthy. The current result was agreed with report Tegegne et al (2013) that the type of housing provided for dairy varied depending upon the classes of dairy animals, agroecology, production system, and physiological stage of dairy animals.

Among the bacterial diseases, Contagious bovine pleuropneumonia was the major (36.2%) and (29.8) disease prevalence in Dugda Dawa and Suro Barguda Districts, respectively. Ayalew (2020) reported that ectoparasites were prioritized to be the most important animal health challenges of cattle in the Lalibela, Sekota and Ziquala Districts of Amhara Region. The difference might be due to the agroecology of where the community rear their livestock. Similarly, Lumpy skin disease was the most existing viral disease with 78.3% in Dugda Dawa and 68.5% in Suro Barguda districts. Besides, parasitic infection diseases both internal and external parasites existed in the study areas. The major internal parasites (78.25%) Lice and Ticks and external parasites Lung worms were the higher existed with (62.75%) in both study areas.

All the respondents vaccinated their animals against rinder pest, anthrax, and foot and mouth diseases with routine medication like antibiotics, multivitamins, and dew ormer administered or traditionally at home. The majority of pastoralists (77.1%) treat diseased animals using traditional herbal remedies (57.6%) and the burning of external parts of cattle (19.5%) in both study areas. Herbal roots and leaves of local plants are used for treating diseased cattle. Bryouy et al (2020) also reported that a range of traditional and biomedical methods were applied by livestock keepers to prevent or treat disease and to promote health. Traditional treatments included herbal preparations that were administered as a drench, intra-nasally or topically and substances such as salt, animal fat, butter, honey, kerosene, or diesel that were applied topically.

Qualitative and Quantitative traits of dairy cattle selection: The major color of dairy cattle that existed in both districts was white (91.5%) and the least frequented color was black (Tables 6 and 7). This was due to the adaptation of white-colored dairy cattle to the agroecology of the study areas. Alphonsus *et al.,* (2012) also reported that white Fulani cattle in Nigeria were selected for their genetic predisposition of hardiness, heat tolerance, and adaptation to local conditions. The colors of the coat pattern were dominated by plain coat color. Similarly, the horn shapes of dairy cattle in study areas were polled. The shiny or smooth hair type helps the cattle tolerate heat. Dikmen et al (2008) also reported that smooth (slick-haired) Holstein cows can regulate body temperature more effectively than wild-type cows during heat stress and are better able to regulate body temperature by increasing sweating rate. Besides, ear shape and hair type were the rounded ear shape and shiny hair type. The conical-humped dairy and medium size humped cattle were dominant in the study areas. In addition, large (60.0) and medium (25.0) udder size dairy cattle were highly observed in the districts. Dairy cattle were selected depending on type; growth rate, body size and composition; efficiency of feed

Table 5. Qualitative traits that aid in the selection of dairy cattle in the study areas

List of traits	Districts				Overall (N=100)	P-value (*P*<0.05)
	Dugda Dawa (N=52)		Suro Barguda (N=48)			
	F	(%)	F	(%)		
Preferred color						
Brownish	34	65.4	35	70.3	67.8	0.8
White	18	35.6	13	29.7	33.2	0.2
Coat color						
Plain	34	64.5	34	68.8	66.65	0.14
Spotted	18	35.5	14	31.2	33.35	0.6
Horn shape						
Polled	30	56.2	30	62.4	59.30	0.7
Straight short	22	43.8	18	37.6	40.70	0.12
Hair type						
Shiny	41	79.9	41	85.6	82.75	0.71
Coarse	11	20.1	7	14.4	17.25	0.06

F= frequency of respondents N= number of respondents

utilization, and disease resistance. The finding showed that medium navel size, medium tail size, and large dewlap size of dairy cattle were dominant and preferable by the pastoralists. The main objective of assessing the traits was to compare the preference of pastoralists with the distribution of existing dairy cattle qualitative and quantitative traits.

Qualitative traits: Pastoralists used indigenous knowledge to remember and rank the animals by naming the animalas well as the phenotypic characteristics of the animal. Accordingly, pastoralists prefer brownish color and white color dairy cattle due to market value and ability to adapt to the environment. McManus et al (2009) also observed that light/white-colored animals are recognized as being advantageous in hot tropical regions as they reflect 50-60% of direct solar radiation compared with dark-colored animals. Similarly, pastoralists preferred plain and spotted coat color pattern cattle. Thus, about 64.5% of respondents from Dugda Dawa and 68.8% from Suro Barguda districts preferred plain coat color pattern followed by spotted coat color pattern which accounts for 35.5 and 31.2% from Dugda Dawa and Suro Barguda districts, respectively. The horn shape and size were other traits preferred for best dairy cattle selection. The pastoralists believed that cattle with polled horns and straight short horns were docile and less risky cattle. However, because of the size of herds involved, pastoralists lose track of the lineage, making the recording system full of errors. Kugonza et al (2012a) pointed outthat in small herds under uneventful settings, the pastoral mental recording was very accurate.

Quantitative traits: The traits pastoralists used for dairy cattle for breeding were hump size, udder, and teat size which were highly preferred traits by pastoralists for the selection of dairy cattle in the study areas. In addition, there were other traits that pastoralists used for selection. Accordingly, pastoralists preferred cattle with medium and large size udder dairy cattle and teat size. Pastoralists experienced cattle with medium and large udder sizes were high potential for milk. They experienced that the teat size of selected dairy cattle during milking and weaning time was large while the non-selected teat size of dairy cattle was small in size (Table 7) Yakubu (2011) also observed strong positive correlation of milk off-take with udder size in both Fogera and Dembia cattle. However, Atkins et al (2008) reported a large udder does not always mean high milk yield. Similarly, cattle with medium and large-sized teats of cattle were preferred for their suitability during milking. Furthermore, pastoralists preferred cattle with shiny hair types and coarse hair types. Besides, navel, tail, and dewlap were used as a criterion to select good dairy cattle breeds by pastoralists. This is because pastoralists believe that cattle with medium and large sizes of navel, tail, and dewlap have high reproductive and productive performance. The current finding was in line

Table 6. Quantitative traits that aid in the selection of dairy cattle in the study

List of traits	Districts				Overall (N=100)	P-value (P<0.05)
	Dugda Dawa (N=52)		Suro Barguda (N=48)			
	F	(%)	F	(%)		
Hump size						
Small	43	82.3	38	76.8	79.55	0.09
Medium	9	17.7	10	23.2	20.45	0.3
Udder size						
Medium	8	13.6	8	17.2	15.4	0.5
Large	44	86.4	40	82.8	84.6	0.4
Teat size						
Medium	8	14.5	5	10.8	12.65	0.1
Large	44	85.5	43	89.2	87.35	0.07
Navel length						
Medium	2	3.8	1	2.7	3.25	0.05
Large	50	96.2	47	97.3	96.75	0.7
Dewlap						
Length						
Medium	3	4.7	2	5.6	5.15	0.07
Large	49	95.3	46	94.4	94.85	0.4

F= frequency of respondents N= number of respondents

with Zewdu (2004) where cattle keepers in their traditional breeding practices use teat size, navel, and dewlap length as criteria to select animals for breeding. However, Zewdu et al (2006) reported that in some indigenous cattle populations of north-western Ethiopia, those criteria were used as indirect indicators of suitability for milk production and as criteria for identifying desirable breeding stock. Additionally, milk pot is a material that pastoralists use for better milk yield and performance animals. Accordingly, they believe that dairy cattle providing 3.5L of milk using traditional material is the best breed.

Pastoralists' dairy cattle breeding practices: The majority of the respondents select the best dairy cow based on qualitative and quantitative traits they experienced (Table 8). Accordingly, color, back profile, tail, head profile, and dewlap were the traits used for selection. The genetic improvement method practiced in the study areas was the natural mating method. The pastoralists know heifers reach for the mating/estrous stage by observing signs such as climbing of male, white-like liquid on her vulva, and vulva size and smoothness. This knowledge helps the pastoralists to reduce inbreeding bulls from outside of herds. Pastoralists keep breeding bulls for long periods as animals raised within the herds. Thus, keeping bulls for a long period led the bulls infertile. Kashoma et al (2010) also reported that in pastoral herds in the nearby district of Mvomelo (Kambala village) in the Morogoro region; up to 65% of bulls in pastoral herds were infertile. This strongly indicated thatthe non-culling of bulls contributes to the keeping of infertile bulls and the poor reproduction performance of pastoral herds. This might show that infertility of bulls resulted from old age and weakness of sperm motility. However, artificial insemination (AI) service) was not used for genetic improvement in the study areas. This was due to; the inaccessibility of AI services and lack of awareness of AI.

Reproductive performance evaluation practices: The dairy cattle reproductive performance evaluation practiced by respondents in the study areas is presented in Table 9.

Age at first service: Age at first service is the age at which heifers attain body condition and sexual maturity for service for the first time and were 3.16 and 3.05 at Dugda Dawa and Suro Barguda, respectively. This finding states that the average AFS in both districts were insignificant. This was as reported by Amin et al (2013) of red Chittagong cattle in Bangladesh (3.35 years). The difference might be due to management, genetic make-up of breed, and agroecology of the areas.

Age at first calving: Age at first calving determines the beginning of the cow's productive life and influences her lifetime productivity. The lengthy age at first calving decreased the lifetime production performances of dairy cattle. Hence, the overall age at first calving of the heifer in

Table 7. Pastoralists' dairy cattle breeding practices in the study areas

Variable	Districts				Overall (N=100)	P-value (*P*<0.05)
	Dugda Dawa (N=52)		Suro Barguda (N=48)			
	F	(%)	F	(%)		
Female breed selection						
Yes	49	94.20	44	91.70	92.95	
No	3	5.80	4	8.30	7.05	
Breeding Method						
Natural mating	52	100	48	100	100	
Artificial insemination		0.00		0.00	0.00	
Source of breeding bull						
Home breed own bull	22	42.3	29	60.4	51.35	
Neighbour bull	16	30.8	12	25	27.90	
Purchased own bull	14	26.9	7	14.6	20.75	**
Time of mating						
Knowingly	40	76.9	26	54.2	65.55	
Unknowingly	12	23.1	22	45.8	34.45	
Long-serving of animals						0.06
indigenous knowledge	52	100	48	100	100	
Recording information	0	0.00	0	0.00	0.00	

F= frequency of respondents N= number of respondents

Table 8. Reproductive performance evaluation practices of the study areas(Mean ± SE)

Parameters	Districts						Overall (N=100)	P-value (*P*<0.05)
	Dugda Dawa (N=52)			Suro Barguda (N=48)				
		F	(%)		F	(%)		
AFS (Year)	3.16±0.05			3.05±0.04			3.11±0.03	0.12
2.5-3.5	3.50±0.06	45	86.5	3.34±0.05		0.48		
3.6-4	2.82±0.04	7	13.5	2.76±0.03	45	93.8		
AFC (Year)	4.11±0.05			4.00±0.05	3	6.2	4.06±0.04	0.13
3.5-4	4.50±0.06	31	59.6	4.21±0.06				
4.1-5	3.72±0.04	21	40.4	3.79±0.04	31	64.6		
CI (Year)	1.30±0.04			1.34±0.04	17	35.4	1.32±0.03	0.52
1-1.5	1.50±0.05	44	84.6	1.62±0.05				
1.6-1.9	1.10±0.03	8	15.4	1.06±0.03	34	70.8		
DO (Days)	106.58±1.25			108.23±1.47	14	29.2	107.37±0.96	0.39
85-115	130.5±1.4	50	96.2	122.3±1.62				
116-130	82.66±1.1	2	3.8	94.16±1.32	37	77.1		
NSPC (Number)	1.56±0.07			1.63±0.07	11	22.9	1.59±0.05	0.50

F= frequency of respondentsN= number of respondents SE= standard error

the study areas was 4.06years. The current finding was insignificant with age at first calving at 4.075 years reported by Taju (2018) of Ethiopian indigenous cows in the Dawro zone. However, the present result disagreed with the average age at first calving at 4.83 years reported by Ayantu et al (2012) for local heifers in the Horro district. The variation in age might be due to a lack of good management, environment, and genetic factors.

Calving interval: The average calving interval (CI) of the Dugda Dawa and Suro Barguda districts were 1.30 and 1.34, respectively. The result of the present finding in study areas was greater than the value of 1.22 years months reported by Million and Tadelle (2003) for the Borana breed. This variation might be due to poor nutrition, disease, and poor management practices.

Days open: The average days open in Dugda Dawa and Suro Barguda districts were 106.58 and 108.23, respectively. This research results were in line with the value ranges between (85 to115 days) reported by Gebeyehu et al (2007) and Tadesse et al (2010) which is considered optimum for dairy cows. However, the current finding results were lower than 148 days reported by Tadesse et al (2010) in Holetta. This difference might be due to the unavailability offeed and poor heat detection. Thus, all factors should be corrected for agro-ecology.

Number of services per-conception: The number of services per conception is the number of services (natural or artificial) required for successful conception. The average numbers of Dugda Dawa and Suro Barguda districts were1.56and 1.63, respectively. Borkowska et al (2012) also reported that the number of services per conception is frequently used asan indicator of fertility and the optimum value is considered to range between 1.6 and 1.92to 2.15 services of local cows Asella district. This difference might be due to management and environmental factors.

CONCLUSION

The majority of the respondents were men and were considered as owners of the resources like livestock and land assets, and responsible for the grazing decisions in the pastoral community. Pastoralists kept different types and species of animals. The main objectives of multi-species rearing were to produce a range of products (meat, milk), and minimize risks emanating from droughts, famines, and floods, owing to their varying degree of coping with the challenges. Breeding practices were key activities for genetic and productivity improvement, and pastoralists select the best dairy cows based on traits like color, back profile, tail, head profile, and dewlap. Besides, the reproductive performance evaluations practiced by pastoralists were age at first services (AFS), age at first calving (AFC), calving interval (CI), days Open (DO), and number of services per conception (NSP), respectively. Above all, pastoralists select females depending on milk yield, pedigree performance, udder size, and mothering ability. In general, it can be concluded that pastoralists practice indigenous knowledge for breeding and reproductive performance evaluation of their cattle without recording. Therefore, based on the research results incorporating indigenous knowledge of the pastoralists in community-based breeding programs will be the best option for improving breeding and reproductive performance to increase production and productivity of livestock is recommended.

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Diel Activity Patterns of Himalayan Ibex and Livestock in the Trans-Himalayan Landscape of Himachal Pradesh, India

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Abstract: Understanding the activity patterns of coexisting species is essential for advancing our comprehension of species ecology and aiding in the development of effective conservation strategies. This holds true for ungulates that inhabit areas beyond protected zones, where human activities pose threats to their survival. Moreover, livestock grazing ranks among the most prevalent human activities in terms of land utilization. In the Lahaul-Spiti districts of Himachal Pradesh, situated in the trans-Himalayan landscape of India, a total of 241 camera traps were strategically positioned. These camera traps captured bimodal activity patterns in both the Himalayan Ibex (*Capra sibirica*) and livestock, encompassing crepuscular and diurnal behaviors. Nonetheless, the overlap coefficient, exceeding 0.7, signified a significant degree of overlap between Himalayan Ibex and livestock during both seasons. This study unveiled the striking similarity in activity patterns between wild Himalayan ibex and livestock, indicative of their comparable resource utilization. Consequently, the findings of this study emphasize the necessity for well-devised conservation planning aimed at fostering the long-term survival of wild ungulates.

Keywords: Diel activity pattern, Activity overlap, Himalayan Ibex, *Capra sibirica*, Livestock

Wildlife experiences adverse effects stemming from the multifaceted anthropogenic activities. Large terrestrial mammals, especially herbivores, are considered highly vulnerable species due to the significant population declines (Craigie et al 2010, Ceballos et al 2017, Atwood et al 2020, Bhandari et al 2022). These declines can be attributed to the continuous and extensive anthropogenic pressure resulted habitat loss and fragmentation (Bhandari et al 2022). Consequently, livestock grazing stands as the most prevalent human activity in terms of land utilisation and sharing habitats with wildlife on a global scale (Steinfeld et al 2006, Robinson et al 2014, Schieltz and Rubenstein 2016). In the past few years, there has been a substantial surge in livestock populations, primarily attributed to the exponential expansion of the cashmere industry (Berger et al 2013, Salvatori et al 2021). Over one fourth of the terrestrial land area on Earth is used for the purpose of grazing, resulting in a substantial disparity in population between the wild ungulates and livestock, with the latter outnumbering the former by multiple magnitudes (Berger et al. 2013, Robinson et al 2014, Bleyhl et al. 2019). In certain geographical areas across the globe, the phenomenon of overgrazing has undeniably resulted in a decline in the richness and total biomass of both flora and fauna populations (Schieltz and Rubenstein 2016). This has consequently led to a reduction in overall biodiversity and has caused significant modifications to landscape heterogeneity, ecological succession, deterioration of forage plants, habitat shift of wild ungulates, transmission of diseases and cycling of nutrients (Mishra et al 2001, Kauffman and Pyke 2001, Shrestha and Wegge 2008, Chirichella et al 2013, Krishna et al 2016, Schieltz and Rubenstein 2016). The potential detrimental influence of livestock overgrazing on indigenous ungulate populations in Asia has garnered considerable attention in scientific discourse (Shrestha and Wegge 2008). While some pastoral systems facilitate coexistence and preserve habitats for wild ungulates, the majority of cases indicate that multifaceted struggle with livestock poses a significant threat to large ungulates, especially in resource-limited places like dry lands or mountainous terrain (Riginos et al 2012, Ekernas et al 2017).

In the Himalayas and Trans-Himalayas, pastoralist practises including migratory livestock grazing are common (Axelby 2007, Bhasin 2011). Several studies illustrated the occurrence of multiple livestock diseases and parasitic infestations in Indian Himalayan rangelands, which are major concern to wildlife. These include haemorrhagic septicaemia, foot and mouth disease (FMD), peste des petits ruminants (PPR), swine fever, and gastrointestinal nematodes (Dixit et al 2009, Muthiah et al 2013, Khanyari et al 2022).

Capra sibirica, commonly known as the Himalayan Ibex, represents a true species of mountain goat within the taxonomic classification of the Bovidae family. The Capra genus comprises a diverse array of ungulate species, with *Capra sibirica* standing out as particularly noteworthy due to its larger size (Fedosenko and Blank 2001). *Capra sibirica* demonstrates a wide-ranging distribution across diverse mountainous areas, *viz.* Afghanistan, Kazakhstan, Tajikistan, Pakistan, India, China, Uzbekistan, Mongolia, Russia and Kyrgyzstan and one among the least studied species (Otgonbayar et al 2017). In India, this species distributed in the Western Himalayan states, mainly in the Himachal Pradesh, Jammu Kashmir, and Ladakh highlands. The Himalayan Ibex lives in a region with rough terrain and steep inclines, where it must rely more on strength than speed to survive (Bhatnagar 1997). Himalayan Ibex are sexually dimorphic, the male and female morphological traits differ significantly (Roberts 1977, Prater 1980). The International Union for Conservation of Nature (IUCN) Red List has classified the Himalayan Ibex as a species of "Near Threatened" status and as Schedule I species in Wildlife (Protection) Act of 1972 in India considering the various threats to the species (Reading et al 2020).

Diurnal activity patterns are an evolutionary response to the fluctuating environmental conditions during the day. These patterns represent a multifaceted trade-off between several factors including as social interactions, competition, foraging, predator avoidance, resting, and environmental limitations, all of which ultimately influence an organism's fitness (Halle and Stenseth 2012, Kronfeld-Schor et al 2013, Vazquez et al 2019). Terrestrial mammalian activity patterns can be classified into four categories crepuscular, cathemeral, diurnal, and nocturnal (Bennie et al 2014). The activity patterns of the mammals have mostly been studied by direct/visual observation or camera trap surveys (Koprowski and Corse 2005, Li et al 2022). The utilisation of camera trapping is prevalent within the fields of ecology and conservation, since it serves as a valuable tool for the examination of species' ranges, the estimation of population densities, inventorying of biodiversity and activity patterns of species (O'Connell et al 2011, Steenweg et al 2017, Frey et al 2017). Temporal data derived from camera trap with time stamps have yielded initial analyses of activity patterns exhibited by animals (Gerber et al 2012, Bu et al 2016). In recent time, there has been a growing interest among researchers in examining the more detailed temporal data obtained from time-stamped camera-trap images (Ridout and Linkie 2009, Rowcliffe et al 2014). The primary aim of this study is to elucidate the activity patterns of Himalayan Ibex and livestock, while also examining the extent of activity overlap between these wild and domesticated ungulates within the study landscape.

MATERIAL AND METHODS

Study area: The valley is characterized by its snow-capped mountains, picturesque valleys, vibrant local community, and the captivating presence of Buddhist hymns, which contribute to the charming atmosphere. Additionally, the valley provides ample habitat for species, allowing for their successful survival. The geographical region of Lahaul and Spiti, located in the Trans-Himalayan range, spans from latitudes 31.7492° to 32.9992° N and longitudes 76.7747° to 78.6928° E (Fig. 1). These districts encompass 24.86% (13,841 km^2) of the overall geographical expanse of the Himachal Pradesh state, hence constituting the largest district within this state. This landmass situated between the Pir Panjal Mountain range of the Trans and Greater Himalaya (Aswal and Mehrotra 1994). The elevation range of this district extends from 2301 to 6580 metres above sea level. The present landscape exhibits distinctive physical features, including majestic mountains adorned with snow-capped peaks, as well as rugged and sloppy terrains. The predominant land cover types in the area are subalpine vegetation, agricultural land, rolling grassland meadows, and permafrost areas. Due to the trans Himalayan characteristic, this landmass has less vegetation cover which made this landscape challenging for various life forms. The Spiti region is endowed with three distinct Protected Areas, namely the Kibber Wildlife Sanctuary, Chandratal Wildlife Sanctuary, and Pin Valley National Park, however, the Lahaul valley does not currently possess any designated protected areas within its boundaries. The Trans- Himalayan Mountain slopes exhibit a distinctive ecological profile characterised by severe climatic conditions, limited precipitation, and a brief period suitable for plant growth. Consequently, the vegetation cover in this region is notably low, measuring less than 20%. However, this challenging environment serves as a habitat for an amazing diversity of indigenous plant and animal species (Joshi et al 2006).

Camera trap direct observation: As part of a research endeavour aimed at documenting endangered vertebrate species in the Indian Himalayan region, camera traps were strategically positioned across the study landscape. During the period from July 2018 to October 2020 and from August 2021 to August 2022, a comprehensive deployment of 241 camera traps was conducted across various study grids. These camera trap had been positioned with a wide variety of elevations, spanning from 2120 m to 5411 m. The trail cameras used included the SPYPOINT FORCE-11D (GG Telecom in Canada, QC), SCOUTGUARD (SG562 D) and Browning 940 Defender. The cameras were operational continuously for a duration of 24 hours each day, with minimal intervals between captures. Additionally, each capture consisted of three quick photos, each accompanied by a time and date stamp. Photographs were regarded as independent records in cases where the time lapse between each record exceeded 30 minutes (Oliveira et al 2018). In addition, we meticulously recorded our direct observations of the Himalayan Ibex, as well as the presence of livestock. Each entry in our documentation includes precise geographical coordinates, the date and time of the sighting, and the specific location where the wild ungulates and livestock were encountered.

RESULTS AND DISCUSSION

In this present study, a total of 41 individual captures of the Himalayan Ibex were documented through camera trap, accompanied by 42 direct observations. In contrast, a total of 44 incidents of livestock captures were documented through camera traps, while 64 instances of Livestock recorded through direct observation. The livestock comprised a diverse range of ruminant and equine species, including goats, sheep, cows, and horses. In the summer season, a total of 44 individual observations were recorded for the Himalayan Ibex, while during the winter season, 39 individual observations were recorded for the same species. Moreover, a total of 77 individual observations were recorded for livestock during the summer season, whereas only 31 observations were recorded during the winter season for the livestock. The Himalayan Ibex and livestock were generally crepuscular and diurnal (Fig. 2). The analysis of activity patterns during the summer season indicates that the wild ungulate exhibits peak activity during 6:00. Additionally, another peak in activity is observed approximately 16:00. Notably, the activity levels of wild ungulates show a relatively high peak just after 18:00 (evening hours) (Fig. 2). During the winter season, the highest activity peak of Himalayan Ibex observed during 12:00, and before 18:00 (Fig. 2). The activity of livestock is observed during the summer season, started from after 6:00 and highest peak observed before 12:00 (approximately 11:00), after 12:00 (approximately 14:00), and before 18:00 (approximately 17:00) (Fig. 2). During the winter season, the occurrence of the highest peak is observed at 12:00, followed by subsequent peaks around 16:00. Furthermore, the overlap pattern indicates a significant degree of overlap between Himalayan Ibex and livestock populations. During the summer season, the computed Δ_4 value was 0.71 (Fig. 3). Conversely, in the winter season, the overlap index indicated a value of 0.74 between the Himalayan Ibex and livestock (Fig. 3). Study conducted in India found that the activity pattern of the Himalayan Ibex primarily follows a bimodal pattern during the winter season (Fox et al 1992). This pattern is characterised by a significant peak in activity observed around sunrise, as well as a minor peak around sunset and consistent with our findings. Additionally, our analysis revealed a notable shift in Ibex activity patterns following periods of significant snowfall. Specifically, noticed an increase of activity throughout the mid-day hours, with a particularly high peak occurring at 12:00. The observed phenomenon may be attributed to the decrease in temperature, which causes Himalayan Ibex to remain in a bedded state until mid-morning, followed by a rise in activity prior to sunset. Our study recorded that the activity patterns of Himalayan Ibex exhibit seasonal variations and corroborated with previous studies (Prater 1980, Fox et al 1992).

The livestock activity pattern is mostly regulated by the attention of the shepherd and villagers. During the summer

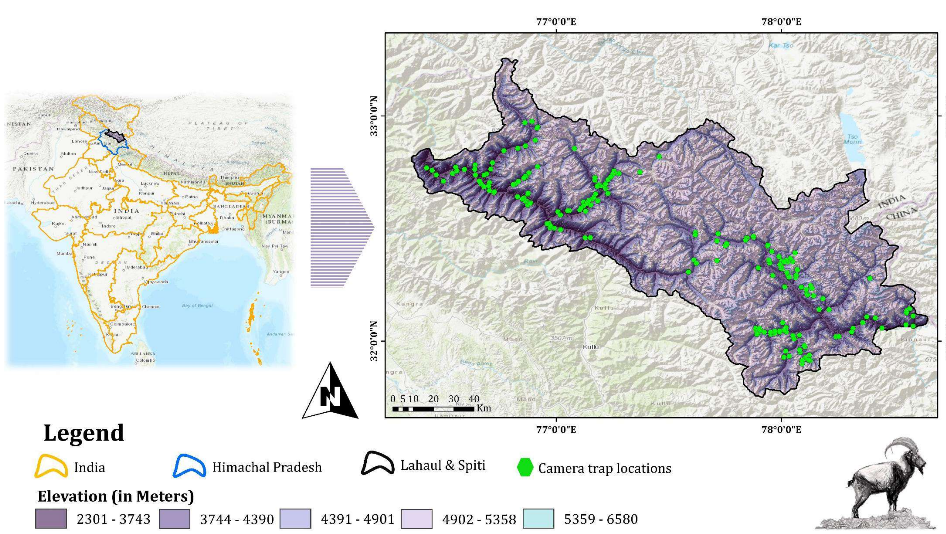

Fig. 1. Map of study area showing the camera trap locations distributed in the study landscape

season, there is a significant migration of livestock primarily originating from the lower regions of Himachal Pradesh, particularly from the Kangra and Chamba districts to this study area due to wide range of available grazing grounds. Thus, significant degree of overlap between the Himalayan Ibex and livestock within the area, however, this indicates a clear similarity in habitat choice between the Ibex and livestock species (Bagchi et al 2004). Migratory shepherds avoid the area in the winter because of the snowfall, which also hinders the growth of plants and local livestock supplemented by stall feeding; however, villagers do take their livestock outside for a brief period which illustrates the observed overlap between the Ibex and livestock during the winters. In rugged mountainous terrain like Lahaul -Spiti landscape, the presence of diverse resources and their distribution over space and time can potentially contribute to the coexistence of competing species). This is due to the fact that the relationship between the species growth rates and the resource densities is likely to be non-linear in such environments (Armstrong and McGehee 1980). However, the presence of wild ungulates has a significant impact on the ecosystem functionality and structure, making them as a valuable indicator of the overall health of terrestrial ecosystems (Gordon et al 2019, Sharief et al 2022). Wild ungulates play a crucial role on vegetation composition. Their trampling, grazing, browsing and defecation activities (Lillian

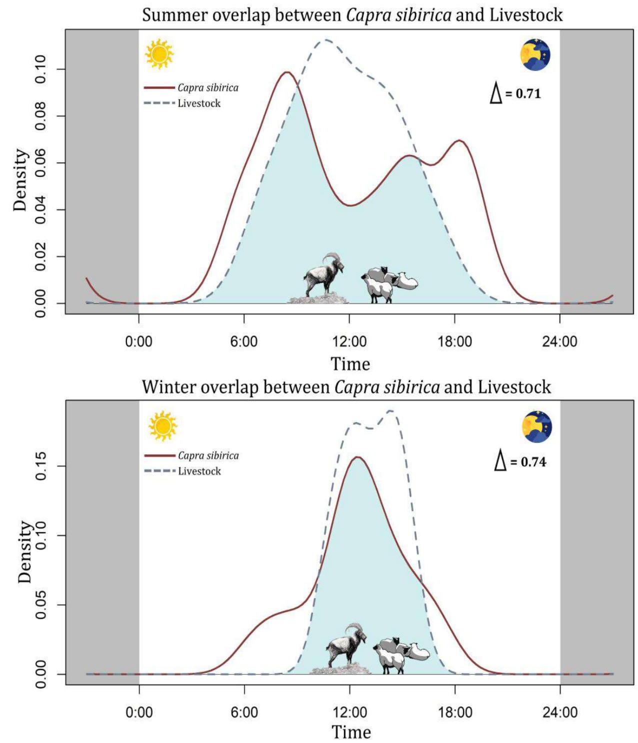

Fig. 3. The overlap coefficient used (Δ) as a means to quantify the extent of the Himalayan Ibex (*Capra sibirica*) and livestock density estimations in summer and winter season, as shown by sky colour

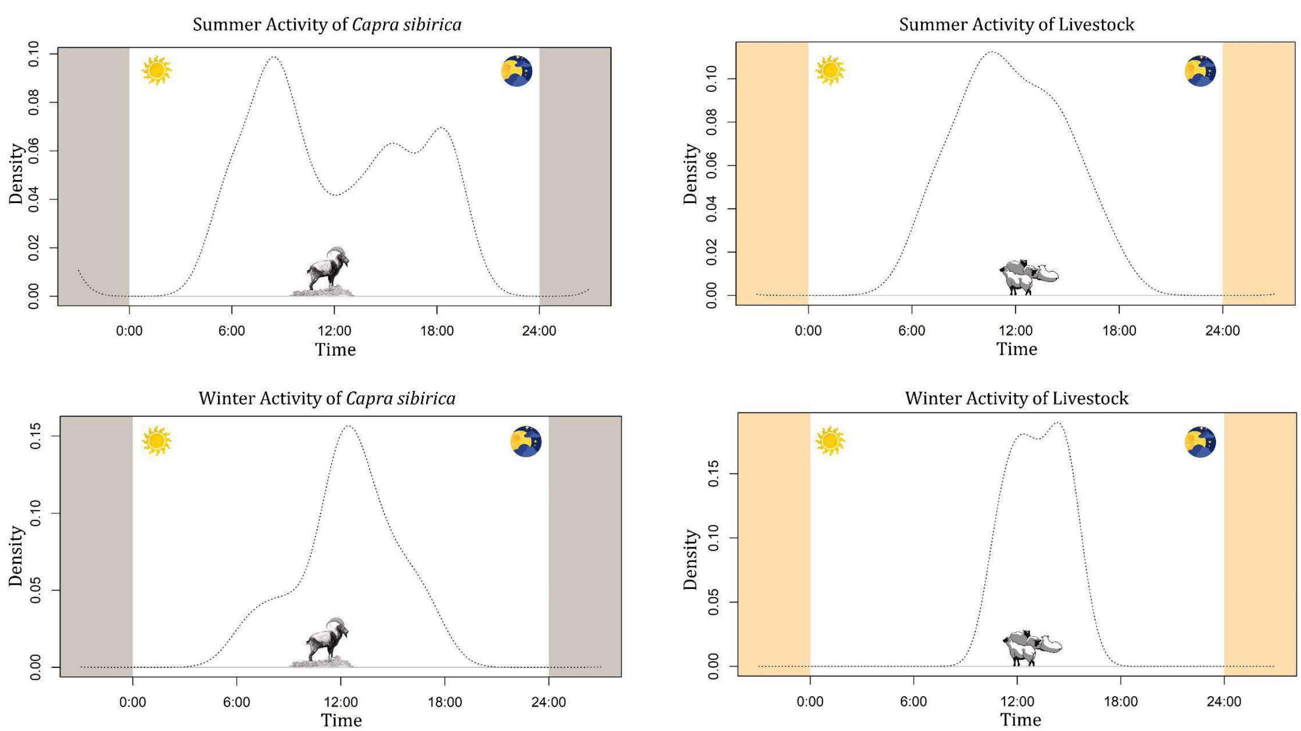

Fig. 2. Diel activity patterns of Himalayan Ibex (*Capra sibirica*) and livestock in summer and winter season from acquired data

et al 2019), have the potential to alter plant communities. These actions affect not only the distribution and structure of the vegetation, but also the flow of nutrients and responses of other related species (Rooney et al 2009, Schulze et al 2014, Kasahara et al 2016). The snow leopard (*Uncia uncia*) is an apex predator inhabiting the uppermost trophic level in the Trans Himalayan ecosystem, exhibits a strong reliance on Himalayan Ibex, serving as a pivotal constituent of its dietary preferences (Suryawanshi et al 2017, Sharief et al 2022, Khanyari et al 2022). Furthermore, the presence of pastoralism poses a significant threat to the population of large carnivores, this threat arises from a series of interconnected and intricate effects (Ekernas et al 2017, Salvatori et al 2021). These effects primarily involve the decrease in the number of wild prey available for carnivores, leading to an increased predation on livestock. Consequently, this situation triggers conflicts between humans and carnivores, resulting in retaliatory killings. These processes are widely recognised as the main factors contributing to the negative impact of pastoralism on large carnivores (Snow Leopard Network 2014, Mishra et al 2016, Salvatori et al 2021). The rangelands in this region experience significant grazing pressure from livestock, which poses conservation challenges for wild ungulates, therefore, effective management policies for this terrain requires the integration of both social and ecological factors (Bagchi et al 2004, Ghoshal 2017, Khanyari et al 2022). The findings of this study underscore the importance of understanding and addressing the overlapping activity patterns of Himalayan Ibex and livestock, highlighting the need for effective conservation planning. This study's implications extend to species conservation and management, particularly in areas with a high prevalence of Ibex activity, and it paves the way for in-depth habitat ecology analysis in these regions.

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Exploring the Dynamic Coexistence of Humans and Wildlife: Understanding Causes, Nature, and Strategies for Managing Human-Wildlife Interactions in Ganderbal, Jammu and Kashmir

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Abstract: This study addresses the rising Human-Wildlife Conflict (HWC) in the human-dominated landscape of Ganderbal district, Jammu, and Kashmir, India, enhanced by human population growth, land-use changes, and increased wildlife populations. This study initiated in response to a specific incident in July 2021 when leopard lifted a girl child and the research spans from July to December 2021. Camera trap installation, questioner surveys, interviews, field observations, and conflict data from the Wildlife Protection Department. The study provides comprehensive insights into the nature, magnitude, and causes of HWC. Out of the eight species recorded in 13,00 captures of camera trap, the highest encounter rates were observed for the Indian crested porcupine and Red fox, while the Kashmir gray langur and common leopard showed the lowest rates. Conflicts were predominantly associated with the Himalayan black bear, peaking during crop harvest in September and October. Questionnaire surveys with 150 individuals and households revealed that land-use conversion from agriculture to horticulture contributed significantly to conflict, constituting 36% of all studied conflict types. Between 2015 and 2021, leopard/bear attacks resulted in 23 injuries and two deaths, predominantly occurring within 3 km of forests or dense plantations. Only 17% of respondents received compensation and reported satisfaction with human-wildlife coexistence. Predation on goats and sheep during winter was attributed to the Himalayan black bear, Himalayan brown bear, and leopard, while Golden jackals and red foxes targeted poultry. Traditional methods were employed by farmers for crop and livestock protection. The study underscores the critical need for effective mitigation strategies and highlights the complex interplay between human activities, land-use changes, and wildlife conservation in the context of.

Keywords: Compensation, Human-wildlife conflict, Mitigation, Camera traps, Land-use change

Human-wildlife conflict (HWC) occurs when the needs and behavior of humans and wild animals impact negatively on each otherand when wild animals damage crops, threaten, kill or injure people and domestic animals, or when humans make disturbances in wild animal habitats (Madden and Quinn 2014). Conflict is becoming a critical problem due to the growing rural population in and around wildlife habitats (Dickman 2010). Human-wildlife conflicts are not evenly distributed throughout the landscape as they depend on the proximity of wild animal habitats, animal species, and seasons of the year.The history of human-wildlife interaction, more popularly known as human-wildlife conflict, is as old as the existence of human beings on the earth. Now this interaction has become a significant problem due to the decrease of free spaces throughout the world with increasing residency areas close to the forests (Redpath et al 2015). Crop feeding, property damage, livestock predation, and human casualties are the most common forms of conflict with wild animals (Ogutu et al 2014). Among these, human injury or death and livestock predation are the most serious forms of conflicts (Nyhus 2016). This makes people act negatively toward wildlife by poisoning, shooting, and trapping them. Such acts bring numerous social, economic, and ecological consequences (Messmer 2009). The number and type of damage caused by wildlife vary according to the species, season, and availability of resources (Mwamidi et al 2018).The major governing factors of the conflict are habitat loss, degradation, and fragmentation of animal habitat through human activities, animal husbandry, horticulture expansion, conversion of agricultural land to horticulture, over-exploitation of natural resources, and increasing developmental activities (Nyhus 2016). Most developed and developing countries are facing issues of conflict (Ogutu et al 2014).

Human-wildlife conflicts are a serious problem across the Kashmir Valley. Mostly Himalayan black bear (*Ursus thibetanus laniger*), common leopard (*Panthera pardus*), Himalayan brown bear (*Ursus arctos isabellinus*), and Indian crested porcupine (*Hystrix indica*) have been implicated as the major wildlife species involved in HWCs. Presently, local communities do not get enough benefit from wildlife resources as they may not be aware of the potential for wildlife-related economic enterprises. There has been no is detailed investigation completed to identify the cause of the conflicts, their consequences, and strategies to mitigate them. The current research comprehensively documents the nature, extent, and roots of Human-Wildlife Conflict (HWC) in the Kashmir Valley, providing a crucial baseline for effective management and promoting positive coexistence between humans and wildlife. This study addresses the need for wildlife conservation and management, benefiting local communities and various organizations involved in environmental well-being.

Study area: This study was initiated after a 10-year girl was lifted by a leopard in the Ganderbal district of Jammu and Kashmir. Ganderbal (34°13'48"N and 74°41'7"E) is located at an altitude of 1,590 meters in the Sindh valley. The district is spread from Safapora in the West (34°15'11.57” N and 74°39'14.71”, with an altitude of 1596 meters) to Zojila in the East (34°15'48.07” N and 75°25'25.15” E with an altitude of 3313 meters). Ganderbal is flanked by district Baramulla in the west, Srinagar in the south, Bandipora in the north-west, Harmukh Mountain in the north, and Kargil in the east. The total geographical area of the Ganderbal district is 1,059 sq. km and it is the smallest district by area in the state. This study includes the data of all the district as taken from wildlife protection department Sindh division Ganderbal based on opportunistic questioner sample of 150 persons directly or indirectly related to wildlife and conflict.

District Ganderbal has a moderate temperature in summer and experiences severe cold in winter months. The average annual temperature of the Sindh Valley is 11°C. In peak summer the average temperature is 21°C in July, and this is the hottest month of the year. While in winter, the average temperature remains around 0.3°C. January is the coldest month of the year. The annual rainfall is around 700 mm. Precipitation is the lowest in October, with an average of 92 mm. In July, the precipitation reaches its peak, with an average of 440 mm. During winter, the district experiences plenty of snow (10 to 50 cm), which falls from the middle of December till late February almost every year. Ganderbal has a topography that ranges from the cold desert with treacherous lofty mountains barren of any vegetation in areas adjacent to district Kargil, and temperate climate in the rest of the district. Ganderbal has about 45,361 households and 298,000 population among which 20% of population belongs to schedule-tribe living close or inside the wildlife habitats. Agriculture is the mainstay of the economy of the district. Farming is the main contributor of the GDP of the district with 316 sq. km under cultivation of horticultural and agricultural crops. Thousands of nomads move to upland pastures in the district during summers with their livestock. As they reside in remote and inaccessible areas, they come in direct contact with wildlife and are the source of Human-wildlife interaction.

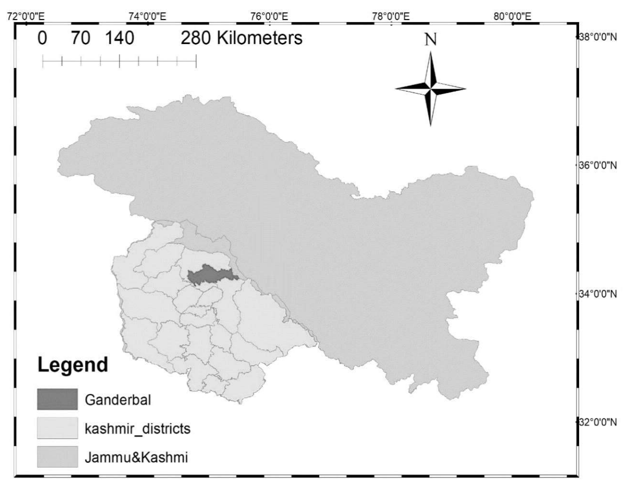
Methodology: The study employed a comprehensive data collection strategy, integrating primary and secondary sources. Primary data acquisition involved camera trap deployment, field observations, and questionnaire surveys. Fifteen camera traps were strategically positioned in and around the vicinity where a leopard-inflicted incident occurred, utilizing a systematic survey approach. These camera traps, comprising Cuddeback 20MP X-Change Color Day & Night Model 1279 and Spypoint Force-20 Trail Camera Brown, LIT 109, were randomly placed on roads, orchards, and trails toward the forest in neighboring villages. The traps operated continuously for 30 days and were monitored weekly. Field observations were conducted to confirm information from interviews, ensuring the accuracy and reliability of on-site data.Secondary data, sourced from the Department of Wildlife in Jammu and Kashmir, provided additional insights into registered cases of human-wildlife conflict. Key informant interviews targeted individuals reliant on agriculture, wildlife protection personnel, and members of the local community. Facilitated discussions and focus groups enabled a nuanced understanding of community perspectives on human-wildlife interaction. The research encompassed most of close forest villages in the Ganderbal district, with a specific focus on 150 households identified as being involved in conflicts based on wildlife protection data.

Data analysis incorporated both qualitative and quantitative methodologies, encompassing simple descriptive techniques and the calculation of encounter rates derived from camera trap data. Encounter rates, or camera trapping rates, were computed as the ratio of independent photographs to the number of trap days, with consecutive photographs of the same species at the same site considered independent with at least a 1-hour interval between them. The analytical framework included mean percentages and encounter rates, contributing to a comprehensive understanding of the dynamics of human-wildlife interactions in the study area.

RESULTS AND DISCUSSION

Wild mammals in human-dominated landscape: In the semi-urban village community of Ganderbal district, Jammu and Kashmir, the study utilized 15 camera traps over one month to document wildlife encounters. A total of 1,302 photographs of seven wild animal species were captured by camera traps during the period. The Indian Crested Porcupine exhibited the highest encounter rate (0.815), followed by the Red fox (0.704) and the Jungle cat (0.593) (Table 1).

Nature and extent of human-wildlife conflict/interaction: A total of 51 conflicts/interactions with the Himalayan black bear were recorded in the study area from 2015 to 2021: among which 45 conflicts lead to loss of economy to the local people (Fig. 3). This has a great negative impact on the conservation of wildlife in the region. Efforts were made to study the temporal and spatial use of the landscape by humans and wild animals using camera traps. Rhesus macaque (*Macaca mulatta*) and Kashmir gray langur (*Semnopithecus ajax*), two primates, showed different habitat-use patterns. The Rhesus macaque was using areas close to human habitation and in fallow land, while Kashmir gray langurs were captured in natural habitats and orchards far from habitation. Carnivores were captured in almost all habitat types, except for the Himalayan Black bears which were never captured in areas near human settlements and fallow landand were in orchards close to the forest. The Indian crested porcupine was seen in all habitats in the study area, from human settlements to forests. Primates were seen during day time while as Indian crested porcupine and carnivores were not observed during the day. They were seen in camera-traps during night, mostly at dusk and dawn (Fig. 4). Among the 175 respondents surveyed, conflicts between humans and wildlife were most frequent during the evening, accounting for 39% of reported incidents, followed closely by the morning with 36%. Daytime encounters



Map 1. Study area map showing Ganderbal in Jammu and Kashmir

Fig. 1. Camera trap images of wild mammals from the intensive study area

comprised 19% of conflicts, while night incidents were notably lower at 5.5%. This data suggests a temporal pattern in human-wildlife conflicts, with higher occurrences during the transitional periods of morning and evening, possibly influenced by factors such as wildlife behavior, human activities, and environmental conditions. Understanding these patterns can be crucial for implementing targeted mitigation strategies to reduce conflicts and promote coexistence between humans and wildlife. Seasonal variation in conflict decreased during winter and increased in summer and autumn months as less agriculture and horticulture activities take place in winter. Based on five-year data collected from the Wildlife Protection Department and surveys, the highest number of human-wildlife interactions

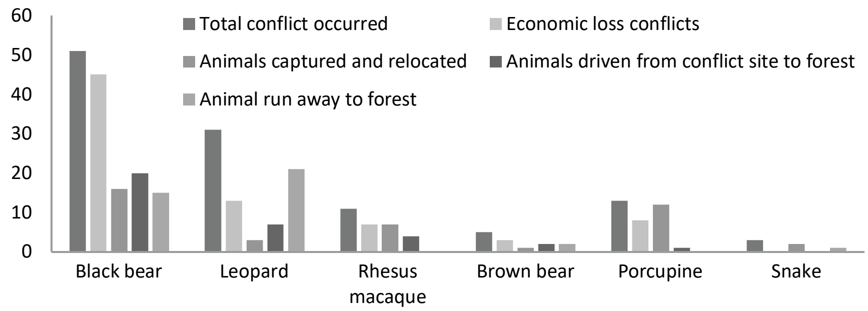


Fig. 2. Conflict cases with range of economic/human loss and relocation of animal

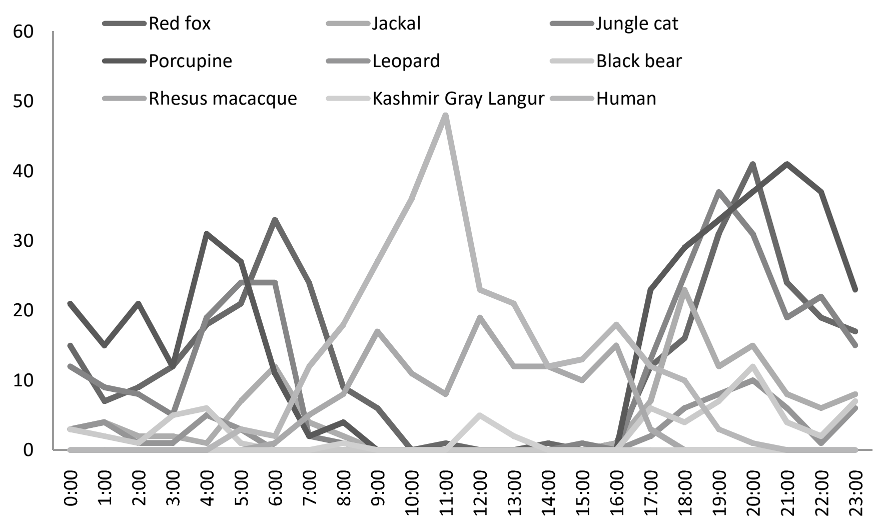


Fig. 3. Temporal segregation and coexistence of human and wild animals (n=2256, including camera-trapped pictures of humans)

Table 1. Encounter rate of wild mammals

Species	Scientific name	Local name	Observations	Encounter rate
Indian crested porcupine	*Hystrix indica*	*Teer Janwar*	367	0.815±0.32
Red fox	*Vulpes*	*Loow*	317	0.704±0.24
Jungle cat	*Felis chaus*	*Leash*	267	0.593±0.13
Golden jackal	*Canis aureus*	*Shaal*	117	0.26±0.22
Rhesus macacque	*Macaca mulatta*	*Ponz*	115	0.255±0.12
Himalayan black bear	*Ursus thibetanus laniger*	*Haput*	60	0.133±0.11
Leopard	*Panthera pardus*	*Suh*	56	0.1244±0.20
Kashmir gray langur	*Semnopithecus ajax*	*Wandur*	8	0.017±0.07

occurred in September and October (Fig. 5) as autumn is the main harvesting season of crops and fruits.

Mostly men were injured during conflict (71 %) as compared to women (29%) as more men work in the field and orchards than women. Males are involved in guarding of crops while females generally do not participate in this activity. Regarding the age-class, labourers and farmers from 20 to 50 year old were mainly effected by the wild animal interactions (44%). Young people below 20 years were involved in 22 percent of the cases, while people above 50 years had 34% interaction. Most of the interactions were fortunately with no human loss or injury (82%). However, 16% interactions resulted in injury to human being, and 2% percent resulted in death. Human casualty and injury attacks by wild animals were significantly associated with the location where the people were present at the time. The substantial majority of conflicts, constituting 60%, were reported to have transpired within a close range of the forest, specifically within 3 kilometers. Furthermore, 33% of conflicts were documented at a moderate distance, falling between 3 to 6 kilometers from the forest. A smaller proportion, amounting to 6%, occurred beyond the 6-kilometer mark. This spatial distribution highlights the significance of the immediate vicinity of forests as a hotspot for human-wildlife conflicts, underscoring the importance of targeted management strategies in this close proximity. During or post conflict, no death of wild animal was reported as the animals were rescued by the Wildlife Protection Department and relocated to safe places. Some of the animals were driven back to the forests. However, some natural and accidental deaths were reported from study area (Table 2). The 11 wild animal deaths in four years, were mostly due road accidents.

Crop and livestock damage: Crops were not equally affected by wild animals. Apple was the most favored crop, followed by maize and grapes. Himalayan black bear, Himalayan brown bear, Rhesus macaque and Indian crested porcupine animals feeding on crops. Black bear was the most commonly crop feeder which causes the most damage, followed by the Indian crested porcupine. They damaged crops during night and dusk/dawn, when people are absent from farmlands. The respondents of the survey conducted in Sonamarg and Sarbal ranked the Himalayan brown bear as the third crop feeder, followed by Rhesus macaque. Kashmir gray langur did no damage to r crops/orchards as were mostly in forests and away from the human dominated landscapes. Peak conflict damage was seen during autumn followed by summer, and crops showed varying seasonal damage to different extent.

Himalayan brown bear and Himalayan black bear attack sheep and goats, while leopard killed oxen, cows, buffalo,

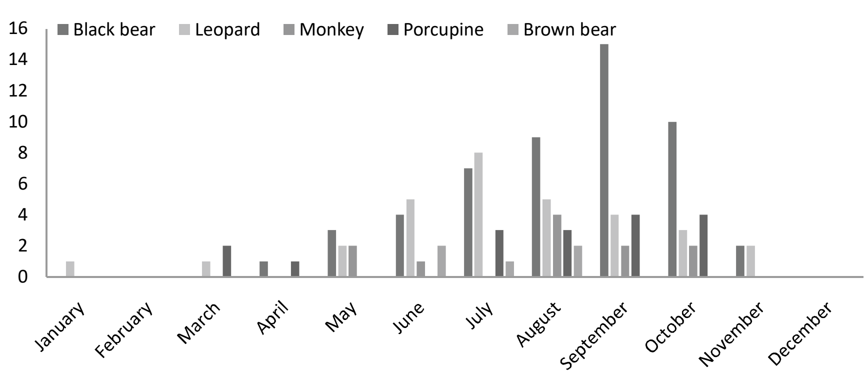


Fig. 4. Percent seasonal variation of human-animal interactions observed in the Sindh Valley conflicts (n=175)

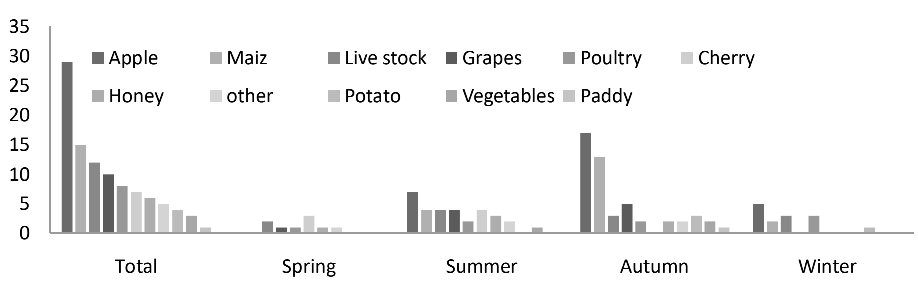
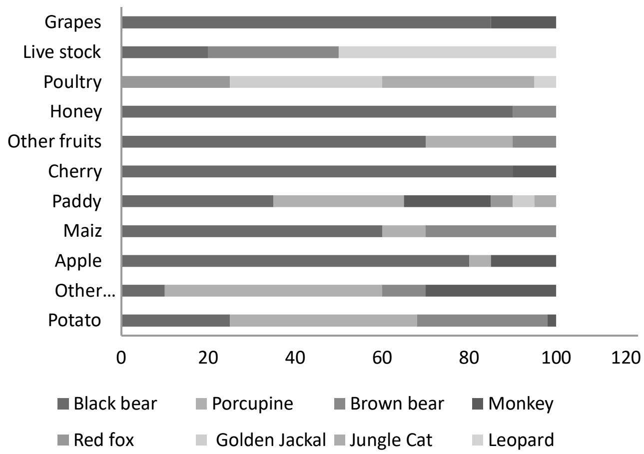


Fig. 5. Seasonal rank of crop feeding and predation by wild animals

domestic dog and horses, besides sheep and goats. Killing of livestock by carnivores is exacerbated by the decline of natural prey due to habitat destruction and poaching. Golden jackal, red fox and jungle cat (*Felis chaus*) were the main threat to poultry, resulting in continuous economic drain to farmers (Fig. 7, 8). Livestock predation was influenced by the movement of shepherds (*chopans* and *bakerwals*) to meadows. Mostly sheep and goats were preyed upon, with a few cases of horse predation (Fig. 10).



Other: (Walnut, Pear, Apricot, Peach, Plum)

Fig. 6. Interviews and field observations

Human-wildlife conflict/interaction: The main causes of human-wildlife-conflict in the Ganderbal were vast area of the valley has been converted to agriculture in recent decades. Thirty-six percent of the respondent agreed that this is the main cause of human-animal conflict/interaction as wildlife has been displaced. The human settlement close to the forest land enhanced the conflicts (28%) respondent and sixteen percent of the respondents said that human-wildlife conflict/interaction was the result of cutting of trees in the forest, displacing the animals to orchards that can be considered as pseudo-forests. Some of the old orchards provide wild animals better shelter than the nearby forests.The people inside the forests for firewood collection and grass cutting face wild animals, resulting in interactions. Ten percent of the people mentioned this is one of the causes. Non-timber forest product (NTFP) collection and poaching activities were considered as 5% of the causes (Fig. 11).

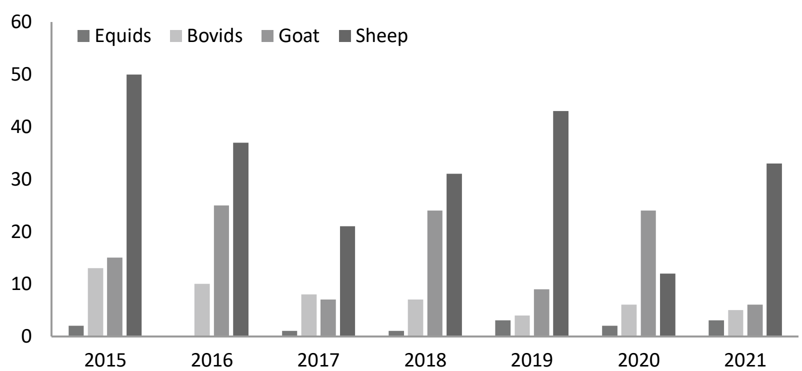
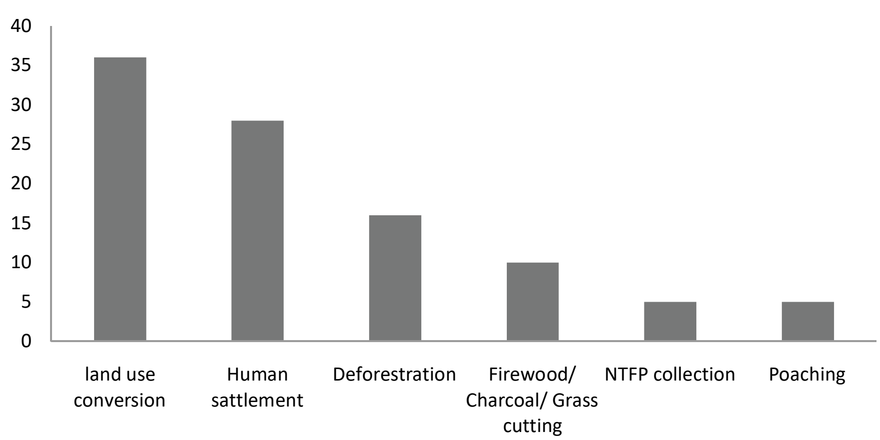


Fig. 7. Yearly Livestock predation



NTFP= Non timber forest products

Fig. 8. Cause for Human-wildlife-conflict in and around the study area (n=300)

Minimizing and mitigations of human-wildlife-conflict: Farmers employ various methods to protect crops from wild animals, as evidenced by interviews with locals. The primary approach, adopted by 31% of respondents, involves physical guarding by individuals. Fencing is the second most prevalent method, chosen by 24% of farmers. Chasing (20%), creating smoke (15%), and scarecrows (10%) also contribute to the arsenal of defense strategies. Notably, for mitigating conflicts with Black bears, chasing and smoke have proven effective, whereas fencing was less so due to its susceptibility to breakage by bears. Furthermore, scarecrows are diminishing in popularity as wildlife has adapted to their presence, rendering them less effective in deterring animals from encroaching on crop fields or orchards.

The nature and extent of the human-wildlife conflict have profoundly impacted humans, wild animals, and the environment in many ways through crop damage, habitat disturbance and destruction, livestock predation, and killing of wildlife and humans. As a result, local communities disliked wildlife inhabiting in their surroundings. The shrinking buffer zone between forests and human settlements is the main factor for increasing wild animals foraying into populated areas. Kashmir has 20% forest cover of its geographical area, with five national parks, 14 wildlife sanctuaries, and 35 conservation reserves. Kashmir has seen a drastic change in land-use patterns in the past three decades, with a complete disregard for wildlife habitats and ecologically sensitive zones. Hence change in land use patterns from agriculture to horticulture is providing food to wild animals outside their natural habitat which leads to the extension of their ranges. The buffer between forests and human habitation has vanished due to expanding apple orchards. Fruits, particularly apples, are one of the most attractive pursuits for Himalayan black bear. Translocation is used as an alternative to lethal control to manage species of carnivores that are potentially dangerous to humans (Athreya et al 2011). But high mortality rates among relocated animals have been attributed to capture-related stress, injuries, and extensive post release movements (Massei et al 2010). Some medicines used for tranquilizing cause complication to animals, like cardiac arrest, pulmonary odema, hemorrhages, hypoglycemia, brain concussion, adrenalin insufficiency, bloat, capture myopathy, shock may be noticed after minutes to hours/days after chemical immobilization (Macintire et al 2012). After translocation carnivores often reappear in their original home range within a relatively short time (Athreya et al 2011). Some studies suggest that translocated carnivores continue to conflict with humans following their release (Athreya et al 2011). Based on statewide survey in Maharashtra, India, Athreya et al (2011) found that translocations of leopards were associated with increased incidence of human-leopard conflict.

Furthermore, removal does not necessarily decrease the incidence of carnivore-human conflict at the site of removal in the long term and may even transfer the conflict to the release site. Another potential explanation for the increased number of attacks on humans is that leopards moving through unfamiliar human-dominated landscapes are more likely to encounter people. Translocated animals should be tagged and/or radio-collared to find out their post-translocated movement. In Kashmir, such studies are urgently required. To find solutions to man-animal interactions, it is necessary to know the population, demography, distribution and behavior of wild animals (Redpath et al 2013). The predictability of food waste as a resource can trigger population increases of opportunistic

Table 2. Unnatural death of wild animals during last 4 years (2018-2021)

Date	Animal	Location	Cause of death
April 18, 2018	Indian crested porcupine	Repora lar	Road accident
May 10, 2018	Jackal	Byepass Manigam	Road accident
June 12, 2018	Indian crested porcupine	Yarmuqam Manigam	Road accident
September 30,2018	Himalayan brown bear (m)	Sarbal Sonamarg	Electric current
January 03, 2019	Jackal	Prang road	Road accident
January 26, 2019	Yellow-throated marten	Panzin Kangan	Unknown
October 01, 2019	Himalayan black bear (m)	Shah mohalla rangil Ganderbal	Unknown
March 6, 2020	Golden jackal	Kangan	Dog attack
August 23, 2020	Himalayan black bear (f)	Gutlibagh Ganderbal	Unknown
January 12, 2021	Red fox	Lar	Unknown
September 23, 2021	Himalayan black bear (f)	Sheikh bagh kangan	Road accident
December 16, 2021	Himalayan black bear (m)	Khulmulla Nagbal Ganderbal	Road accident

species, in turn altering predator-predator and predator-prey dynamics (Oro et al 2013, Newsome et al 2015).

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Impact of Alien Invasive Species (*Cassia spectabilis* DC.) on Soil Properties in Nagarahole Tiger Reserve

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***Abstract*:** The aggressive behavior of invasive alien plants has been reported to alter the plant species composition and is even observed to replace the native species. The current study was carried out to evaluate the impact of *Cassia spectabilis* on soil properties in D B Kuppe and Anechowkur Range of Nagarahole Tiger Reserve, located in Karnataka, India. The intensity of infestation was *categorized into three level viz.,* highly infested, moderately infested and non-infested areas. Four soil samples were collected at 0-20 cm and 20-40 cm depths randomly and composite sample was made and analyzed for soil physicochemical properties, which varied significantly between different levels of infestation across locations as well as across different depths. In both locations, the moderately infested areas recorded the highest percentage of organic matter. Soils within *C. spectabilis* had greater moisture content, electric conductivity, higher pH and highest percentage of organic matter than soils from other levels of infestation. But bulk density was highest in non-infested areas of *C. spectabilis*. Correlation analysis for tree regeneration with soil properties revealed that most of the variables were correlated with each other.

***Keywords*:** *Cassia spectabilis* DC., Nagarahole Tiger Reserve, Alien invasive, Physicochemical properties, Soil properties

Alien invasive species are alien species in natural or semi-natural ecosystems or habitat, act as agent of change and threatens native biological diversity. These invasives are widely distributed in all kinds of ecosystems throughout the world and include all categories of living organisms. All introduced species do not become invasive; those will often become better competitors for native species. However, out of the many introduced species some become invasive and problematic. Factors such as rapid reproduction and growth, high dispersal ability, phenotypic plasticity and ability to survive on various food types and in a wide range of environmental conditions are likely to help these invasives to spread when compared to native species. The ecological interactions between exotic and native species are complex and still there is huge knowledge gap about this. The invasion of alien plants into natural habitats involves a number of significant changes to the habitat, often negatively affecting resident flora as well as fauna. Alien plants may directly modify the structure and complexity of the physical environment. The impact of alien invasive species results in direct displacement of native plant species, changes the structure of the soil by affecting the rate of decomposition, soil profile, nutrient content and moisture availability. Sharma and Raghubanshi (2006) reported that *L. camara* biology promotes the accumulation of litter under the shrub, resulting in a buildup of organic carbon and nitrogen and can also hold water for a longer time. Higher soil phosphorus often is correlated with invasion. Herr et al (2007), observed that *Solidago gigantea* (giant golden rod), an invasive to Europe showed lower soil pH and higher labile phosphorus fractions in invaded regions compared to non-invaded areas. The invasive- native interactions are prerequisite for formulating management strategies to safeguard the biodiversity (Zingthoi and Rai 2021a).

Cassia spectabilis DC*.* was introduced to botanical gardens in India as an ornamental plant. It escaped from the forest areas of Sikkim and widely became invasive in southern India. Ecological investigation is performed along disturbance gradient to emphasize the plant-plant and plant-soil interrelationship (Zingthoi and Rai 2021b). The Western Ghats in Southern India is one among the twelve mega biodiversity centers in the world and has rich biodiversity for its fauna and flora. *C. spectabilis* was introduced in the Western Ghats without proper knowledge about its potential to become an invasive species. After the introduction, started establishing itself extensively in the new areas and its management has become a challenging task. *C. spectabilis* is recognized as invasive plant in India Global Invasive Species Database of 2021 is now threatening several ecosystems including Nagarahole Tiger Reserve. The aggressive behavior of Invasive Alien Plants (IAP) reported to alter the plant species composition and is even observed to replace the native species and changes the soil properties. Hence the current study was carried out to evaluate the impact of *C. spectabilis* on soil properties in D B Kuppe and Anechowkur Range of Nagarahole Tiger Reserve, located in Karnataka, India.

MATERIAL AND METHODS

The study was conducted to observe the impact of invasive alien species on soil properties in Nagarahole Tiger Reserve which lies between the latitudes 12° 15' 37.69" N and longitudes 76° 17' 34.4" E. The area receives 1000 to 1540 mm annual rainfall and favors the area to have high humidity with a temperature ranged between 12°C and 32°C. Elevation of the park ranges from 687 to 960 m. The total geographical area of the reserve is 843.96 sq. km. located in the Kodagu and Mysore districts of Karnataka, India. Based on the preliminary survey, *C. spectabilis* populations in the D B Kuppe and Anechowkur ranges were observed. The study was conducted in these two ranges of Nagarahole Tiger Reserve, *viz.,* D B Kuppe and Anechowkur. These parts were *categorized* into highly infested, moderately infested and non-infested areas based on cover/density of *C. spectabilis*.

Methodology: A preliminary survey was conducted to collect information about the infestation level. Based on the cover of *C. spectabilis*, infestation levels were grouped into different categories and a stratified random sampling technique was adopted with different levels of infestations as different strata (Fig 1). The quadrates having 60-80% of *C. spectabilis* cover was categorized as highly infested, 40-60% as moderately infested and areas with no *C. spectabilis* cover were considered as non-infested area. In each category, 20 quadrates of 20 m × 20 m were laid randomly in forests. In each of the main quadrates, four soil samples at 0- 20 cm depth and 20- 40 cm depth were collected randomly and the composite sample was prepared. The composite samples were air dried at room temperature. Soil samples were analyzed for pH, electric conductivity, percentage of organic matter and available organic carbon by adopting standard procedures.

Soil Analysis

Moisture content (%): Moisture content was measured by subtracting the weight of the dry soil from the weight of the moist soil, and then dividing by weight of the dry soil and it was expressed in percentage (Das and Keener 1997).

$$\text{Moisture (\%)} = \frac{\text{Weight of moist soil} - \text{Weight of oven dry soil}}{\text{Weight of oven dry soil}} \times 100$$

Bulk density (g cc^{-1}): Bulk density was calculated by using the core sampling (5 cm diameter), the samples were then placed in an airtight container and oven drying at 10^{o}C until the constant weight was obtained in the laboratory. Then the bulk density was determined by dividing the weight by the sample volume and expressed as gram per cubic centimeter.

$$\text{Bulk density } (\text{g cc}^{-1}) = \frac{\text{Dry Weight}}{\text{Volume}}$$

pH (hydrogen ion concentration): The soil pH values were determined using a glass electrode digital pH meter with a soil and water ratio of 1:2.5. 10 g of sieved, air-dried soil (Fig 4), Sample was taken in a 50 ml beaker and 25 ml of water was added. It was stirred at a regular interval of half an hour and then allowed to settle for 30 minutes. The residue was taken for estimation of pH. The pH meter was standardized using pH 4 and 7 buffer solutions (Jackson 1967).

Electrical conductivity (dSm^{-1}): The soil electrical conductivity (EC) measures the number of various salts present in the soils (soil salinity) and directly related to its specific conductance. The EC of the soil samples were determined in 1:2.5 soil water suspension with an electric conductivity meter (Gliessman 2000).

Electric conductivity (dSm^{-1}): = Observed conductivity × Cell constant

Soil organic carbon (%): The soil organic carbon percentage was calculated as described by Walkley- Black method (Prabhat Kumar Rai 2021).

$$\text{OC (\%)} = \frac{\text{BTV} - \text{STV} \times \text{N of FAS} \times 0.003}{\text{Weight of soil sample}} \times 100$$

OC (%) = % Organic Carbon ×1.724

OC: Organic carbon, OM: Organic matter, BTV: Burette reading of blank (without soil)

STV: Burette reading with the soil, N of FAS: Normality of Ferrous Ammonium Sulphate

Data analysis: The data obtained was analysed using SPSS.

RESULTS AND DISCUSSION

Soil moisture: The soil moisture content varied significantly among the different levels of infestation except D B Kuppe range at 0-20 cm depth. The highest moisture content was recorded in a moderately infested area followed by a highly infested area in D B Kuppe range. At Anechowkur range soil moisture was highest at highly infested area followed by a moderately infested area (In D B Kuppe range, at 20-40 cm soil depth, maximum moisture content was recorded in moderately infested areas followed by a highly infested area. Similarly, higher moisture content was observed in moderately infested area followed by highly infested areas of Anechowkur range (Table 1). The highest moisture content was recorded in a highly and moderately infested areas followed by a non-infested area in both locations. Similar results were obtained in Osunkoya and Perrett (2011) where, moisture content was significantly higher in *L. camara* infested patches areas. Contrasting the present study Debnath and Debnath (2018) showed moisture content is low in the invaded (*C. odorata*) sites than in the non-invaded natural sites.

Bulk density: The bulk density is expressed in terms of mass per unit volume of dry soil and it was calculated for all the soil samples and expressed in gram per cubic centimeter. The bulk density varied significantly in D B Kuppe range across all the infestation levels and in Anechowkur was non-significant among different level of infestation across different depth. In D B Kuppe Wildlife range, the non-infested areas recorded more bulk density at both soil depths followed by the highly infested areas. In Anechowkur range, maximum bulk density was recorded in non-infested areas in both depths, followed by moderately infested areas at 0-20 cm and 20-40 cm depth respectively. In both ranges highest bulk density was recorded in non-infested areas. Panwar et al (2016) reported that, Bulk density decreased and pore space increased as the invasion of Lantana increased. Similar results were obtained in the present study, where the soil bulk density showed a significant difference across all the infestation levels. The non-infested areas recorded more bulk density followed by the highly and moderately infested areas of both ranges. Contrasting to the present study Debnath and Debnath (2018) showed no significant differences among invaded and non-invaded sites of *Chromolaena odorata*. The bulk densities were higher in all the three strata of *Chromolaena odorata* invaded sites.

pH: Invaders contributing nitrogen-rich litter with higher decomposition rates increase soil nutrients and change pH. The hydrogen ion concentration (pH) was analysed for all the soil samples from different levels of infestation. There was significant difference in pH among different levels of infestation in both locations. In D B Kuppe range recorded neutral pH in all infestation levels. All the infestation levels of Anechowkur recorded acidic soil pH ranging from 5.87 - 6.22. Presence of high *C. spectabilis* will enhance the pH. Similar results reported for *L. camara*-infested soils in Australia where the higher soil pH was found in Lantana invaded sites compared to noninvaded sites (Osunkoya and Perrett 2011). In contrasting to the present study Comole et al (2021) reported that almost all soils collected from under the *Prosopis velutina* canopies had a significantly higher soil exchangeable Ca, K, Mg, and Na, organic matter (OM), total nitrogen (TN), available phosphorus (P), Electrical conductivity (EC), and cation exchange capacity (CEC) than the other sample positions, except for the pH which had the high value in inter-canopies.

Electric conductivity: The electric conductivity did not vary significantly between infestation levels in D B Kuppe range. Highly infested as well as moderately infested areas recorded the highest electric conductivity indicating high salinity in *C. spectabilis* infested areas. The electric conductivity did not show any significant difference between the infestation levels in D B Kuppe range. The electric conductivity varied significantly among different levels of infestation in Anechowkur range. Highly infested as well as moderately infested areas recorded the highest electric conductivity indicating high salinity in *C. spectabilis* infested areas. Osunkoya and Perrett (2011) observed was no significant difference in EC among Lantana invaded and non-invaded sites of Australia. Debnath and Debnath (2018) also reported that soil conductivity was higher in both the non-invaded sites of lower and middle strata respectively while it is higher in invaded site of top strata of *Chromolaena odorata* (Table 2).

Organic matter and organic carbon: The organic matter content of the soils differed significantly across locations and different infestation levels. Among different infestation levels, moderately infested areas recorded the highest organic matter. The values illustrated in Table 3 depict the organic matter percentage In D B Kuppe range, highest percentage of organic matter was in the moderately infested areas (4.13

Table 1. Moisture content (%) and Bulk density (g/cc) under different infestation level at D B Kuppe and Anechowkur range in different depths

Level of infestation	D B Kuppe				Anechowkur			
	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm
	Moisture content (%)		Bulk density (g/cc)		Moisture content (%)		Bulk density (g/cc)	
Highly infested	6.96	7.51	0.89	0.88	3.92	3.51	0.95	0.94
Moderately infested	8.16	9.08	0.85	0.88	3.58	3.71	0.95	1.00
Non-infested	6.68	6.18	0.94	0.96	1.91	2.24	0.98	0.98
CD (p=0.05)	NS	1.94	0.05	0.05	1.16	0.71	NS	NS

NS - Non-significant

%) followed by highly infested areas at 0-20 cm depth, whereas in 20-40 cm depth also observed the maximum percentage of organic matter in moderately infested areas followed by highly infested areas (Table 3). Highest percentage of organic matter was recorded in the moderately infested areas at 0-20 cm depth, followed by non- infested area. At 20-40 cm depth, the maximum percentage of the organic matter was in moderately infested areas followed by the non-infested areas in moist deciduous forest of Anechowkur. Sharma and Raghubanshi (2006) reported that *L. camara* biology promotes the accumulation of litter under the shrub, resulting in a buildup of organic carbon and nitrogen and can also hold water for a longer time. Similar results were obtained from the present study, that in among different infestation levels, infested areas recorded highest organic matter and organic carbon, followed by non-infested areas. Debnath and Debnath (2018) also showed that total carbon and organic matters are higher in the non-invaded sites of *Chromolaena odorata* than the invaded sites at Tripura, but Zingthoi Khuppi Sakachep and Prabhat Kumar Rai (2021) reported that alteration in native vegetation composition cause depletion in soil organic carbon and soil organic matter.

Association of tree regenerates with soil properties in different levels of infestation: Spearman rank correlation analysis for tree regeneration with soil properties revealed that most of the variables were correlated with each other in D B Kuppe range and Anechowkur (Table 4). Tree regeneration

Table 2. pH and electric conductivity (dS/m) under different infestation level at D B Kuppe and Anechowkur range in different depths

Level of infestation	D B Kuppe				Anechowkur			
	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm
	pH		Electric conductivity (dS/m)		pH		Electric conductivity (dS/m)	
Highly infested	7.08	7.23	0.11	0.10	6.22	6.18	0.09	0.10
Moderately infested	7.15	7.05	0.10	0.09	6.17	6.15	0.09	0.08
Non-infested	6.82	6.91	0.11	0.08	5.87	5.87	0.06	0.06
CD (p=0.05)	0.20	0.16	NS	NS	0.15	0.17	0.02	0.02

Table 3. Organic matter (%) and organic carbon (%) under different infestation level at D B Kuppe and Anechowkur range in different depths

Level of infestation	D B Kuppe				Anechowkur			
	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm	0-20 cm	20-40 cm
	Organic matter (%)		Organic carbon (%)		Organic matter (%)		Organic carbon (%)	
Highly infested	3.82	3.54	6.59	6.10	2.56	2.60	4.41	4.48
Moderately infested	4.13	3.92	7.11	6.76	3.09	3.18	5.33	5.49
Non-infested	3.60	3.29	6.20	5.66	3.07	2.81	5.30	4.85
CD (p=0.05)	0.40	0.34	0.69	0.59	0.30	0.32	0.53	0.55

Table 4. Association of tree regenerates with soil properties

Infestation level	Moisture content (%)	Bulk density (g/cc)	pH	Electric conductivity (ds/m)	Organic matter (%)	Organic carbon (%)
D B Kuppe range						
Highly infested	-0.042	-0.103	0.404**	0.343*	0.235	0.235
Moderately infested	0.003	0.039	0.132	-0.131	-0.124	-0.124
Non-infested	-0.147	0.342	-0.098	0.081	-0.426**	-0.426**
Anechowkur range						
Highly infested	0.285	0.271	-0.571**	-0.447**	-0.423**	-0.423**
Moderately infested	0.315*	0.326*	-0.167*	0.248	-0.006	-0.006
Non-infested	-0.391*	0.133	-0.262	-0.268	-0.305	-0.305

**Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level which was collected from same plots of soil samples taken.Correlation analysis for tree regeneration with soil properties revealed that most of the variables were correlated with each other. In D B Kuppe range tree regeneration in highly infested area negatively correlated with moisture content and bulk density, significantly positively correlated with electric conductivity and pH. Positively correlated with organic matter and organic carbon. Regeneration of moderately infested area were positively correlated with moisture content, bulk density and pH and negatively correlated with electric conductivity, organic matter and organic carbon. In non-infested area moisture content and pH negative correlation, bulk density and electric conductivity shows positively correlation and regeneration were significantly negatively correlated with organic matter and organic carbon. The correlation for tree regeneration with soil properties in Anechowkur range tree regeneration in highly infested area showed positively correlation with moisture content and bulk density and all other parameters like EC, OC and organic matter were significantly negative correlation. In moderately infested area regeneration significantly positively correlated with moisture content and bulk density (significantly negative correlated with pH) but positively correlated with EC and negatively correlated with organic matter and organic carbon. Significantly negative correlation was observed between regeneration and moisture content in non-infested area of Anechowkur, but regeneration was positive correlation with bulk density. Other parameters include EC, OC and organic matters were negatively correlated with regeneration. Dassonville et al (2008) observed strong positive impacts in sites with initially low nutrient concentrations in the topsoil of invaded plots compared to uninvaded ones, while negative impacts were generally under the uninvaded plots. Ahmad et al (2019) reported that invasion by *Leucanthemum vulgare* had a significant impact on key soil properties in the invaded plots. The soil pH, water content, organic carbon and total nitrogen were significantly higher in the invaded plots as compared with the uninvaded plots. In contrast, the electrical conductivity, phosphorous and micronutrients*, viz.* iron,

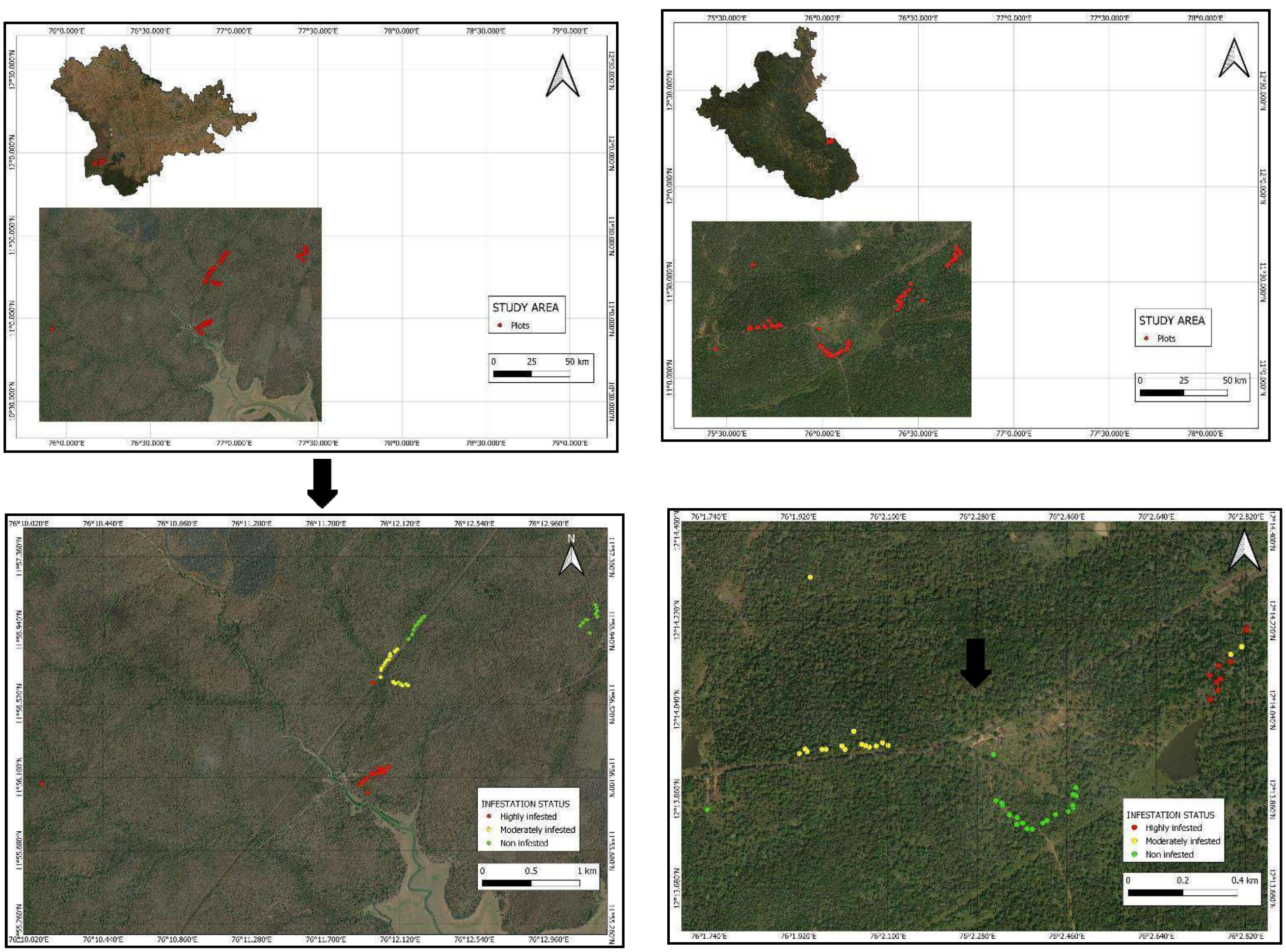
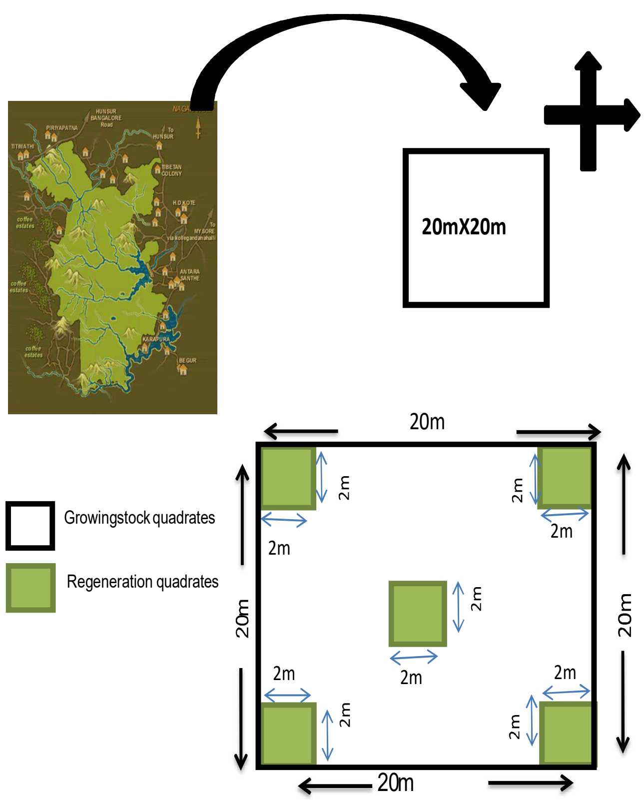


Fig. 1. Location map of the study area

A. Highly infested area B. Moderately infested area (D B Kuppe Wildlife Range) C. Non-infested area

A. Highly infested area B. Moderately infested area (Anechowkur Wildlife Range) C. Non-infested area

Fig. 2. Different levels of infestation



copper, manganese and zinc, were significantly lower in the invaded plots as compared with the uninvaded plots.

CONCLUSION

Soil physicochemical properties varied significantly between different levels of infestation across locations as well as across different depths. In both location of moist deciduous forests, the moderately infested areas recorded the highest percentage of organic matter. Soils within *C. spectabilis* had greater moisture content, higher electric conductivity, higher pH and highest percentage of organic matter than soils from other levels of infestation. But bulk density was highest in non-infested areas of *C. spectabilis*. Correlation analysis for tree regeneration with soil properties revealed that most of the variables were correlated with each other. Based on the present study, management plan can be made for removal of *C. spectabilis* through different ways in the future. Allelopathic effect of *C. spectabilis* need to studied and value addition of *C. spectabilis* can be taken up to improve the livelihood of local tribal communities. A long-term study can also be taken up to see the impacts of *C. spectabilis* and its removal on floristic diversity and regeneration over a time scale by establishing permanent plots.

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Microarthropod Diversity, Co-occurrence and Ecosystem Impacts among Invasive and Native Plant Species

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Abstract: The study compared aerial micro-arthropod diversity in exotic and native shola species in a high-altitude shola ecosystem. The thysanoptera, hymenoptera, and ixodida were more abundant in exotic plants, while entomobryidae, paronellidae, and acariformes are more abundant in shola species and exotic *Cestrum*. The native shola dependent plant *Piper brachystachyum* has abundant entomobryidae but is less diverse. The study concluded that shola species have an indigenous population of micro-arthropods, particularly collembolans. The exotic plants act as a significant reservoir of those micro-arthropods, which could potentially damage the local ecosystem and agriculture.

Keywords: Exotic plants, Shola, Collembola, Nilgiris

The British entry to the Nilgiris Hills in the 18th century paved the way for introducing exotics or invasive plants (Nazia and Sanil 2015). The pristine primitive shola grasslands are either converted to pine forests, eucalyptus plantations, or tea estates. The vegetation of the high range (1800m above sea level) has a mosaic pattern of forest (C4 plants) locally called *"Shola"* and grasslands (C3 plants). The shola interspersed with grasslands that occur in the mountain folds is the perennial source of water and forms tributaries of rivers in the lower elevation (Thomas and Palmer 2007). The introduction of exotic/invasive plants like *Eucalyptus* and *Pinus* leads to converting forests to tea estates and residential areas, which impacted the endemic flora and fauna (Raman et al 2020a). *Cyprus* and *Acacia* were the later entrants to this fragile ecosystem, followed by the automatic invasion of orange *Cestrum*, *Lantana,* and *Parthenium* (Bhavana et al 2015). Invasive species management became a priority issue as the CBD in 1992 (Convention of Biological Diversity) identified it as a threat to the ecosystem, economics, and human health. Wind, water, and birds are the key factors that help in the dispersal of seeds of many exotic species. They sprout earlier than the native species and fall out last, ensuring a higher life span (Srivastava and Singh 2009). The exotic/invasive species can adversely affect the shola plants by competing and eliminating them, and interrupting the trophic interaction associated with them (Maron and Vila 2001).

Some exotic/invasive species have turned to weed, multiplying at an alarming pace (e.g *Parthenium*, *Lantana* and *Eupatorium*, etc.). The spread adversely affect the ecosystem by altering the geo-morphological process, hydrological cycle, bio-geochemical cycle and fire regime. The stress exerted by the invasive species devastates native species by causing changes in dominance, distribution, and shifting the entire ecosystem balance (Goyal and Brahma 2001, Jackson et al 2002). These exotics are vastly spreading in the ecologically fragile Nilgiris as they competitively eradicate the shola patches that threaten the existing shola. The leading theory behind the increase in exotics/invasive is that they escape from natural enemies that hold them back (Keane and Crawley 2002).

The exotic species suppress the growth of the native plant species as well as the behavior of native insects' guilds such as herbivore, parasitoids, and pollinators through a variety of mechanisms (Boettner et al 2000, Snyder and Evans 2006) and disturbs the agriculture sustainability and food security (Sakachep and Rai 2021). They act as the specialized antagonist and do allelopathic (chemical) interaction or release volatile compounds with native plants and variability in response and resistance (Thebaud and Simberloff 2001; Mitchell and Power 2003, Callaway and Ridenour 2004). They also act as *"evolutionary traps"* for the native aerial micro-arthropods, which readily get attracted and adapted to the food resources of exotic/invasive plants. Though the direct impacts are visible, they indirectly reduce the abundance or activity of both native plants and insects. Many aerial micro-arthropods depend on mutualism with the exotic plants depending upon the presence or absence of flowers. The relationship becomes an ecological interaction between exotic/invasive and resident micro-arthropods.

Canopy research is gaining responsiveness in present days; especially the role of aerial micro-arthropods and their ecological interactions are hazy. Micro-arthropods are omnipresent and have defined environmental roles in the soil. The antique relationship of the micro-arthropods as pollinators of moss (Rosential et al 2012), opens the curiosity on these micro-organisms. The arboreal micro-arthropod communities differ qualitatively from what is found in leaf litter at soil level, being generally dominated by a few specialist species that are uncommon in the soil (Lindow and Winchester 2006, Affeld et al 2009, Rodgers and Kitching 2011, Bolger et al 2013). Documentation of wind circulation of flightless groups such as collembolan and mites is lacking. They are hypothesisied as a pioneer community spread by a mechanism called aerial ballooning (Hawes et al 2007). Like other plant-animal relationships, the micro-arthropod community may have species-specific dominance and occupancy in different fauna. The oldest "living fossil" shola (Raman et al 2020b) may also host specific micro-arthropods species, which may have their ecological role in perpetuating the stability of ecosystem (Sharma and Singh 2021) . The present work was conducted to compare the diversity, density, and adaptive patterns of various micro-arthropod groups in shola/ native and exotic/invasive plants in the Nilgiris.

MATERIAL AND METHODS

Study area: The Nilgiri hills the Tamil Nadu state of India, is the part of the Nilgiri Biosphere reserve, a UNESCO recognized world heritage site. The Nilgiri hills is the second highest peak (~2637 asl) in the Western Ghats is a joining point of Eastern Ghats also. The region lies at a latitude of 11° 08' N to 11° 37' N and longitude of 76° 27' E to 77° 4' E, and the central location is 11°22′30″N 76°45′30″E. The area is approximately 2,479 Km^2 and the temperature reaches a maximum of 25°C in summer and up to-4°C during winter. The native vegetation is by short, stunted montane evergreen sholas and the adjoined grasslands. Plantations like tea, *Eucalyptus*, *Pinus*, *Acacia*, and exotic bushes are also common. The shola forest occurs in the higher elevations of the Western Ghats and its associated hill ranges in Southern India (Raman et al 2020a, Raman et al 2020b). Shola forests can befound at an altitude of 1800 meters above sea level. They are found only in Western Ghats regions and are always wet and contain a lot of humus, which is a suitable habitat for decomposers and wet soil dwellers. In many places, the shola regions are patchy or interspersed with exotic plantations. The invasive species like *Lantana, Parthenium, etc.,* are spreading at an alarming rate towards the shola regions.

Sample collection: The twigs with dense leaf samples were collected from five shola/native and five exotic/invasive species from various parts of the Nilgiris. *Cestrum aurantiacum, Solanum mauritianum, Polygonum divaricatum, Lantana camara,* and *Acacia dealbata* were exotic/invasive species collected. Species like *Rhodomyrtus tomentosa*, *Rhododendron nilagiricum, Photinia lasiogyna, Rubus ellipticus,* and *Piper brachystachyum* were the native/shola species. The twig samples were from twelve different sampling locations minimally separated by ~10km. The sampling regions include pristine shola regions, exotic-shola mixed regions and exotic bushy regions. Multiple samples (approximately 10-25) of each flora under consideration in each sampling locality (~2km radius) are collected mixed to maintain the homogeneity of sampling by collecting a single layer of twig with leaves in a zip lock cover of 39cm x 31cm (surface area of 1209cm^2). The total sampled area is the product of the number of samples to the surface area sampled (e.g., if N is the sample repeats in a location, the total sampled area is N x 1209 cm^2). The value is expressed in square meters using the following equation, density of aerial micro-arthropods per square meter (m^2) = No species observed / the total area sampled x10^{-4}.

Separation, mounting and identification: Micro-arthropods were extracted 24 hrs from the twigs-with leaves using the Berlese -Tullgren funnel (Dietick et al 1959) under a 60V light source. The upper region of the funnel kept airtight to prevent the escape of micro-arthropods. The separated micro-arthropods were collected and fixed in Gisin's fixative and preserved in 70% alcohol and made permanent mounts in the Hoyer's medium and temporary mounts in glycerol. Collected micro-arthropods using a 0.0 tip brush under Olympus Magnus MSZ-TR stereo microscope. The specimens were identified to the possible taxa (family or superorder)at high magnification using Lawrance and Mayo Model NLCD-307B digital microscope. Identified the collembolans to family level Entomobryidae, Paronellidae, hypogastruridae and neanuridae following Bellinger et al (1996-2023). The other micro-arthropods acariformes, thysanoptera, ixodida, and hymenoptera were classified following Imms et al (2012).

Diversity and multivariate analysis: Estimated the micro-arthropods diversity and evenness for each flora under consideration (α-diversity $H\alpha$) separately and evaluated the gamma diversity ($H\gamma$) and micro-arthropod diversity and evennessin all the native/sholaorexotic flora (Hill 1973). Whittakar index was followed to estimate the beta diversity as the ratio of$H\gamma$to $H\alpha$ ($H\gamma/H\alpha$) following (Whittakar 1960). Beta diversity interprets the similarity and overlap and allows us to understand the variations between distributions. Shannon equitability, Simpson's dominance (λ), Gini-Simpson index (λ-*1*) and Berger-parker index (BPI), Hill number-true diversity (${}^{q}D$), and the Renyi entropy (${}^{q}H$) in a programmed excel sheet (Goepel 2018). Principal component analysis (PCA) was performed, according to Josse et al (2014), in the R- platform (R studio version 4.0.2) using the ggplot2 package. The PCA is a type of linear transformation on a given data set. This transformation fits the micro-arthropod data set to a coordinate system and executes the most significant variance in the first coordinate and used the percentage of principal component I and principal component II variance to determine the variation of micro-arthropods in ten selected plants. To visualize the floristic dependence of the various micro-arthropods, the Non-metric multidimensional scaling (NMDS) (Oksanen et al 2005) using Bray-Curtis distance method in packages vegan and ggplot2 in R studio. NMDS is an indirect gradient analysis that produces ordination based on distance or dissimilarity matrix.

Co-occurrence of species: The species association of different micro-arthropods in two diverse vegetation were analysed using 'co-occur' package in R studio. The 'co-occur' package analyse the species co-occurrence using a probabilistic model. This method provides information such as observed co-occurrence and probability co-occurrence. This model also determines the observed frequency of co-occurrence is significantly greater (positive association, (Pgt) ≥α (α=0.05) or significantly less (negative association, (Pgt)≤α (α=0.05), or not significant (random association) (Veech 2013, Griffth et al 2016).

RESULTS AND DISCUSSION

Aerial micro-arthropods observed: A total of 8 different categories of micro-arthropods were observed from the flora under study. The observed micro-arthropods are thrips (thysanoptera), bees (hymenoptera), red mites, oribatid mites (acariformes), ixodida, and springtails (belongs to entomobryidea, paronellidae, hypogastruridae and neanuridae).The oribatid mites and the springtails such as entomobryidea and paronellidae seem to be present mainly in the shola plants. The bees, red spider mites, thrips, and the springtails of the family hypogastruridae and neanuridae are observed predominantly in the exotic plants (Table 1).

Species richness and abundance: Diversity indices (Table 2) showed a significant variance in the micro-arthropod diversity between exotic and native flora. The higher the Shannon index, the micro-arthropods may be equally distributed, while the high dominance of a particular fauna indicates a lower value. The H_{β} is a clear indicator of dominance, the higher the value higher the abundance of a particular species compared to the community (H_{γ}) (e.g. Shola/native, exotic, etc.) All the indices indicate that the shola species are more diverse (H_{γ}=1.45) than the exotic plants (H_{γ} =099). The low evenness suggests that one or two micro-arthropod communities are dominating in that particular plant. The high abundance of specific fauna was in the shola-associated native species like *Piper brachystachyum* and *Rhodomyrtus tomentosa*. In the former species was thrips, while in the latter was entomobryidea. In shola/ native plant species, micro-arthopod richness varied between 3-5, while in that of exotics it is 3-8. The flora like *Cestrum aurantiacum* (H_{β}=0.79) and *Polygonum divaricatum* (H_{β}=0.64) among the exotic species are highly diverse. The *Solanum mouritianum* is less diverse (H=0.15 λ=94.60%, H_{β}=6.60) and has high abundance of thrips. The true diversity as Hill numbers and the Renyi entropy in the order of 'q' for the shola/native and the exotic species given in Figure 1. The

Table 1. Density of micro-arthropod/ Sq.m (Mean ± standard error) observed from the native and exotic flora in the Nilgiris

Micro-arthropod fauna observed	Flora studied (Mean ± SE)									
	Exotic flora					Native/ shola flora				
	Ca	Sm	Ad	Pd	Lc	Rn	Rt	Re	Pl	Pb
Entomobryidae	9.65±1.76	0.00±0.00	0.00±0.00	98.57±3.04	0.00±0.00	50.32±4.48	35.15±3.43	0.00±0.00	16.54±2.19	232.29±3.45
Paronellidae	13.76±3.51	13.79±2.65	0.00±0.00	16.54±2.19	0.00±0.00	21.37±2.81	16.54±2.75	0.00±0.00	14.47±1.89	16.54±2.42
Hypogastruidae	6.89±3.93	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Neanuridae	1.38±1.76	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
Acariformes	0.00±0.00	11.03±2.30	73.75±3.96	173.70±4.56	48.25±3.93	90.30±5.55	55.83±3.43	0.00±0.00	36.53±2.89	30.33±2.48
Thysanoptera	111.66±7.07	1204.16±11.11	29.64±3.30	194.38±6.17	148.19±6.08	4.14±2.68	15.85±2.30	137.17±3.22	0.00±0.00	0.00±0.00^{c}
Ixodida	19.99±4.92	0.00±0.00	0.00±0.00	42.74±3.61	19.99±4.35	2.76±2.68	0.00±0.00	48.94±3.30	0.00±0.00	0.00±0.00
Hymenoptera	13.10±2.51	7.58±2.30	2.07±1.89	54.45±3.22	13.10±2.02	0.00±0.00	0.00±0.00	9.65±1.76	0.00±0.00	0.00±0.00

Ca: *Cestrum aurantiacum*, Sm: *Solanum mouritianum*, Ad: *Acacia dealbata*, Pd: *Polygonum divaricatum*, Lc: *Lantana camara*, Rn:, *Rhododentron nilagiricum*, Rt: Rhodomyrtus tomentosa, Re: *Rubus ellipticus*, Pl: *Photinia lasiogyna*, Pb: *Piper brachystachyum* illustration indicates four micro-arthopods (2q=3.66) effectively using the shola/native plants, while two species (^{2}q=1.84) are effectively using the exotics. The micro-arthropods effectively using the shola/ native flora are the entomobryidea, paranonellidae and acariformes. The thrips (thysanurans) are the species that are commonly using the exotic species.

Floral dependency and community composition: Principal component analysis in exotic/invasive, the PCI showed 39.41% and PCII 27.01% with a total of 66.42%. In shola/ native plants, the PCI was 32.07% and PCII 26.97%, with total of 59.04% (Fig. 3). The first coordinate contain sacariformes, entomobryidae, paronellidae, and hymenoptera, the second coordinate have thysanoptera, and the fourth coordinate contains Neanuridae, Hypogastruridae, and Ixodida. In shola, the most significant variance in the first coordinate is displayed by entomobryidae and in the second coordinate containing Paronellidae and

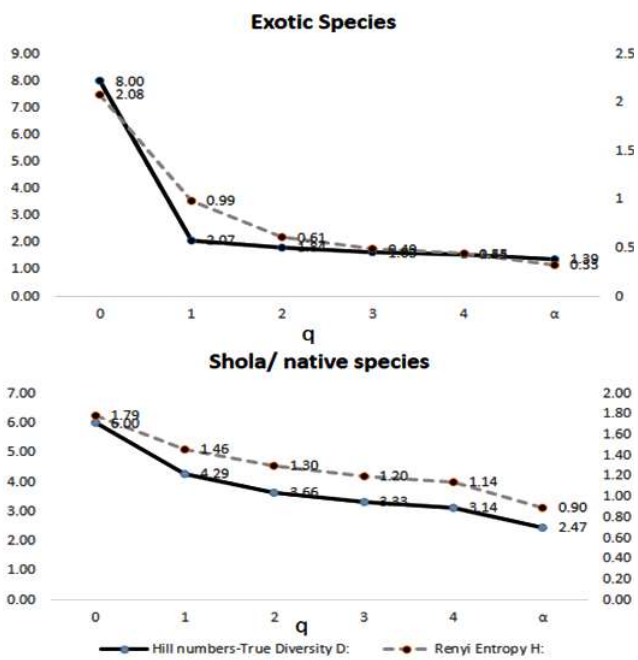

Fig. 1. Hill numbers of true diversity (^{q}D) and the Renyi entropy (^{q}H) in shola/native and exotic plants

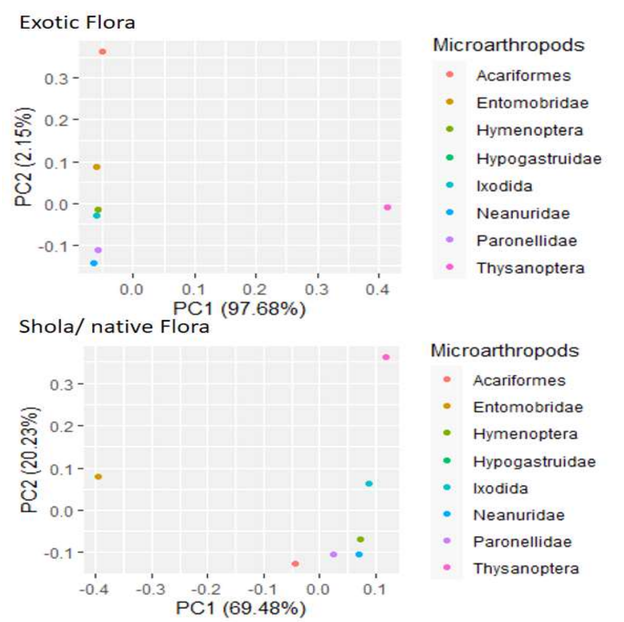

Fig. 2. Principal component analysis of microarthropods in native/shola and exotic flora

Table 2. Diversity analysis of micro-arthropods in native and exotic flora

Flora	Faunal richness	Diversity index	Faunal evenness	Shannon equitability (%)	Simpson dominance (%)	Gini-Simpson index (%)	Berger-Parker index (%)	β - diversity
Exotics (Hγ: R=8; H= 0.99; λ= 54.30% ;λ-1 = 45.70%; BPI = 72.15%)								
Cestrum aurantiacum	7	1.26	0.50	64	42.10	57.90	62.40	0.79
Solanum mouratianum	4	0.15	0.29	11.	94.60	5.40	97.30%	6.60
Polygonum divaricatum	6	1.55	0.78	86.50	24.40	75.60	33.30	0.64
Lantana camera	4	0.97	0.65	70.00	47.80	52.20	64.90	1.02
Acacia delbata	3	0.66	0.64	59.60	58.00%	42.00	70.90	1.50
Native/ Shola (Hγ: R = 6; H= 1.45; λ= 27.40% ; λ-1 = 72.60%; BPI = 40.50%)								
Rubus ellipticus	3	0.75	0.70	67.90	55.50	44.50	70.00	1.94
Rhodomyrtus tomentosa	4	1.24	0.87	89.60	32.30	67.70	45.10	1.17
Rhododendron nilgiricum	5	1.16	0.64	71.80	37.50	62.50	51.70	1.25
Photinia lasiogyna	3	1.01	0.91	91.80	39.80	60.20	54.00	1.44
Piper brachystachyum	3	0.55	0.58	49.80	71.80	28.40	83.70	2.65

Hγ is the gamma diversity, R is the micro-arthropod richness, H is micro-arthropod diversity index, λ is the Simpsons dominance, λ-1 is the Gini-Simpson index and BPI is the Berger-Parker index)

Thysanoptera, and third coordinates with Acariformes and Ixodida. Non- metric multidimensional scaling (NMDS) ordination produced a stress value of 0.108979. The stress versus dimension plot indicates that two dimensions were the best suited for presenting our data. The NMDS plot shows an apparent clustering of the shola/native plants and the exotics and indicates its dissimilarity in micro-arthropod diversity. Except for the *Rubus elipticus*, the other shola species share the same type of micro-arthropod faunal composition. The exotic species do not have a unique kind of micro-arthropod composition, and it varies from plant species to species.

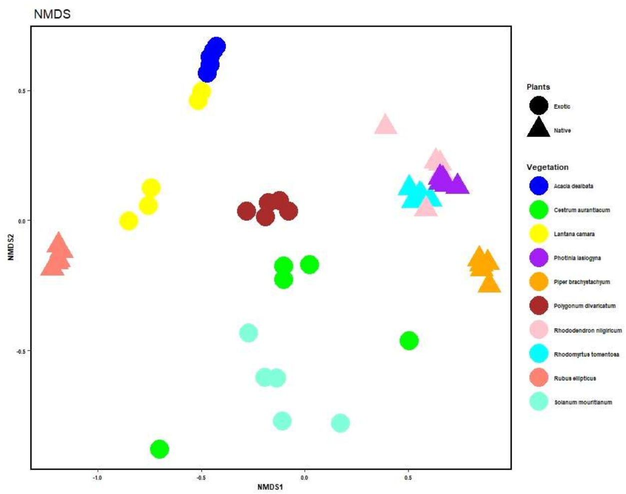

Fig. 3. NMDS of various microarthropods in relation the shola/ native and exotic plants

Co-occurrence of species: The co-occur results suggest that 16 pairs of species association were observed from shola and exotic vegetation (Table 3). All the associations are random except that of the entomobryidae and paronellidae. They are predominantly present in the shola species and a few exotics.

Micro-arthropods are omnipresent, and the literature on aerial micro-arthropods is scanty owing to the lack of proper taxonomical descriptions. The ecological role of these animals in the aerial environment is yet unknown. The curiosity about the ecology of these groups increased as Rosenstiel et al (2012) showed oribatids and collembola have role in moss pollination described the relationship as an antique one, and relationships exist much before the evolution of flowering plants. In the soil, micro-arthropods act as decomposers and maintain nutrient cycles, but such type of role in aerial habitat is unclear. The collembolans are considered as fungal feeders by Jorgensen et al (2005). It may be assumed that they check the fungus growth in the old plant twigs and protect them. Acariformes like Oribatids are predators and feed on the collembola and other micro-arthropods in an aerial ecosystem. The epiphytes, mosses, and lichens are common in the shola fauna (Bunyan et al 2012). Hence the existence of this species has a significant role in maintaining epiphytic, moss, and lichen growth. If collembola and mites are absent, the mosses will not proceed to the sporophyte generation (Rosenstiel et al 2012).

Table 3. Association of micro-arthropods. Fauna A and B are the comparing micro-arthropods in a locality

Fauna A	Fauna B	Obs	P(obs)	Exp	P (lt)	P (gt)	Faunal association
Entomobridae	Paronellidae	6	0.42	4	1.0000	0.0333	Positive
Entomobridae	Acariformes	5	0.48	5	0.8667	0.6667	Random
Entomobridae	Thysanoptera	5	0.54	5	0.6000	1.0000	Random
Entomobridae	Hymenoptera	2	0.36	4	0.0714	1.0000	Random
Entomobridae	Ixodida	5	0.42	4	0.9667	0.3333	Random
Paronellidae	Acariformes	6	0.56	6	0.9333	0.5333	Random
Paronellidae	Thysanoptera	6	0.63	6	0.7000	1.0000	Random
Paronellidae	Hymenoptera	3	0.42	4	0.1667	1.0000	Random
Paronellidae	Ixodida	5	0.49	5	0.8167	0.7083	Random
Acariformes	Thysanoptera	7	0.72	7	0.8000	1.0000	Random
Acariformes	Hymenoptera	4	0.48	5	0.3333	1.0000	Random
Acariformes	Ixodida	5	0.56	6	0.4667	1.0000	Random
Thysanoptera	Hymenoptera	6	0.54	5	1.0000	0.4000	Random
Thysanoptera	Ixodida	6	0.63	6	0.7000	1.0000	Random
Hymenoptera	Ixodida	4	0.42	4	0.6667	0.8333	Random

Observed: The observed number of sites having both A and B. P(obs); Probability that both A and B occur at a site. Exp: Expected co-occurrence of A and B. P(lt): The probability that A and B would co-occur in a site at a frequency lesser than P(obs), if distributed independently.P(gt): The probability that A and B would of co-occur at a frequency greater than the observed frequency. If P(lt) ≤ α two species are negatively associated (α = 0.05). (Refer Griffith et al. 2016 for more details).

The present study demonstrates the pattern of micro-arthropod occupancy varies from species to species and collembolans and oribatid mites are present in much higher density and diversity in shola plants than the exotics/invasive. Collembolans, in particular, seems to be absent in almost all of exotic/invasive species, except the *Cestrum aurantiacum* and *Polygonum divaricatum*. The exotics selected for the present study are bushes, while shola species are stunted woody. As the epiphytic growth is absent in the bushy exotics the collembola and mites may not colonized. Zeppelin et al (2009) opined that in thorny plants, springtails are absent owing to their soft bodied nature. The *Rubus ellipticus* and *Lantana camara* are spiny plants where springtails are absent. *Cestrum aurantiacum* and *Polygonum divaricatum* are exotics having nectar rich flowers (Bhavana et al 2015; Wanner and Dorn 2006). The presence of Entomobryidea springtails in these exotics can be attributed to their nectar content.

The changing pattern of exotic invasion and the depletion of the shola plants thereby increase harmful insects. Thysanoptera is one of the most significant agricultural pests globally, altering the micro-arthropod community by competitive replacement (Reitz, 2009).The native mountain shola plants are primitive, short, stunted semi-evergreen vegetation (Jose 2012), and the species-specific relation can also be old. Shola forests maintain a unique humid atmosphere, which is highly favorable for soft-bodied springtails prefer relatively high humidity and show an inverse relationship with the temperature (Hayward et al 2001, 2003). The native species *Piper brachystachyum* have dense populations of springtails (e.g. Entomobryidae) and are more diverse than the other shola species. The pepper plant contains many specific alkaloids, as collembola and oribatids are attracted chemically (Ratnayake 2014, Rai and Singh 2020).

CONCLUSION

The springtails and the oribatids mainly depend on the shola plants and absent in the exotic/invasive species. An in-depth taxonomic analysis is needed to anlyse the specificity of species present. The presence of Thysanoptera and Ixodida seems to be more in exotic/invasive plants. In exotic/invasive plants having nectar, the presence of collembolan is there, and in thorny plants is absent. The presence of thrips in the exotic plants raises doubts that they act as hosts for the thysanopetra, which is a threat to agriculture and indigenous biodiversity.

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Soil Organic Carbon Stocks along Altitudinal Gradient under *Shorea robusta* Gaertn. F. Plantations in Darjeeling Himalayas

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***Abstract*:** The carbon storage potentiality of forest land use systems has been recognized as a major factor in the recent climate change scenario. The current study was designed to quantify the soil organic carbon (SOC) stocks at three soil depths (0-20 cm, 20-40 cm and 40-60 cm) in *Shorea robusta* Gaertn. f. (Sal) plantations along the elevation gradients of 150-300 m, 300-450 m, 450-600 m and 600-750 m in the Darjeeling Himalayas. There was an increasing trend of SOC stock along the elevation gradient, reaching the maximum stock (67.53 Mg C ha^{-1}) at the mid elevational range of 450-600 m at the surface soil layer and the minimum (26.81Mg C ha^{-1}) at 150-300 m. The highest elevational range (600-750 m) was quantified with significantly lesser SOC stock (51.01 Mg C ha^{-1}) than 450-600 m elevational range. Correlation between elevation gradient and SOC stock exhibited moderate positive relationship between the two (R^2= 0.485).

Keywords: SOC stock, Sal plantations, Elevation gradient, Darjeeling Himalayas

Offsetting carbon dioxide (CO_2) emissions through carbon sequestration by vegetation is an efficient and viable mitigation tool for climate change. Forest ecosystem thus has been recognized as the custodian of biodiversity and carbon sinks in regulating the global climate (Dirzo and Raven 2003, Gibbs et al 2007, Fahey et al 2010). Plantation forests are also recognized as a receptacle of carbon stock like natural forests, since stand age is the leading factor affecting the total carbon pool of plantation ecosystems (Justine et al 2015). In India, increasing forest plantations, regenerating damaged forests, and protecting existing stands have all significantly increased productivity of ecosystem and carbon content in soil (Ravindranath et al 2008). The soil organic carbon (SOC) pool in forest soils is crucial for predicting and assessing the carbon sequestration potential of forests. In fact, SOC storage in soil is influenced not only by a variety of factors including vegetation, climate, interaction with soil organisms, soil properties but also topography (Bird et al 2004, Wang et al 2023). Globally, the recent estimate of SOC stocks is approximately 1500 Pg C while, 27 earlier global studies estimated the range within 504 to 3000 Pg C (Scharlemann et al 2014). Sal plantations/forest is spread over an area of about 13 million hectares in India (Deka et al 2012). The species has a high timber value, makes a major contribution to the permanent carbon stock of the tropical forest due to its high rotation age of more than 120 years (Siddique et al 2021). The sal forests confined to the Darjeeling Himalayas have been classified as moist sal forests (Kushwaha and Nandy 2012), with deep, moist and nutrient rich soil, distributed along the lower elevation gradients from 150 m to 750 m mean sea level, which is kept aside for carbon storage in a vast area.

The carbon storage in soil also depends on tree species (Gogoi et al 2017), where higher rotation age species like Sal and Teak have higher capacity to store carbon in soil for longer time than short rotation species like poplar and eucalyptus (Kaul et al 2010). Since, species specific studies have been explored only about above ground biomass and carbon stock in a few species like *Tectona grandis* (Gangopadhyay et al 2021), *Cryptomeria japonica* and *Pinus patula* (Banerjee and Prakasham 2012) in Darjeeling Himalaya, none of these studies examined the effect of altitude on SOC stock. Vegetation diversity pattern along the elevation gradient in the Darjeeling Himalaya have been explored previously by several researchers (Moktan and Das 2012, Das and Ghosh 2022, Rai and Moktan 2022, Vineeta et al 2022) but the effect of altitude on SOC stock under specific tree plantation is yet to be explored. Only a few studies have reported that soil carbon stock in forests of Darjeeling Himalayan region increases with increasing altitude (Banerjee 2014, Devi and Sherpa 2019). In this context, we hypothesised that SOC stock under Sal plantations in forests of Darjeeling Himalayas will also increase with increasing altitude. The present study was thus attempted with the objective of determining the effect of elevational gradient on SOC stock under Sal plantations with research question i.e., Does altitude influence the SOC stock of Sal plantations in Darjeeling Himalayas?

MATERIAL AND METHODS

Study Site: The study site is in the Darjeeling Himalayas, encompassed by Kalimpong and Darjeeling districts. This part of the eastern Himalayas lies at 27° 13′ N to 26° 27′ N latitude and 88° 53′ E to 87° 59′ E longitude. The elevation extends from >100 to 3636 m; nevertheless, the current study was only able to be carried out in the 150-750 m range due to the lack of sal plantings above this level. Climatically, the region is sub-tropical, influenced by the south-west and north-east monsoons, which provide rainfall in the range of 1877 mm to 2333 mm. The winter is cold and dry while, the summer is quite rainy. Pedologically, the area is distinguished by four different soil texture classes: gravelly-loamy, gravelly-loamy to loamy skeletal, gravelly-loamy to coarse-loamy and fine-loamy to coarse-loamy (Pramanik 2016). The Sal plantations are mainly distributed in the Teesta range of the Darjeeling Forest division. For better convenience, the study site was classified into four elevational ranges or classes i.e., 150-300 m (A1), 300-450 m (A2), 450-600 m (A3) and 600-750 m (A4). The study site covered different areas of Kalimpong and Darjeeling district such as Peshok, Mangwa, Teesta, Mungpoo, Bagrikote and Munsong (Fig. 1).

Soil sampling and analysis: Quadrates of 20 m x 20 m dimensions was laid out for extracting soil samples and estimate density of Sal plantations from all the elevational classes across its elevation, i.e., five quadrates in each class with a total of 20 quadrates. The soil samples were collected from every quadrate at three different depths (0-20 cm, 20-40 cm and 40-60 cm). In every quadrate three soil samples were collected diagonally (two at corners and one at centre) and then made into a composite sample for analysis. Soil samples were air dried, grinded, and sieved (2 mm sieve) before carrying out the analysis. Bulk density was estimated by core sampling method (Gupta and Dakshinamoorthy 1980) and SOC content was determined by wet digestion method (Walkley and Black 1934). The SOC stock was quantified multiplying the organic carbon content with the mass of the soil (bulk density and depth) for each soil depth (Pearson et al 2005) and was expressed as Mg C ha^{-1}.

Statistical analysis: The data were subjected to one-way analysis of variance to test the significance of the effects of different elevation gradients on SOC stock and SOC and DMRT were applied to test the pairwise comparison of means between the elevation gradients. Pearson's correlation was performed to assess the relationship between dependent variables (elevation gradient) and independent variables (SOC stock). All data were analysed using R Studio (4.3) and SPSS (21).

RESULTS AND DISCUSSION

SOC Content: The highest SOC content was estimated at altitude class A3 in all the studied three depths (Table 1). The significant difference is recorded among all altitudinal classes except between A2 (2.11%) and A4 (2.3%) at the top layer. Significant increase in SOC from A1 to A3 followed by a significant decrease in A4 at all depths. The SOC in different soil depths decreased from top to bottom layer of the soil in all altitudinal classes except in the A1 class, where the estimated SOC was lowest in the 20-40 cm (0.84%) depth.

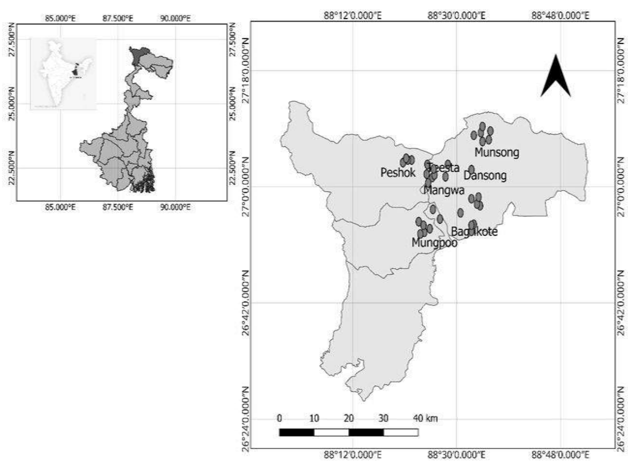

Fig. 1. Map of study area

Table 1. SOC and bulk density of sal plantations at different altitudinal classes

AC	Soil depth (in cm)					
	0-20	20-40	40-60	0-20	20-40	40-60
	SOC (%)			Bulk density (g cm^{-3})		
A1	1.22±0.24^{c}	0.83±0.33^{c}	0.84±0.32^{c}	1.11±0.03	1.20±0.05	1.24±0.06
A2	2.11±0.61^{b}	1.56±0.5^{b}	1.42±0.38^{b}	1.07±0.03	1.16±0.03	1.22±0.03
A3	3.20±1.16^{a}	2.40±0.8^{a}	2.12±0.70^{a}	1.06±0.04	1.15±0.04	1.22±0.04
A4	2.30±0.84^{b}	2.06±0.83^{ab}	1.51±0.68^{b}	1.09±0.05	1.18±0.05	1.25±0.08

AC = Altitude class; A1 = 150-300 m asl; A2 = 300-450 m asl; A3 = 450-600 m asl; A4 = 600-750 m asl

The significant increase in SOC along the elevation could be explained as due to an increase in Sal density from A1 to A3 altitude class (478.6 to 482.7 trees/ha, Fig. 2), which produces a denser canopy (Sheikh et al 2020) and higher accumulation of leaf litter, as well as temperature drop that decrease mineralization through lesser decomposition rates (Chan 2008, Choudhury et al 2016) with higher SOC at higher altitudes (Banday et al 2019). Moreover, anthropogenic disturbances were lesser in higher altitudes as compared to lower altitudes due to limited accessibility due to steeper terrain (Spracklen and Righelato 2014). However, SOC content decreased above the altitude class A3 which might be due to lesser tree density (Fig. 2). Tree density and temperature are simultaneously influencing the SOC along the altitudinal gradient of Sal plantations in the Darjeeling Himalayas. SOC content was highest in top soil layer at all altitudinal classes. The top layer's supremacy in organic matter could be due to the higher availability of leaf litter and higher microbial activity (Chimdessa 2023). Bulk density varied along the elevation gradient; maximum bulk density was observed at A1 altitude class and minimum at A3 class at all soil depths. Bulk density increased with increasing soil depth throughout the altitudinal gradient.

SOC Stock: The highest SOC stock was quantified at altitude class A4 in all the three depths i.e., 67.53 Mg ha^{-1} at 0-20 cm followed by at 20-40 cm and at 40-60 cm followed by A4 class, A2 class and the least at A1 altitudinal class with 26.81, 19.64, and 20.57 Mg ha^{-1}, respectively (Table 2 and Fig. 3). SOC stock significantly increased from altitudinal class A1 to A3 and then significantly decreased from A3 to A4. The stock increased by 71.4% from A1 to A2 and by 51.6% from A2 to A3 and thereafter decreased by 21.6% A3 to A4.

At higher altitudes, high annual precipitation and low mean temperatures favour a decline in the decomposition of organic matter and high plant biomass production, both of which influence the higher accumulation of SOC stock (Tornquist et al 2009). The trends of SOC stock along the elevation gradient in present study are similar to Devi and Sherpa (2019) and Banerjee (2014) in the Darjeeling Himalayan Forest along the altitudinal gradient. The maximum SOC stock up to 60 cm depth was quantified at altitude class A3 (174.2 Mg C ha^{-1}) and minimum at A2 class (67.02 Mg C ha^{-1}, Fig. 4). This was also evidenced from

Table 2. SOC stock (Mg ha^{-1}) of Sal plantations at different altitudinal classes

AC	SOC stock		
	0-20 cm	20-40 cm	40-60 cm
A1	26.81±4.4^{c}	19.64±6.9^{c}	20.57±7.1^{c}
A2	44.52±12.6^{b}	35.91±10.9^{bc}	34.44±8.6^{b}
A3	67.53±22.9^{a}	55.36±19^{a}	51.31±16.4^{a}
A4	51.01±18.1^{b}	48.39±20.1^{ab}	37.19±16.1^{b}

AC = Altitude class; A1 = 150-300 m asl; A2 = 300-450 m asl; A3 = 450-600 m asl; A4 = 600-750 m asl

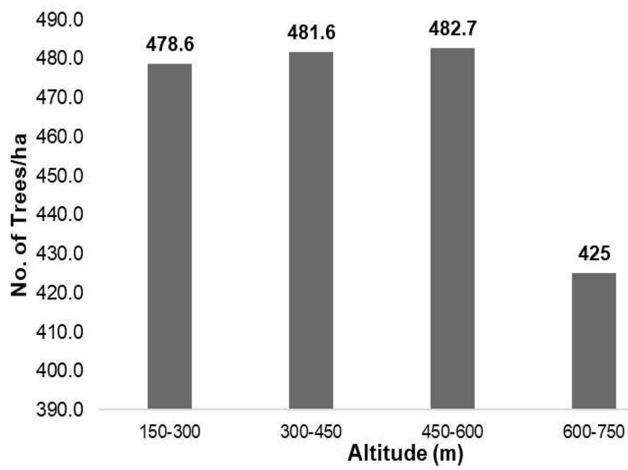

Fig. 2. Tree density of Sal plantations at different altitudinal classes

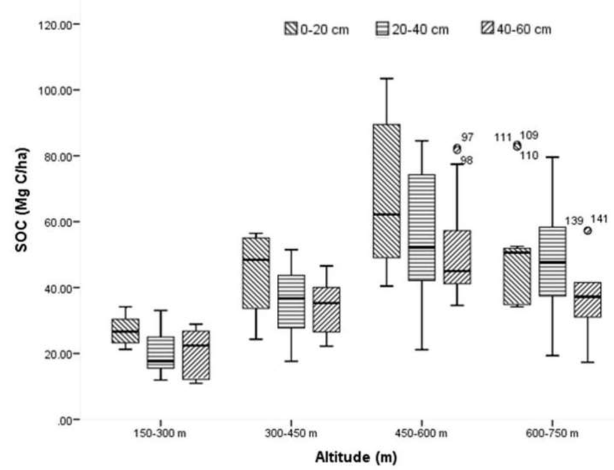

Fig. 3. SOC stock of Sal plantations at different soil depths

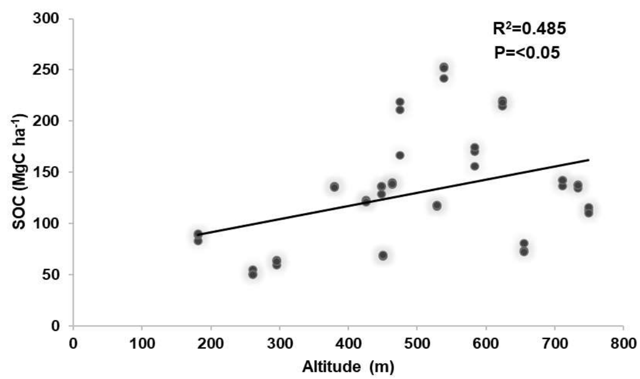

Fig. 4. Total SOC stock at different altitudinal class

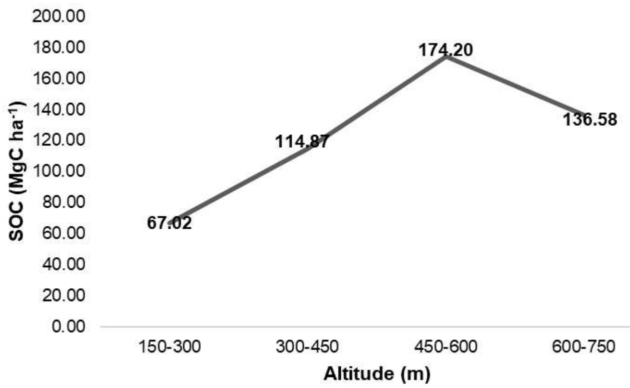

Fig. 5. Pearson correlation between altitude and SOC stock of Sal plantation

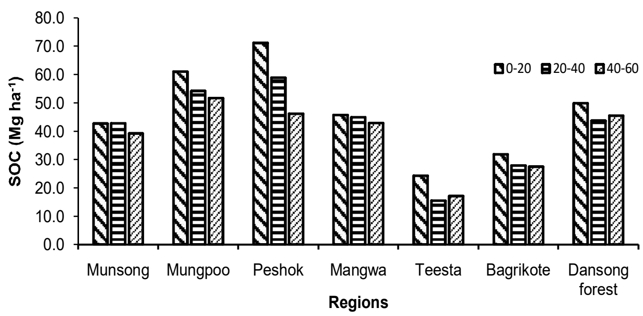

Fig. 6. SOC stock of Sal plantations in different regions of Darjeeling Himalaya

moderately positive and significant relationship between altitude and SOC stock (R^2= 0.485, $p < 0.05$, Fig. 5).

Regional SOC stock: Regional estimation of SOC stocks of top soil layer also indicated higher stock in places located at higher elevation (500 -750 m asl) like in Peshok region (71.1 Mg ha^{-1}), followed by Mungpoo and Dansong region than in places located at lower elevations like in the Teesta (24.3 Mg ha^{-1}) region (Fig. 6). Similarly, SOC stock of the entire soil layers i.e., up to 60 cm depth in these areas was 172.2 Mg C ha^{-1}, 167 Mg C ha^{-1}, 139 Mg C ha^{-1}, and 56.9 Mg C ha^{-1}, respectively. The sal plantations at places located in higher elevations have higher tree density. The temperature decreases at a rate of 0.62°C for every 100 m rise in elevation (Acharya et al 2011). Decreasing temperature reduces the microbial activity which decrease soil organic matter decomposition. The higher tree density in these regions indicates higher litter build-up resulting into higher SOC stock. Even though Teesta is not at the lowest altitude, the lowest SOC stock might be due to the location of the sal plantation, closer to the river Teesta.

CONCLUSION

The study estimated the SOC stock of Sal plantations up to 60 cm depth along the elevational gradient from 150 m to 750 m asl in four elevational steps of the Darjeeling Himalayas. The highest SOC stock was found at the surface soil layer throughout the elevational gradient. SOC stock varied with altitude exhibiting a significant and direct relationship. SOC stock gradually increased up to third elevational step and thereafter decreased. Factors like tree density, altitude, and temperature influenced the SOC stock of the Sal plantations. Increasing elevation resulting in to lower temperature reduced the decomposition rate of organic matter building-up higher SOC stock. It is thus recommended to conserve this Sal plantations in Darjeeling Himalayas for permanent storage of carbon to mitigate climate change.

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AUTHOR CONTRIBUTIONS

The material preparation, data collection and analysis were performed by Arshad A, Manendra Singh, Mendup Tamang, Kanchan, Shahina NN. The first draft of the manuscript was prepared by Arshad Aand all the corrections are made and the final manuscript was done Vineeta, Ganesh Ch. Banik, Gopal Shukla and Sumit Chakravarty.

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Assessing the Spatial Variability of Soil Quality Index of Ganjigatti Sub-Watershed Using GIS-Based Geostatistical Modeling

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Abstract: The present study was conducted to appraise the soil quality and its spatial variability from 393 surface soil samples of the Ganjigatti sub-watershed of Karnataka by using geospatial techniques. Principal component analysis was applied to identify the MDS from a set of fourteen soil quality indicators. The major factors that influence soil quality include pH, OC, available N, Zn, B, P and Mn. Six leading PCs were significant based on an eigenvalue of '>1' and explained 74.71% of the variance in soil parameters. SQI (Soil Quality Index) and RSQI (Relative Soil Quality Index) values ranged from 0.41 to 0.81 and 0.51 to 1.00 respectively. The geo-database was subjected to ordinary kriging through the best-fit experimental semivariogram based on the lowest root mean square error. The study concluded that the measured SQI (range 720.82 m) in regular gird sampling at a given scale was enough to capture spatial dependence using the ordinary kriging technique and to derive thematic maps for efficient soil management strategies at the sub-watershed level. The higher nugget: sill ratio (0.81) indicates that the spatial variability or dependency is primarily caused by stochastic factors. The SQI map of the Ganjigatti sub-watershed showed that about 9.69% of the sub-watershed had medium SQI (0.35-0.55), whereas 80.87% of the area had higher SQI (0.55-0.75).

Keywords: Soil quality index, Principal component analysis, Spatial variability, Ordinary kriging

Assessment of soil quality is a sensitive and dynamic method for documenting the status of the soil, as well as the soil's response to management and its resilience to stress, whether that stress is imposed by natural forces or by human interventions. Karlen et al (1997) defined soil quality as the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. In agricultural research, soil productivity is analogous to soil quality. Soil quality is an important aspect that is closely related to soil degradation and defined as the change in soil quality over time. Soil suffers from a mix of physical degradation by puddling or excessive cultivation, chemical degradation by nutrient depletion, pollution from industrial wastes and excessive use of pesticides and fertilizers and biological degradation by organic matter depletion and losses of soil flora and fauna. In order to evaluate the status of soil degradation and the shifting patterns that have resulted from various land uses and smallholder management interventions and required to conduct a fundamental assessment of soil quality.

Maintaining or enhancing soil quality is a key to sustaining soil resources of the world and there is a need for better understanding of the relationship between soil quality and agricultural productivity. In order to estimate soil quality, a variety of soil parameters or indicators have been identified. Yin et al (2021) assert that soil nutrients and other physicochemical properties are useful indicators for determining the overall soil quality. Harsha et al (2021) evaluated the soil quality index of the Channegowdarapalya micro-watershed (Karnataka) using 16 soil physical, chemical and biological characteristics. The most crucial critical indicator of soil quality was soil pH, which was followed by exchangeable Ca, DTPA extractable Zn, OC and available N. Yadav et al (2022) assessed the soil quality of the sub-humid southern plains of Rajasthan by using fertility characters. Geospatial modelling advances, such as geographical information system (GIS) and geostatistical tools, can be used effectively to assess the spatial variability of SQI. Geostatistical analyses, including fitting semi-variogram model and ordinary kriging procedure was carried out using *Arc*GIS to assess the degree of spatial variability of SQI. Kriging is an interpolation technique used in geostatistics using known values and a semivariogram to determine unknown values (Marques et al. 2015). Thus, keeping in view the importance of soil quality in land use planning and management, the present study was carried out with the specific objectives of determining the soil quality index and mapping the spatial variability of the soil quality index using remote sensing techniques in the Ganjigatti sub-watershed of the Hilly zone of Karnataka.

MATERIAL AND METHODS

Field description of the study area: Ganjigatti sub-watershed belongs to Kalghatgi *taluk* of Dharwad district. It is located between 15° 10' 10.114″ to 15° 17' 1.147″ N latitude and 75° 0' 57.672″ to 75° 4' 50.525″ E longitude in the Hilly zone of Karnataka, India. The area covers 4323.84 ha and receives an annual average rainfall of 917.00 mm (average annual rainfall of the zone ranges from 539 to 1256 mm). Annual average *kharif* (June to September), *rabi* (October to January) and *summer* (February to May) rain fall 616.00 mm, 139 mm and 162 mm, respectively. The annual temperature ranges from 24.68 to 26.67°C, with an average maximum temperature of 40.72°C during April and an average minimum temperature of 12.33°C in December. Soils of the study area were derived from schist parent material.

Soil sampling and laboratory analysis: The topographic map of the study area in a scale of 1:7,920 was digitized and geo-referenced to a map coordinate system so as to generate spatial information and subsequent use in a GIS environment. Soil samples (0-30 cm) were collected in summer by grid method. The grid interval was fixed 320 × 320 m^2 and 393 composite soil samples were collected from the field covering whole area of Ganjigatti sub-watershed. The samples were labelled, air-dried and sieved through a 2-mm sieve for analysis of soil fertility parameters. The pH and EC were analyzed using soil-water suspension in 1:2.5 ratio (Richards 1954). Soil organic carbon was determined using Walkley and Black (1934) method. Available N ($KMnO_4$-N) was estimated through alkaline permanganate method given by Subbiah and Asija (1956). Olsen et al (1954) method was used for available P estimation in which 0.5 M $NaHCO_3$ (Olsen's reagent) is used as an extractant. The available K (NH_4OAc-K) was determined by flame photometry method (Jackson 1973). Exchangeable calcium and magnesium were determined in neutral normal ammonium acetate extract by Versanate Titration (Thomas 1982). Available sulphur was extracted from the soil using 0.15 per cent calcium chloride solution and sulphur in solution was determined by turbidometry (Black 1965) using Spectrophotometer (Spectronic 20-D) at 420 nm. Micronutrients (Zn, Cu, Fe and Mn) were analyzed in atomic absorption spectrophotometer (AAS) using DTPA extractant (Lindsay and Norvell 1978). Available Boron were extracted by using hot water method (Berger and Truog 1939).

Statistical analysis: Descriptive statistics of measured soil properties including minimum, maximum, mean, standard deviation, coefficient of variation, skewness and kurtosis were calculated by using Statistical Package for Social Sciences (SPSS) ver.26.0. Correlation and regression analysis of soil properties were carried out by using SPSS ver.26.0.

Soil quality assessment: The SQI was calculated on the basis of minimum data set (MDS) framework. To identify the MDS, various successive steps of data analysis were followed, primarily employing the PCA technique (Andrew et al 2002a) using SPSS (version 26.0). The principal components (PCs), which received eigen values ≥1 and variables which had high factor loading were considered to the best representative of the system attributes. Within each PC, only highly weighted factors were considered for the MDS. The 'highly weighted' variables were defined as the highest weighted variable under a certain PC and absolute factor loading value within 10% of the highest values under the same PC (Wander and Bollero 1999). The values of each indicator were transformed using linear scoring technique (Andrew et al 2002b). To assign the scores, indicators were arranged in an order depending on whether a higher value was considered 'good' or 'bad' in terms of influencing the soil function. For the 'more is better' category of indicators, each observation was divided by the highest observed value such that the highest observed value received a score of one. For the 'less is better' indicators, the lowest observed value (in the numerator) was divided by each observation (in the denominator) such that the lowest observed value received a score of one. After transformation using linear scoring procedure, the MDS indicators for each observation was weighted using the PCA results. Each PC explained a certain amount (%) of the variation in the total data set. This percentage when divided by the total percentage of variation explained by all PCs with eigen vectors >1 gave the weighted factors for indicators chosen under a given PC. After performing these steps to obtain SQI, the weighted MDS indicator scores for 'n' observations (no. of indicators qualified from PCA) were summed up according to following equation:

SQI = Σ Principal component weight × Individual soil parameter score

For better understanding and relative comparison, the SQI values were reduced to a scale of 0-1 by dividing all the SQI values with the highest SQI value (relative SQI).

Spatial variability mapping: Spatial variability of soil quality index was mapped by ordinary kriging interpolation method. For mapping the soil quality index, all the analyzed data from sample sites were first fed into GIS as point-based, geo-coded data through table management. The data on SQI processed and classified into homogenous groups of SQI, as per the classification of low category of SQI (<0.35), medium category of SQI (0.35-0.55) and high category of SQI (>0.55).

RESULTS AND DISCUSSION

Apart from maintaining soil physical conditions to optimise yield, one of the major components of soil fertility that would impact the productivity of agricultural system is the efficiency of soils to supply nutrients for crop growth. The results of soil fertility parameters based on 393 surface samples taken from grids are described and SQI is calculated. Out of total geographic area of sub-watershed of 4323.84 ha, 343 ha (7.93%) was covered by gullied area, waterbody and settlements, while 13 ha area (0.29%) was under mining. About 3969 ha (91.77%) area was observed as cultivable land.

Assessment of soil quality index: The soils of total cultivable areas of Ganjigatti sub-watershed were assessed for soil quality in which PC analysis was performed for 14 variables (Table 1). The surface soil properties of 393 samples were subjected to PCA to reduce the data dimension. The PCA data for the sub-watershed showed that six PCs have an eigenvalues >1, which explained 74.71% of the cumulative variance in the data (Table 2). The MDS were chosen based on the highly weighted factor loading of variables. The representative screen plot showing the variation of eigenvalues with soil components is shown in Figure 1 and 2.

The parameters in each PC were considered based on higher values of the factor loading. The soil parameters obtained from PCA under PC1 were exchangeable Ca, exchangeable Mg and pH. However, multivariate correlation matrix was utilised to calculate the correlation coefficients between the parameters when more than one variable was retained under a given PC (Andrews et al 2002 a, b). To avoid redundancy, only the parameter with the highest loading factor was kept in the MDS if there was a significant correlation between them (r >0.60, p 0.05). The non-correlated parameters under a particular PC were considered important and retained in the MDS (Andrews and Carroll 2001, Andrews et al 2002a). Among these highly weighted variables of PC1, pH is a parameter that governs nutrients availability and is an indicator of soil fertility. It is a very significant soil parameters that affects the stability of the soil's structure, the availability of nutrients and soil microbial activity. Other parameters are highly correlated to each other, so pH was retained for MDS in PC1 (Table 3). Available Zn, available B, available P_2O_5 and available Mn were selected as indicators from PC2, PC4, PC5 and PC6, respectively. From PC2 both OC% and available N were considered for MDS due to wide variability of OC and complete low levels of available N in soils of the Ganjigatti sub-watershed. Among the variables included in the MDS, pH has most significant weight and contribution in the SQI determined by MDS, followed by OC, available N, Zn, B, P and available Mn, which have been widely reported as effective and sensitive factors

Table 1. Descriptive statistics of measured surface soil properties

Parameter	Maximum	Minimum	Mean	SD	CV (%)	Kurtosis	Skewness
pH (1:2.5)	8.65	5.02	7.07	0.78	11.03	-0.668	-0.157
EC (dS m^{-1})	1.00	0.03	0.21	0.16	76.19	4.335	1.803
OC (%)	1.22	0.11	0.68	0.21	30.88	-0.358	-0.091
Available N (kg/ha)	245.50	18.50	158.60	32.65	20.59	0.632	-0.213
Available P (kg/ha)	120.23	7.35	46.24	23.15	50.06	-0.206	0.463
Available K (kg/ha)	948.00	72.00	369.24	178.65	48.38	-0.539	0.482
Ex. Ca [cmol (p^+) kg^{-1}]	24.72	3.13	15.01	4.01	26.72	-0.180	-0.167
Ex. Mg [cmol (p^+) kg^{-1}]	16.87	2.04	8.45	2.70	31.95	0.800	0.499
Available S (kg/ha)	89.38	1.25	27.55	16.02	58.15	0.764	0.995
Available Fe (ppm)	69.40	2.37	27.32	11.82	43.27	1.018	0.892
Available Mn (ppm)	30.42	1.17	14.70	5.91	40.20	0.382	0.090
Available Cu (ppm)	8.42	0.96	3.20	1.18	36.87	0.737	0.638
Available Zn (ppm)	4.26	0.18	1.11	0.67	60.36	5.918	2.251
Available B (ppm)	0.90	0.10	0.35	0.14	40.00	0.572	0.542

for the development of SQI (Harsha et al 2021, Sathish and Madhu 2021, Yadav et al 2022).

After the selection of parameters for the MDS, all selected observations were transformed using linear scoring functions (less is better, more is better and optimum). The organic carbon, available nitrogen, phosphorous, Mn, Zn and B were considered as more is good from the soil quality point of view when they are in increasing order, hence the 'more is better' approach was followed. In pH, the 'optimum is better' approach was followed. Once the selected observations were transformed into numerical scores (ranged 0-1), a weighted additive approach was used to integrate them into indices for each soil sample (Andrews et al 2002b; Mukherjee and Lal, 2014). Thereafter, to obtain the weighted additive SQI, the weighted MDS indicator scores for each observation were summed up. The mean contribution of soil parameters to SQI ranged from 0.0421 (Zn) to 0.30 (pH) (Table 4). The pH had minimum CV, while available Zn had maximum CV in the contribution to SQI. The SQI values ranged from 0.41 to 0.81 with mean of 0.69. Using SQI values, RSQI was derived for

Table 2. Principal components of soil quality parameters, eigenvalues and component matrix variables

	PC1	PC2	PC3	PC4	PC5	PC6
Eigen values	3.255	1.683	1.655	1.319	1.291	1.256
% of Variance	23.247	12.023	11.824	9.425	9.218	8.974
Cumulative %	23.247	35.269	47.093	56.518	65.736	74.710
Weightage factor	0.3112	0.1609	0.1583	0.1262	0.1234	0.1201
Factor loadings (Rotated component matrix)						
pH	0.871	-0.204	0.079	0.210	-0.113	-0.228
EC	0.310	-0.084	-0.021	0.638	0.152	0.250
OC	0.032	0.123	0.882	0.008	0.110	-0.042
Available N	0.023	-0.007	0.890	0.060	-0.018	0.158
Available P_2O_5	0.063	0.049	0.126	0.096	0.843	0.105
Available K_2O	0.276	0.633	-0.114	0.294	0.323	0.130
Exchangeable Mg	0.921	0.045	0.039	-0.083	0.062	-0.201
Exchangeable Ca	0.909	0.063	0.044	0.04	-0.005	-0.021
Available S	0.087	-0.144	0.048	0.057	-0.635	0.459
Available Fe	-0.751	0.198	0.089	-0.045	-0.111	-0.295
Available Mn	-0.161	0.011	0.102	0.002	-0.024	0.846
Available Cu	-0.367	0.704	0.052	-0.061	0.073	-0.115
Available Zn	-0.033	0.800	0.123	-0.005	-0.019	-0.010
Available B	0.107	-0.119	-0.089	-0.867	0.034	0.144

Table 3. Correlation between the highly weighted variables of PC at 0-30 cm depth of soil

	pH	OC	N	P	Mg	Ca	Fe	Mn	Zn	B
pH	1									
OC	0.025	1								
N	0.070	0.520**	1							
P	-0.014	0.183**	0.065	1						
Mg	0.755**	0.076	0.002	0.104*	1					
Ca	0.697**	0.039	0.056	0.095	0.660**	1				
Fe	-0.499**	0.036	0.000	-0.090	-0.549**	-0.572**	1			
Mn	-0.222**	0.015	0.197**	0.014	-0.248**	-0.078	-0.015	1		
Zn	-0.166**	0.159**	0.094	0.091	-0.044	0.000	0.162**	-0.006	1	
B	-0.099*	-0.074	-0.048	-0.099*	0.096	-0.043	-0.078	-0.020	-0.097	1

**. Correlation is significant at the 0.01 level (2-tailed)

*. Correlation is significant at the 0.05 level (2-tailed)

393 grids, which ranged from 0.51 to 1.00 with mean of 0.78. SQI was highest in parts of lowlands and midlands where soil has neutral to slightly alkaline pH and more OC due to good cultivation practices. It was lowest in upland, where soil has acidic pH and low OC indicating less soil productivity (Mandal et al 2011; Harsha et al 2021).

Soil pH, which influences soil physical, chemical, and biological properties and processes, has emerged as a key indicator for the soils of Ganjigatti sub-watershed. It is a crucial factor that significantly influences the health and productivity of the soil, as well as the plants that grow in the sub-watershed. pH is a measure of the acidity or alkalinity of a substance, and in the context of soil, it refers to the concentration of hydrogen ions (H^+) in the soil solution. The result suggests that pH increases as the slope of the landscape decreases. The soil at higher elevations on the landscape displays the lowest pH, likely due to the leaching away of exchangeable bases through runoff and erosion, which then accumulate on the lower slopes. This circumstance leads to an escalation in the presence of hydrogen ions within the soil, consequently causing a reduction in pH. Comparable research, including Dessalegn

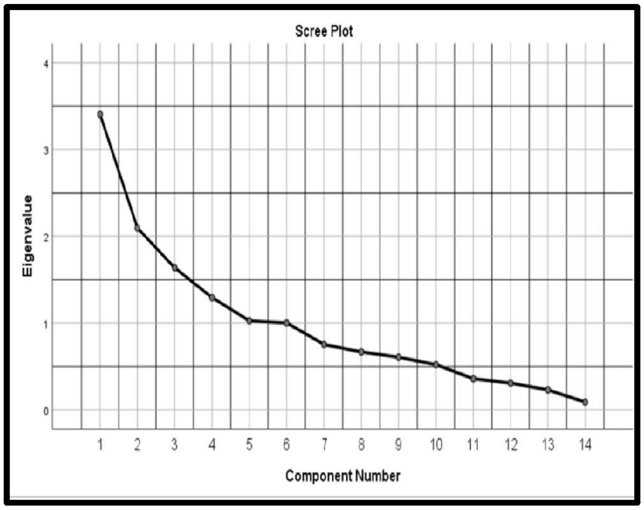

Fig. 1. Screen plot explaining the relationship of eigenvalue and principle component for 0-30 cm depth of soil

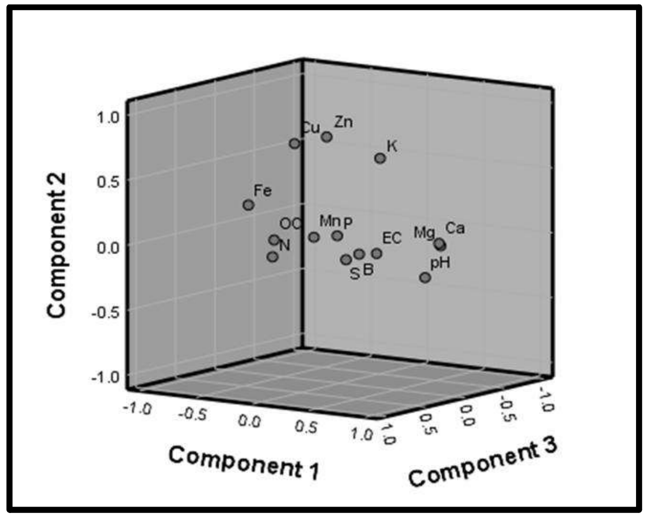

Fig. 2. Rotation of components (PCs)

Table 4. Contributions of significant soil parameters to soil quality index

Parameters	Contribution to SQI	Minimum	Maximum	Mean	SD	CV (%)
pH	W × Optimum is good	0.240	0.311	0.300	0.0140	4.67
Available Zn	W × More is good	0.0068	0.1608	0.0421	0.0253	60.09
Organic carbon	W × More is good	0.0149	0.1586	0.0879	0.0272	30.94
Available N	W × More is good	0.0120	0.1583	0.1023	0.0211	20.63
Available B	W × More is good	0.0141	0.1262	0.0492	0.0191	38.82
Available P	W × More is good	0.0076	0.1234	0.0475	0.0238	50.11
Available Mn	W × More is good	0.0047	0.1202	0.0581	0.0234	40.28
SQI		0.41	0.81	0.69	0.0699	10.18
RSQI		0.51	1.00	0.78	0.0789	10.17

Table 5. Parameters for different theoretical semivariogram models used to fit the experimental semivariogram of soil quality index (SQI)

Semi variogram model	ME	RMSE	MSPE	RMSP	Average standard error
Circular	-0.0007	0.1897	-0.0036	1.0100	0.1876
Spherical	0.0003	0.1906	0.0015	1.0123	0.1878
Exponential	0.0006	0.1934	0.0029	1.0134	0.1903
Gaussian	0.0004	0.1917	0.0024	1.0121	0.1889

et al (2014), Miheretu and Yimer (2018) and Bufebo et al (2021), echoes the current study's observations, indicating that the average soil pH is higher in the lower slope position compared to the higher areas of the landscape. Maintaining the appropriate soil pH is crucial for maximizing nutrient availability, supporting beneficial microbial communities, promoting plant growth, preserving soil structure and making informed decisions about crop selection and soil management practices.

Organic carbon (OC) is a fundamental component of soil health and plays a vital role in maintaining soil fertility, productivity and overall ecosystem functioning (Abebe et al 2020, Ebabu et al 2020). Zhang et al (2002) suggested that organic carbon (OC) constitutes a crucial element influencing soil quality and long-term sustainability. The reduction in carbon content results in a decrease in the cation exchange capacity (CEC) of soils, the stability of soil aggregates and crop yield. Organic carbon serves as a primary nutrient source and the depletion of organic matter corresponds to a decline in soil productivity. The presence of organic matter significantly impacts both the growth and yield of crops, either by directly supplying nutrients or by indirectly altering soil physical characteristics, which enhance root conditions and foster plant growth (Hati et al 2007). In addition to its role as a supplier and reservoir of nutrients for plants, organic carbon also plays a vital role in the carbon cycle. The reduction in organic matter content would lead to the physical deterioration of soils and properties reliant on organic matter become valuable indicators for evaluating soil quality.

Available nitrogen (N) is a critical component of soil quality and plays a central role in supporting plant growth, crop productivity and overall ecosystem functioning. Nitrogen is an essential nutrient required by plants in relatively large quantities and availability in the soil significantly influences various aspects of soil quality and health (Sathish and Madhu 2021, Prasad et al 2023). When assessing SQI, available phosphorus is typically considered within the context of other soil properties and factors. The phosphorus is essential for soil fertility and plant growth, but availability should be balanced to avoid over-application, which can lead to environmental issues. Sustainable soil management practices, such as precision nutrient application, cover cropping and soil erosion control, can help maintain optimal available phosphorus levels while promoting overall soil quality and minimizing negative environmental impacts (Mesfin et al 2022). Available zinc (Zn), manganese (Mn) and boron (B) are essential micronutrients that play critical roles in soil quality and plant health, which are crucial for promoting healthy plant growth, preventing nutrient deficiencies and maximizing crop yields (Harsha et al 2021).

Digital mapping of SQI by using kriging: Ordinary kriging was used to assess the spatial variability of SQI. Based on the lowest root mean square error (RMSE), circular semivariogram model was selected for the significant fit for SQI (Table 5). The geostatistical approach begins by identifying the spatial variation parameters (nugget, sill and range) from a spatial soil database using a semivariogram and uses kriging to estimate the unbiased soil characteristics at an unsampled location. The best-fit semivariogram model (Fig. 3) and model parameters (range, nugget and partial sill) of SQI are presented in Table 6. The range was higher for SQI (720.82 m) than distance of grid interval indicated that the rational sampling distance for the Ganjigatti sub-watershed was within their spatial correlation range. The C_0 values show a positive nugget effect, which may be explained by the sampling error, short-range variability, randomness and inherent variability (Liu et al 2006). The, nugget value for SQI is 0.0282 and is small and close to zero indicate a spatial continuity between the neighboring points. The finding is similar to the result of Jafarian and Kavian (2013) and Khan et al (2021). C_0/ C_0 + C (N:S ratio) represents the degree of spatial variability, which is affected by both structural and stochastic factors. The higher ratio (0.81) indicates that the spatial variability/ dependency is primarily caused by stochastic factors such as fertilisation, farming measures, cropping systems and other human activities.

In present study, geostatistical tools along with GIS used to map the spatial variability of SQI. They were grouped into various classes based on range which, represent their magnitude in soil and the area of each class were estimated. The cadastral integrated spatial variability maps indicate survey number wise spatial distribution of SQI (Fig. 4). SQI map of Ganjigatti sub-watershed showed that about 9.69% of

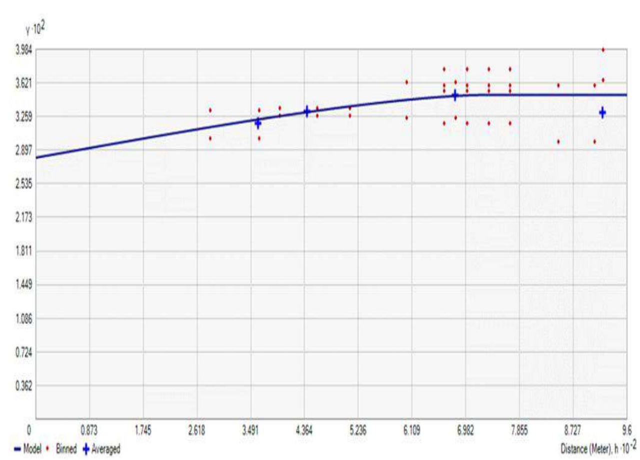

Fig. 3. Experimental semivariogram of soil quality index with fitted model

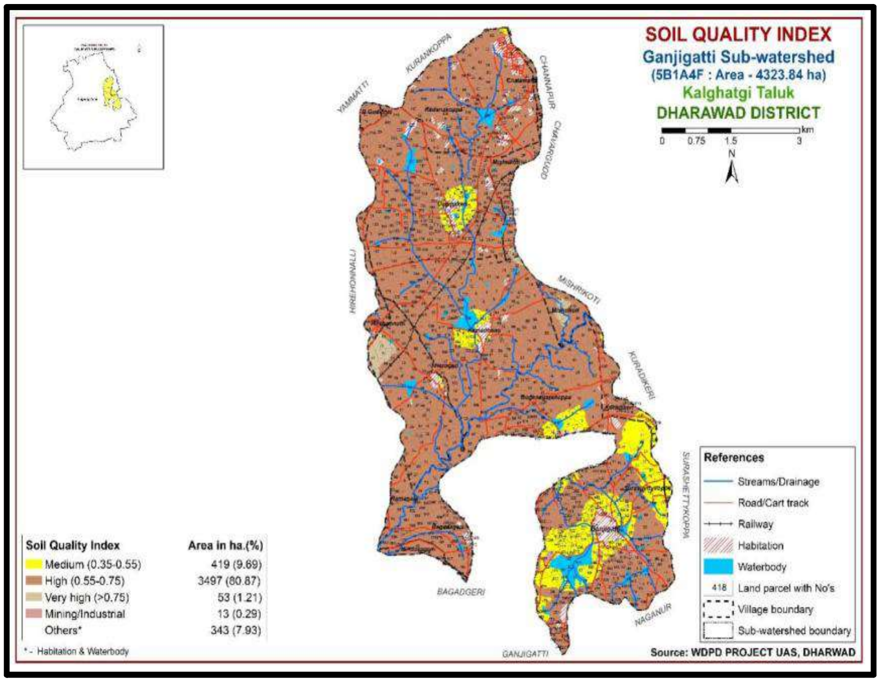

Fig. 4. Spatial distribution of soil quality index of Ganjigatti sub-watershed

Table 6. Semivariogram model parameters for soil quality index (SQI)

Model	Lag distance (m)	Range (m)	Nugget (Co)	Partial Sill (C)	Sill (Co+C)	N:S ratio	Spatial dependence
Circular	80	720.82	0.0282	0.0067	0.0349	0.81	Weak

the sub-watershed has a medium category of SQI (0.35-0.55). The high category of SQI (0.55-0.75), which is the bulk of the area covered in the sub-watershed, comprises about 80.87%.

CONCLUSION

Examining the variability present in soil parameters to assess soil quality clearly reveals that the SQI within the sub-watershed ranges from medium to very high. Investigating parameter relationships and conducting a principal component analysis highlighted the substantial contribution of seven parameters to the SQI. Foremost among these indicators is soil pH, serving as a pivotal factor for gauging soil quality. Following closely are organic carbon, available nitrogen, manganese, boron, phosphorus, and zinc. For areas with a medium SQI, farmers can enhance soil quality by regulating soil pH and enhancing soil aggregation using amendments and fertilizers rich in calcium. To ensure the sustainability of agricultural systems and uphold soil quality, the preservation and augmentation of organic matter are imperative. The augmentation of organic matter exerts a noteworthy influence on the mineralization and recycling of carbon and nitrogen. Addressing deficiencies in available zinc (Zn) and boron (B), which are of paramount importance for crop growth and consequently higher yields, holds significance. The higher N:S ratio (0.81) points towards spatial variability and dependency predominantly stemming from land management practices implemented in the sub-watershed. Further in-depth investigations in this realm will be instrumental in generating crucial insights required for sustainable land use planning. These studies will also aid in comprehending soil quality under diverse management practices and appropriate nutrient management within the sub-watershed.

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Isolation and Biochemical Characterization of Endophytic Bacterium *Gluconacetobacter diazotrophocus* from Native Sugarcane Cultivar of Middle Gangetic Plains of India

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Abstract: The study focused on the isolation and characterization of *Gluconacetobacter diazotrophocus*, an endophytic bacterium obtained from various parts of a native sugarcane cultivar in India's middle Gangetic plains. Using conventional culturing methods, isolated and screened 115 isolates, ultimately selecting 15 highly efficient isolates based on their production of growth-promoting hormones. Among these, GdS08S, isolated from sugarcane cultivar CoP-9301, exhibited the highest nitrogen-fixing ability, with 153µg of N/mg of carbon used. Isolate GdS15S, from sugarcane cultivar Co-0238, produced the highest concentration of gibberellic acid (8.19µg/25ml). Additionally, GdS07R displayed notable phosphorus and zinc solubilization zones, measuring 4.22 cm and 4.52 cm, respectively. *G. diazotrophocus*, residing within sugarcane tissues, plays a pivotal role in promoting rooting, cell elongation, and overall sugarcane growth through the biosynthesis of indole-3-acetic acid (IAA) and gibberellic acid (GA). Furthermore, it actively fixes atmospheric nitrogen, offering a significant nitrogen supply to the growing crops. This research underscores the significance of *G. diazotrophocus* as a potential biofertilizer for native sugarcane cultivars in the middle Gangetic plains of India, contributing to sustainable agriculture practices.

Keywords: *Gluconacetobacter,* Sugarcane, Nitrogen fixation, Phytohormones, Organic acids

The endophytic bacteria *Gluconacetobacter diazotrophicus*, initially discovered in sugarcane fields (Euan et al 2001), has been a pivotal model for studying plant-bacterial interactions. It has also been identified in coffee and in wild and salt-tolerant rice varieties. This endophytic nitrogen fixation has gained significant attention, offering a solution for nitrogen deficient soils. *G. diazotrophicus* has demonstrated the remarkable ability to produce auxins and gibberellins, which promote efficient plant growth (Figueroa Viramontes et al 2011). Evaluating microorganisms for phosphorus solubilization is a critical trait for endophytic bacterial isolates. Globally, many soils lack essential micronutrients like Zn, Fe and Mn, with Zn being particularly crucial (Alloway 2001). Unfortunately, the soluble form of Zn applied to the soil undergoes transformations into inaccessible forms due to soil reactions. Out of the total phosphorus fertilizers applied to the soil, only 15-20% can be utilized by the standing crops, while the remaining portion becomes locked in the soil as phosphates of Ca, Al, Mn, Zn and Fe complexes in acidic and calcareous soils respectively (Ibrahim et al 2022), even before plant roots have the opportunity to absorb it (Vikram 2007). This isolate possesses the ability to convert insoluble forms into soluble ones and its use can significantly enhance sugarcane productivity. Several studies have revealed that in grassy plants, these microorganisms naturally solubilize phosphorus, zinc, iron, potassium and magnesium (Eshaghi et al 2019). Despite the widespread application of phosphorus fertilizers to soils, a substantial portion of this nutrient becomes immobilized in the soil, hindering its absorption by plants (Paredes Villanueva et al 2020). Specifically, *G. diazotrophicus* can solubilize phosphates in significant amounts (Restrepo et al 2017), which represents a crucial trait for economically significant crops. Investigations on native isolates of *G. diazotrophicus* in sugarcane crops have demonstrated positive impact on growth and thereby reducing the need for chemical fertilizers (Ferreira et al 2019). This endophyte produces gluconic acid in significant amounts, through the direct oxidation of glucose by a pyrroloquinoline-quinone-linked glucose dehydrogenase within this bacterium, which further promotes plant growth (Carlos et al 2014). The subtropical region of the Indo-Gangetic plain comprises 55% of the area and contributes to 45% of the total sugarcane production.

Among the twelve significant biodiversity hotspots globally, India is endowed with two: the North-eastern region and the Western Ghats (Rajaram and Suri 2000). Therefore, investigating the presence and impact of *G. diazotrophicus* in the subtropical region holds considerable importance. Presently, there is limited information available on this crucial endophyte *Gluconacetobacter* from the subtropical region of India, recognized as one of the global biodiversity hotspots. Given the substantial ecological and economic significance of *G. diazotrophicus*, this study was conducted to isolate, screen, characterize and estimate growth-promoting parameters. Factors such as nitrogen-fixing ability, growth hormone production and phosphorus and zinc solubilization were evaluated to identify the most efficient strains of endophytic *Gluconacetobacter* in sugarcane crops grown in the north-east alluvial plains of Bihar.

MATERIAL AND METHODS

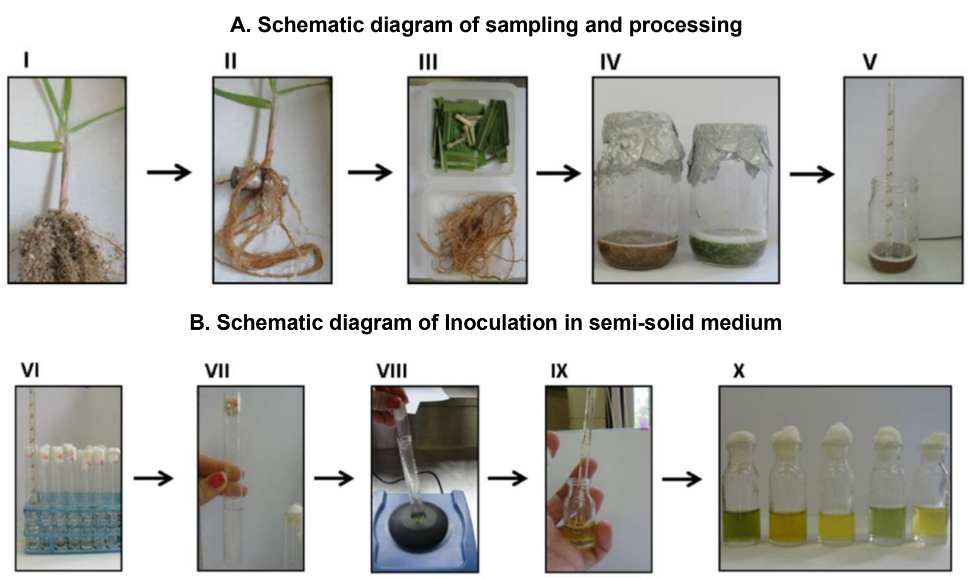
Location of experimental/sampling sites: The study was conducted at experimental site near the Burhi Gandak River in Bihar, situated at coordinates 26.0039° N, 85.6753° E. The research farm located at an altitude of 52.0 m above sea level. This site experiences an annual rainfall of 1909 mm, a relative humidity of 80.45%, and an average temperature of 22.45 °C. The experiment was carried out in both in vitro and in vivo conditions on a medium upland terrain with consistent topography. This site falls within the Ustic moisture regime of the subtropical climatic. The experimental soil is classified as Entisols order, Fluvents suborder and Typic Ustifluvent great group. It has a sandy loam texture and a bulk density of 1.52 Mg m^{-3}.

Collection of samples: The root, shoot and leaf samples of different elite varieties of sugarcane viz CoP-16437 (RG-1), CoP-09437 (RG-2), CoP-18437 (RG-3), Co-P 9301 and Co-0238, collected from the gene park of Sugarcane Research Institute, RPCAU, Pusa, located in office premises.

Preparation of media and cultures: An N-free semisolid LGI medium enriched with 0.5% sugarcane juice at a pH of 4.5 was utilized. For isolation and culture development, acetic acid LGI agar plates supplemented with yeast extract (50 mg/l) and potato agar plates with 10% cane sugar were used, as per Cavalcante and Dobereiner's methods (1988).

Preparing root, stem and leaf samples: Since *G. diazotrophicus* is an endophyte, so root, stem and leaf samples were used in the isolation process. The plants were uprooted, and the various plant parts were separated and rinsed with sterile distilled water. The dissected plant parts were surface sterilized for 5 minutes using a 5% sodium hypochlorite solution and then rinsed 5-7 times with sterile distilled water (Fig. 1).

Isolation of *G. diazotrophicus:* The surface sterilized different plant parts, viz., root, stem and leaf samples were weighed, massrate and homogenized separately in a sterile sucrose solution (1%) using a sterile pestle and mortar. Aliquots of 500 ml each were inoculated in semisolid LGI and were then incubated at a temperature of 28±2°C for a period of 5-7 days. Five samples from each plant part were



I: Sampling of plants; II: Root free from soil and substrate; III: Root and shoot tissue separated, IV: First dilution of sample (10^{-1}) on saline solution; V & VI: Serial dilution; VII & VIII: Vortexing sample before inoculation; IX & X: Inoculation of 0.1 ml into semisolid media

Fig. 1. Schematic diagram of sample preparation and inoculation in media for isolation of *G. diazotrophicus* (A and B)

inoculated into semisolid LGI tubes. The yellowish bacterial growth from the tubes was streaked onto LGI plates (Cavalcante and Dobereiner, 1988) and then incubated at a temperature of 28±2°C for duration of 5-7 days.

Characterization of isolates through biochemical analysis: Isolates that were presumably identified as *G. diazotrophicus* based on morphology using LGI media underwent further characterization through a range of biochemical tests. These included gram stain, motility, catalase, gelatin hydrolysis, over oxidation of ethanol, brown pigment production on GYC agar, growth on various carbon sources, growth at different sugar concentrations, and growth at various temperatures (Dong et al 1995).

Assessment of Plant Growth-Promoting Activities

Evaluating nitrogen fixation capability: The nitrogen-fixing ability was determined by using the micro-Kjeldahl method. Cultures aged 48 hours were inoculated into 5 ml of N-free semi solid broth of LGI medium and incubated for another 48 hours. Then, 1 ml of this broth was inoculated into 50 ml of semisolid medium and left to incubate for 15 days. The nitrogen was estimated from 10 ml of this culture following the standard procedure of the Micro-Kjeldahl technique (Reis et al 1994).

$$N_2\,\frac{mg}{g} = \frac{\text{ml of } H_2SO_4 \text{ in the sample } \times \text{Normality of } H_2SO_4 \times 14.01}{\text{The weight of the sample (the amount of carbon used, in grams)}}$$

Evaluating phytohormones (IAA and GA): Conical flasks containing 50 ml of Czapeck's solution (composed of 1000 ml distilled water, 30 g cane sugar as an energy source and the only carbon source, 1 g dipotassium phosphate as a buffering agent, 0.5 g magnesium sulfate as a cation source, 0.5 g potassium chloride as an essential ion source, and 0.01 g iron sulfate as a cation source) were prepared and autoclaved. These flasks were inoculated with 500 µl of a 72-hour old culture from each isolate and incubated at 28±2°C for 7 days. The cultures were then centrifuged at 3300 rpm for 20 minutes. The supernatant was used for the estimation of Indole-3-acetic acid (IAA) and Gibberellic acid (GA). The quantity of IAA was determined using a spectrophotometer (Ivanova et al 2001), while GA was estimated using the method described by Bastian et al (1998).

Solubilization of phosphorus and zinc: To evaluate the potential for phosphorus and zinc solubilization, assays were conducted both on plates and in broth using LGI medium. For the plate assay, glucose was selected as the carbon source at a 1% concentration, and the medium was supplemented with insoluble zinc compounds, namely, zinc oxide (ZnO), zinc carbonate ($ZnCO_3$), and zinc phosphate ($ZnPO_4$), each at a 0.1% concentration as separate treatments. The media supplemented with insoluble nutrient compounds were added to sterile petri dishes. After solidification, 48-hour-old cultures of *G. diazotrophicus* strains ($6x10^8$ CFU mL^{-1}) at a 10 µl concentration were placed over the media and incubated at 28±2°C for 3 days. Post incubation, the diameter of the solubilization zone was measured in cm. The amount of solubilization was assessed following the procedure described by Fasim et al (2002). The measurement of halozone diameter was done for screening and assessing the phosphate and zinc solubilizing activity of isolates.

Measurement of low molecular weight organic acids: The production of low molecular weight organic acids was quantified in broth using the paper chromatography technique. These organic acids play a crucial role in the solubilization of insoluble zinc and phosphorus. For quantification, the yellow-colored spots were cut from the paper using scissors and placed in a petri dish. Approximately 3 mL of n-butanol was spread over the cut part of the chromatograph to dissolve the compounds from the yellow spots. Once the paper strip became colorless, the filtrate was poured into a 5 mL volumetric flask and topped up to 5 mL with n-butanol. The intensity of the light yellow-colored spots from each sample was measured at a wavelength of 426 nm, where it yields maximum absorbance (%). Since most of the isolates produced tartaric acid, a standard was prepared with this acid. Standard curves were plotted with the reaction product of tartaric acid (L.R grade) and bromophenol blue at different concentrations of tartaric acid, namely 2.5, 5.0, 10, 15, 20, and 25 mg L^{-1} dissolved in butanol. The percentage absorbance of the sample was measured, and the actual amount produced was calculated from the standard curve.

Determination of titratable acidity: It is a measurement of the concentration of total dissociated plus undissociated H^+. The titratable acidity (mmol H^+ $Liter^{-1}$) was determined by titrating 10 mL of the culture filtrate with 0.05 M NaOH solutions using phenolphthalein indicator.

RESULTS AND DISCUSSION

Isolation, identification, screening, and biochemical characterization of endophytic bacterial isolates: For initial screening, the cultures were isolated using LGI medium. Out of the 115 strains that were isolated from five different sugarcane varieties (CoP-9301, RG-1, RG-2, RG-3, Co-0238), 15 efficient isolates were identified: GdS25R, GdS08S, GdS19L, GdS17S, GdS07R, GdS26L, GdS5R, GdS13S, GdS16L, GdS04R, GdS11S, GdS18L, GdS02R, GdS15S, GdS21L, based on their nitrogen-fixing capacity, phytohormone production, phosphorous and zinc solubilization, and production of low molecular weight organic acids in broth. These were selected based on their morphological and biochemical characteristics, as well as their plant growth-promoting traits. The formation of an orange-colored colony on LGI media was the primary criterion to identify the *G. diazotrophicus* isolates (Fig. 1, Fig. 3). *G. diazotrophicus* isolates were collected from sugarcane plants, roots, stems and leaves. Notably, the CoP-9301 variety provided the highest number of isolates, totaling 29, isolated from the root, stem and leaf portions. The RG-1 variety also produced a substantial number, with 28 isolates, while the RG-3 and Co-0238 varieties provided 19 and 22 isolates, respectively. In contrast, the RG-2 variety provided the lowest number of isolates (17). This comprehensive isolation and distribution of *G. diazotrophicus* isolates from different sugarcane varieties (Fig. 2) serve as a valuable resource for future research on the ecological and agricultural significance of this endophyte. These isolates underwent further biochemical characterization to confirm specific characteristics of *G. diazotrophicus*, in accordance with Bergey's Manual of Systematic Bacteriology (Table 1, Fig. 3). The colonies of *G. diazotrophicus* typically have a circular shape with a smooth texture. The color can vary, but is often pale yellow or cream-colored. The edges of the colonies (margins) are typically entire, slightly raised and opaque. All the isolates tested positive for most of the traits. Additionally, all isolates tested negative for the biochemical characteristic of gelatin liquefaction hydrolysis. The endophytic colonization of sugarcane by *G. diazotrophicus* is a ground breaking discovery that provides substantial fixed nitrogen for plant growth. This finding is the uniqueness of this relationship in the plant kingdom, where typically, numerous bacterial endophytes have been isolated from a single plant species (Zinniel et al 2002). The type of plant tissue and the location of the endophytes can influence the frequency of colonization. Kaur and Vyas (2017) isolated thirty five bacterial endophytes, focused on the isolation and characterization of *G. diazotrophicus* from various parts of sugarcane cultivars.

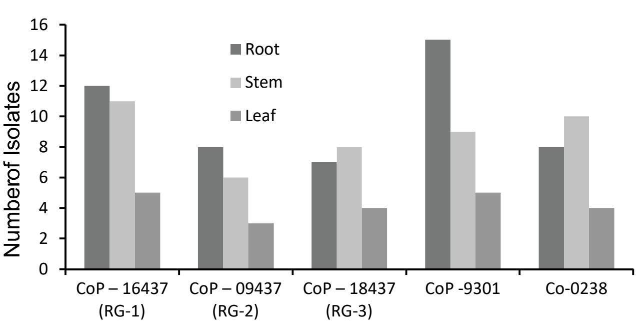


Fig. 2. Isolates of *Gluconacetobacter diazotrophicus* from different varieties of sugarcane

Plant growth-promoting traits: The cultures were evaluated for nitrogen fixation ability, production of phytohormones as well as phosphorus and zinc solubilization capabilities.

Ability to fix nitrogen: All 115 isolates were evaluated for their nitrogen-fixing capacity using the Micro-Kjeldahl method. Among them, 35 isolates showed efficient nitrogen fixation and were able to fix a considerable amount of nitrogen from these 15 top-performing isolates were selected for further characterization. Five isolates were chosen from each plant part, namely, the root, stem and leaf. Among the isolates, GdS08S, derived from the CoP-9301 sugarcane variety, fixed the highest amount of N_2, around 153.10 µg of Nitrogen/mg of Carbon use. This was closely followed by the GdS18L isolate from the RG-3 sugarcane cultivar, The isolate GDS02R, from the Co-0238 sugarcane variety, fixed the least amount of nitrogen at 68.23 µg/mg of carbon (Table 2). The *G. diazotrophicus* elucidate various growth promoting properties. As per Fisher and Newton (2005), the molybdenum dependent mechanism (Mo-nitrogenase) utilized by *G. diazotrophicus* for nitrogen fixation provide a significant amount of fixed nitrogen to its host plants. Various studies have shown that certain sugarcane cultivars may obtain up to 200 kg of nitrogen per hectare from *G. diazotrophicus*. This contribution can meet more than half of the crop's nitrogen requirement (Boddey et al 2001). Studies also highlight the unique feature of *G. diazotrophicus* - it does not contain a nitrate reductase protein. Therefore, this bacterium can effectively fix nitrogen that are supplemented

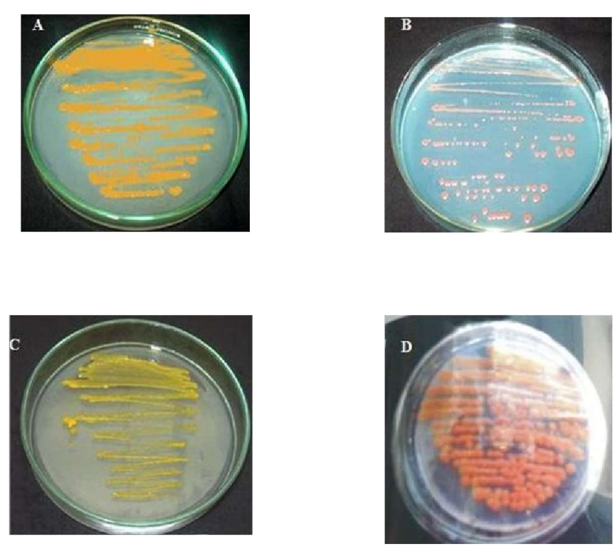


Fig. 3. Actual colony morphologies of the *Gluconacetobacter diazotrophicus* isolates A (GdS25R), B (GdS08S), C (GdS15S) and D (GdS07R) grown at 28°C for 72 h in LGI medium obtained from sugarcane varieties from CoP-9301 (both A & B), Co-0238 and RG-1, respectively

with either nitrate-based fertilizers or with low amounts of ammonium based fertilizers (Eskin et al., 2014). This finding underscores the potential of *G. diazotrophicus* in reducing the dependence on fertilizers. The strain of *G. diazotrophicus* exhibited increased nitrogen fixation activity, which is consistent with the findings of Nong et al (2022), who characterized the strain under various physiological and nutritional conditions. The nitrogenase activity of the strain was significant at temperatures between 28°C to 37°C. Additionally, different carbon sources were tested and the strain showed enhanced nitrogenase activity with 5% sucrose.

Phyto-hormone production: The highest IAA production was observed in the isolate GdS08S, (7.58 µg/ml). This isolate was derived from the sugarcane variety CoP-9301., the isolate GdS07R, obtained from the sugarcane variety RG-1, produced the lowest amount of IAA, i.e., 3.49 µg/ml. the pattern for GA production did not match that of IAA production. The isolate GdS15S, obtained from the sugarcane variety Co-0238, produced the highest amount of GA, around 8.19 µg/25ml and was closely followed by the isolate GdS17S from the RG-1 variety, (8.10 µg/25ml.) The lowest amount of GA (4.98 µg/25ml) was produced by the isolate GdS16L, derived from the RG-2 sugarcane variety (Table 3). A standout isolate from sugarcane, GdS08S, exhibited the highest amount of nitrogen fixation, approximately 153µg of N/mg of carbon used, and also produced the highest concentration of Indole Acetic Acid (7.58µg/ml). Meanwhile, the GdS15S isolate produced the maximum concentration of GA (8.19µg/25ml). The GdS07R isolate displayed the highest phosphorus solubilization zone with a diameter of 4.22 cm and a zinc solubilization zone of 4.52 cm. *G. diazotrophicus*, which resides in the intercellular space of plant tissues, contributes to N fixation and the biosynthesis of the IAA, promoting root development and enhancing sugarcane growth. The synthesis of GA aids in cell elongation, which ultimately increases cane length. The top 15 screened isolates were further examined for their production of various organic acids and titratable acidity, which play a crucial role in the solubilization of insoluble phosphorus and zinc. These findings highlight the significant potential of these bacterial isolates in promoting plant growth

Table 1. Selective biochemical assays performed on *Gluconacetobacter diazotrophicus* isolates from sugarcane crop varieties

Biochemical characters		Varieties of sugarcane crop				
		RG-1	RG-2	RG-3	CoP-9301	Co-0238
Cell shape		Rod shaped	Rod shaped	Rod shaped	Rod shaped	Rod shaped
Gram reaction		Gram negative	Gram negative	Gram negative	Gram negative	Gram negative
Motility		+	+	+	+	+
Brown pigment on GYC medium		+	+	+	+	+
Gelatin liquefaction		-	-	-	-	-
Catalase activity		+	+	+	+	+
Oxidation of ethanol		+	+	+	+	+
Growth on C - sources						
i.	Glucose	+	+	+	+	+
ii.	Sucrose	+	+	+	+	+
iii.	Ethanol	+	+	+	+	+
iv.	Mannitol	+	+	+	+	+
Growth at various concentration of sugar						
i.	5%	+	+	+	+	+
ii.	10%	+	+	+	+	+
iii.	20%	+	+	+	+	+
iv.	30%	+	+	+	+	+
Growth at various temperatures						
i.	4°C	-	-	-	-	-
ii.	28°C	+	+	+	+	+
iii.	32°C	+	+	+	+	+
iv.	37°C	+	+	+	+	+

GYC: Glucose, yeast and calcium carbonate and nutrient utilization. Though *G. diazotrophicus* was initially isolated from sugarcane, numerous studies have documented its widespread presence in a variety of crops (Hernandez et al 2000). This bacterium has been isolated from sugarcane, maize, pineapple, and carrot. These plants, having significant amounts of sucrose in their cell sap,

Table 2. Nitrogen fixation ability of *Gluconacetobacter diazotrophicus* isolates from different sugarcane cultivar

Isolate code	Cultivar	isolated from			µg of Nitrogen/ mg of carbon
		Root	Stem	Leaf	
GdS25R	CoP-9301	-	-	√	135.82
GdS08S	CoP-9301	√	-	-	153.10
GdS19L	CoP-9301	-	√	-	139.42
GdS17S	RG-1	-	√	-	123.15
GdS07R	RG-1	√	-	-	109.06
GdS26L	RG-1	-	-	√	127.53
GdS05R	RG-2	√	-	-	91.06
GdS13S	RG-2	-	√	-	98.46
GdS16L	RG-2	-	-	√	108.32
GdS04R	RG-3	√	-	-	84.06
GdS11S	RG-3	-	√	-	98.19
GdS18L	RG-3	-	-	√	141.25
GdS02R	Co-0238	√	-	-	68.23
GdS15S	Co-0238	-	√	-	78.95
GdS21L	Co-0238	-	-	√	112.34
CD (p=0.5)		-	-	-	35.41

Gd represents *Gluconacetobacter diazotrophicus;* S – Sugarcane crop; Numerical number represents isolates serial number and last alphabet represents different plant parts viz R - root, S- stem and L- leaf

Table 3. The production of IAA, GA, phosphorus and zinc solubilization zone by the efficient strains of *G. diazotrophicus*

Isolate code	Cultivar	IAA (µg/ml)	GA (µg/25ml)	Diameter of solubilization zone	
				P-solubilization Zone (cm)	Zn-solubilization Zone (cm)
GdS25R	CoP-9301	5.53	6.75	2.80	3.81
GdS08S	CoP-9301	7.58	7.73	2.60	3.19
GdS19L	CoP-9301	6.43	5.63	2.91	3.05
GdS17S	RG-1	5.74	8.10	3.96	4.47
GdS07R	RG-1	3.49	6.53	4.22	4.52
GdS26L	RG-1	4.43	5.72	3.41	4.15
GdS05R	RG-2	5.68	7.95	3.08	4.11
GdS13S	RG-2	5.12	5.93	2.99	3.97
GdS16L	RG-2	4.08	4.98	2.76	3.59
GdS04R	RG-3	7.44	6.36	2.74	3.71
GdS11S	RG-3	4.54	7.87	2.87	3.54
GdS18L	RG-3	5.76	6.84	3.28	3.61
GdS02R	Co-0238	4.86	6.18	2.54	3.22
GdS15S	Co-0238	5.53	8.19	2.45	3.18
GdS21L	Co-0238	4.49	6.51	3.21	3.79
CD (p=0.05)		2.38	1.04	1.07	1.15

provide suitable environments for *G. diazotrophicus* to survive and proliferate. These endophytic strains showed considerable abilities in nitrogen fixation, phytohormone production and solubilization of zinc and phosphorus. The mechanisms for growth promotion are the production of growth hormones detected in the cultures of *G. diazotrophicus* (Bastian et al 1998). Different plant hormones interact synergistically or antagonistically through complex regulatory pathways to regulate plant development. It is noteworthy that IAA, produced by *G. diazotrophicus*, can exert its effects independently on nitrogen fixation (Lee et al 2004).

Ability to solubilize phosphorus and zinc: The largest phosphorus solubilization zone, measuring 4.22 cm, was for the GdS07R isolate from the root of the RG-1 sugarcane variety, the smallest solubilization zone, measuring 2.45 cm, was for the GdS15S isolate from the stem of the Co-0238 sugarcane variety. The pattern of zinc solubilization varied from that of phosphorus. The largest zinc solubilization zone, (4.52 cm) was for GdS07R isolate from RG-1, followed closely by the GdS26L isolate. The smallest zone, (3.05 cm), was for the GdS19L isolate from the CoP-9301 sugarcane variety (Table 3). Isolates, a strain from sugarcane (GdS08S) demonstrated the highest capacity for nitrogen fixation (153.10 µg of Nitrogen/mg of carbon) and the highest IAA production (7.58 µg/25 ml). This indicates its potential for use as a bio-inoculant. Based on morphological, biochemical, and functional characteristics, it can be concluded that the GdS08S, GdS15S, GdS07R, and Gds17S isolates, obtained from the sugarcane cultivars CoP-9301, Co-0238, and RG-1, proved to be the most potent. These isolates could be harnessed in the future as biofertilizers to enhance sugarcane productivity. Alloway (2001) also highlighted the beneficial role of solubilizing bacteria for phosphorus and zinc as microbial inoculants, where over 70% of soils suffer from zinc deficiency. Nutrients like phosphorus and zinc often transform into insoluble forms due to complex soil reactions. To enhance the nutrient status, *G. diazotrophicus* could be used in conjunction with less expensive materials, such as rock phosphate and zinc ores. Considering its ability to fix nitrogen, produce growth hormones and now solubilize essential nutrients like phosphorus and zinc.

Production of low molecular weight organic acids and titratable acidity: Organic acids were produced in LGI broth by *G. diazotrophicus* isolated from different sugarcane cultivar plant parts. The isolates produced a variety of organic acids including gluconic, tartaric, malonic, fumaric, citric, and lactic acids. The isolate GdS16L produced the highest total amount of organic acids (9.36 mg L^{-1}), followed by GdS15S, GdS08S and GdS19L, while GdS25R produced the lowest amount (2.27 mg L^{-1}). The most commonly produced organic acids were tartaric acid (13 isolates) and gluconic acid (5 isolates), while malonic and lactic acids were produced exclusively by GdS08S and GdS18L, respectively. Isolates GdS18L and GdS02R produced citric acid with moderate (++) and strong (+++) intensity, respectively. Strong yellow color intensity of gluconic acid spots in paper chromatographs was with GdS19L and GdS17S, while a lower intensity was with GdS08S, GdS16L, and GdS26L. All *G. diazotrophicus* isolates synthesized tartaric acid, except for GdS18L and GdS02R. The highest titratable acidity (34.5 mmol H+/liter) was for isolate GdS16L, followed by GdS15S. The lowest value (14.5 mmol H+/liter) was recorded for isolate GdS21L. The production of low molecular organic

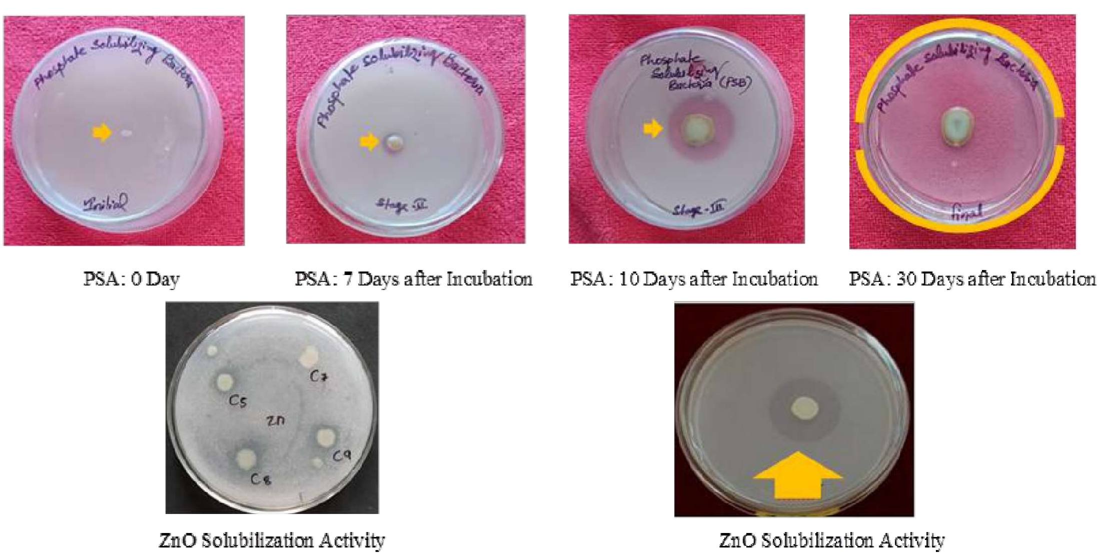


Fig. 4. Halozone formation of phosphorus and zinc solubilization activity by endophytic bacteria

Table 4. Low molecular weight organic acids produced by *Gluconacetobacter diazotrophicus* in broth and their impact on titratable acidity and lowering of pH

Isolate code	Organic acid produced	Colour (yellow) *intensity of organic acid spots in chromatograph	Total organic acid (mg/L)	Titratable acidity (m mol H^{+} liter $^{-1}$)
GdS25R	Tartaric	++	2.27	16.0
	Fumaric	+		
GdS08S	Malonic	+	8.61	17.5
	Tartaric	++		
	Gluconic	+		
GdS19L	Gluconic	+++	8.07	23.0
	Tartaric	++		
GdS17S	Gluconic	+++	4.54	24.0
	Tartaric	++		
GdS07R	Tartaric	++	4.41	23.0
GdS26L	Gluconic	+	6.27	21.0
	Tartaric	++		
GdS05R	Tartaric	+++	4.24	22.0
	Fumaric	+		
GdS13S	Tartaric	+++	7.93	21.0
	Fumaric	+		
GdS16L	Tartaric	++	9.36	34.5
	Gluconic	+		
GdS04R	Tartaric	+++	7.26	17.5
GdS11S	Tartaric	+++	7.36	21.0
GdS18L	Citric	++	2.81	22.0
	Lactic	+		
GdS02R	Citric	+++	5.77	18.5
	Fumaric	+		
GdS15S	Tartaric	++	8.92	28.0
	Citric	+		
GdS21L	Tartaric	+++	3.36	14.5
SEM ±	---	---	0.21	1.21
CD (p= 0.05)	---	---	0.89	3.38

* Key: + = Low intensity
++ = moderate intensity and
+++ = strong intensity

acids reveals that *G. diazotrophicus* mainly produces tartaric, gluconic and fumaric acids. Illmer and Schinner (1995) also observed that *Aspergillus niger* produces modest quantities of gluconic acid but Whitelaw et al. (1999) indicated that the phosphate solubilizing microbial strains did not produce gluconic acid. The type and amount of organic acids produced by phosphate solubilizing strains can vary depending on the composition of the medium, and growth conditions. Glucose has been identified as a common carbon source used by microorganisms to produce organic acids. Nautiyal et al (1999) also observed increased organic acid production when glucose was used as a carbon source. Among the phosphate-solubilizing bacterial isolates, GdS15S exhibited the highest total amount of organic acids, followed by GdS02R and GdS18L. The effectiveness of these isolates in chelating calcium was attributed to the presence of citric acid, a tribasic acid known for its strong chelating properties towards calcium. In contrast, aliphatic monobasic acids showed less potent calcium chelating abilities. Wada et al (2021) supports these findings, showing that citric acid produced displayed the powerful Ca chelation compared to other organic acids.

CONCLUSION

The isolates from sugarcane roots performed best in terms of organic acid production, phosphorus, and zinc solubilization, while the isolates from sugarcane stems excelled in phytohormone production and nitrogen fixing ability. These findings indicate that *G. diazotrophicus* has the potential to be utilized as a biofertilizer to enhance nutrient (nitrogen, phosphorus and zinc) use efficiency in sugarcane, which is known as a high-input crop. By harnessing the growth-promoting properties of *G. diazotrophicus*, may be able to reduce the reliance on costly nitrogenous fertilizers and mitigate the environmental risks associated with their overuse. The results indicate new possibilities for sustainable sugarcane production and offer insights into the diverse roles of *G. diazotrophicus* as an endophytic bacterium in promoting plant growth and nutrient acquisition.

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Geo-Statistical Analysis of Soil Pollutants of Tannery Industrial Area, Kanpur

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Abstract: Earth's soil is a valuable natural resource that is easily damaged by excessive agriculture, industrialization, and other industrial or environmental activities. Accurate and rapid assessment of soil properties is key component of the agriculture. Heavy metals pollution and their toxic levels in soils is one of the major problems associated with the environment. The main objective is to measure the soil properties and their spatial variability. A combination of conventional analytical methods and geostatistical methods were used to analyze the data for spatial variability. A total of 50 Soil samples were collected grid wise at an interval of 500 m with the help of Global Positioning System (GPS) from the plough layer (0-25 cm) covering the study area which is highly contaminated. A classical ordinary kriging (OK) interpolation method with three types Spherical, Gaussian and Exponential were used in ArcGIS software. The findings showed that Cd varied from 3.6 to 24, Cr from 44.6 to 4596, EC from 0.41 to 1.230, OC from 0.2 to 1.54 and pH from 7 to 8.3. There was a strong spatial dependence for chromium, moderate for cadmium and weak for pH, EC and OC. Semivariograms showed spherical model best for cadmium and chromium, gaussian for OC and exponential model best fitted for pH and EC.

Keywords: Soil properties, Semivariogram, Spatial distribution, GIS, Ordinary Kriging

The presence of soil heavy metals is a severe threat to the environment, crop production, and human health. The entry of poisonous and toxic metals in human food chain by the vegetables crops is of great concern. Higher concentrations of heavy metals in field are often not caused by pedogenesis but by human activities, such as mining and smelting, combustion of fossil fuels, application of agrochemicals, and wastewater irrigation. It is crucial to ascertain and quantify the sources of heavy metals in farmland for designing pollution controls and remediation strategies. Spatial distribution and source identification of pollutants in soils are essential for risk evaluation and soil reclamation. With the development of geographic information system (GIS) and geostatistics, Kriging is a prevalent technique used in spatial interpolation on soil contamination. Multivariate analyses, including principal component analysis (PCA), cluster analysis (CA), enrichment factor (EF) and positive matrix factorization (PMF), are valuable tools for identifying sources of heavy metals in soil. Because of its environmental significance, studies to determine risk caused by metal levels in soil on human health and forest ecosystem have attracted attention in recent years.

Soil heavy metal pollution studies focus on the identification of high pollution risk areas. Samples from high pollution risk areas are usually local spatial outliers (Zhang et al 2009). Interpolation techniques all have a smoothing effect, which underestimates the local high values and overestimates the local low values (Journel et al 2000). This smoothing effect leads to bias in soil pollution assessment and has an effect on relevant environmental decision making (Goovaerts 2000). Consequently, there is need to monitor and evaluate the amount and distribution of soil heavy metals (Choe et al 2008). Mapping the spatial distribution of heavy metals in soils is critical for risk assessment of potential environmental pollution and for establishing protocols for pollution remediation. The use of advanced technology Geographical Information Systems (GIS) is one of the most efficient tool and valid alternative for studying soil heavy metals. This method allows repetitive coverage of large-scale areas in a relatively cost-effective way, have become attractive for identifying and assessing spatial patterns of the soil properties. There are a lot of studies of the performance of the spatial interpolation methods mentioned above, but the results are not clear-cut (Shi et al 2009). Some of them found that the kriging method performed better than IDW (Yasrebi et al 2009); while others showed that kriging was no better than alternative methods. Conventional statistical method and geographical information system (GIS) are powerful tools for predicting the spatial distribution of soil HMs at a regional scale (Yang et al 2020). Kriging is one of several methods that use a limited set of sampled data points to estimate the value of a variable over a continuous spatial field. It differs from simpler methods, such as Inverse Distance Weighted Interpolation, Linear Regression, or Gaussian decays in that it uses the spatial correlation between sampled points to interpolate the values in the spatial field. Kriging also generates estimates of the uncertainty surrounding each interpolated value. This helps to reduce bias in the predictions. Ordinary kriging, for which the assumption of stationary (that the mean and variance of the values is constant across the spatial field) must be assumed. The objective of the study was to prepare spatial variability distribution maps of soil properties of tannery industrial zone which is highly contaminated with long term irrigation of tannery effluents in the nearby zones.

MATERIAL AND METHODS

Study area: Jajmau Industrial Zone, Kanpur, India which is lies between 26.46^0 North latitude to 80.35^0 East longitude. It is situated on the banks of the Ganges River. The main industry is the leather industry. It is home to some of the biggest leather tanneries in Northern India. It is highly chronic polluted area and one of the biggest exporting centres of the tanned leather. The study area is situated in the zone of humid subtropical climate and the year is divided into three seasons with heavy rainfall during the monsoon season in the months of July, August and September about 70-80 % of the total rainfall.

Soil sample collection: Soil samples were collected grid wise at an interval of 500 m with the help of Global Positioning System (GPS). A total 50 soil samples are collected from the plough layer (0-25 cm) covering the study area which is highly contaminated.

Soil analysis: Soil sample collected are air dried under shade and then grinding is done using porcelain made mortar and pestle than the sample sieved through a 2.0 mm size sieve for pH, EC, Cd and Cr. For organic carbon 0.5 mm size sieve is used. The soil that passed through sieves is collected and stored in air-tight polythene bags for further use. Soil pH, EC, OC, Cd and Cr were determined using the standard analytical methods.

Geostatistical analysis: In general, geostatistical methods were used to estimate and map the soil properties. It is based on the theory of recognized variables, which was used to investigate the soil spatial variability. It is expressed by a Semivariogram, which measures the average dissimilarity between data separated by a vector h it is computed as half the average squared difference between the components of data pairs:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [\, Z(x) - Z(x_i + \mathrm{h})] \qquad (1)$$

Where, N(h) is the number of data pairs within a given class of distance and direction, z(xi) is the value of the variable at the location xi and z(xi+h)is the value of the variable at a lag of h from the location xi .

Experimental semivariogram value for each property was computed using ArcGIS 10.3. During pair calculation, maximum lag distance was taken half of the minimum extent of sampling area to minimize the border effect. Using the semivariogram model, basic spatial parameters such as nugget (C0), partial sill (C+ C0) and range (m) was calculated. Nugget is the variance at zero distance, partial sill is the lag distance between measurements at which one value for a variable does not influence neighbouring values and range is the distance at which values of one variable become spatially independent of another. Three commonly used semivariogram models were fitted for soil properties (pH, EC, OC, Cd and Cr). These are the Spherical, Exponential and Gaussian model. Expressions for different semivariogram models are below:

Spherical model

$$\gamma(h) = C_0 + C\left[1.5\frac{h}{a} - 0.5\left(\frac{h}{a}\right)^3\right] \quad \text{if } 0 \le \mathrm{h} \le \mathrm{a}, (2)$$

Exponential model

$$\gamma(h) = C_0 + C\left[1 - exp\left\{\frac{h}{a}\right\}\right] \qquad \text{for } \mathrm{h} \ge 0 \ (3)$$

Gaussian model

$$\gamma(h) = C_0 + C\left[1 - exp\left\{\frac{-h}{a}\right\}^2\right] \qquad \text{for } \mathrm{h} \ge 0 \ (4)$$

In all these models, nugget, sill and range were expressed by Co, (C+ Co) and m, respectively. From spatial data on soil properties corresponding point feature file was prepared in ArcGIS. ArcGIS geo-statistical analyst extension was used to carry out exploratory variogram analysis and then extend this exploratory approach to spatial interpolation by way of kriging. Geo-statistical analysis consisting of variogram calculation, kriging, cross-validation and mapping was performed using the geo-statistical analyst extension of ArcGIS 10.3. All the statistical calculations were performed using SPSS statistics 17.0.

RESULTS AND DISCUSSION

A descriptive statistic of Cd and Cr concentrations and soil properties (EC, OC and pH) value of plough layer (0-25 cm) soil of 50 soil samples is listed in Table 1. The Cd varied from 3.6 to 24, Cr from 44.6 to 4596, EC from 0.41 to 1.230, OC from 0.2 to 1.54 and pH from 7 to 8.3. The kurtosis values for Cr were low, however, that for Cd were high and skewness values for Cr is negative, however for EC is high. Figure 1 presents the semivariogram and fitted model for soil properties. The attributes of the semivariograms for each soil property is summarized in Table 2.

C_0 is the nugget variance; C is the structural variance, and C_0+C represents the degree of spatial variability, which is affected by both structural and stochastic factors. Nugget variance represents the experimental error and field variation within the minimum sampling spacing. The Nugget/Sill ratio can be regarded as a criterion to classify the spatial dependence of soil properties. The higher ratio

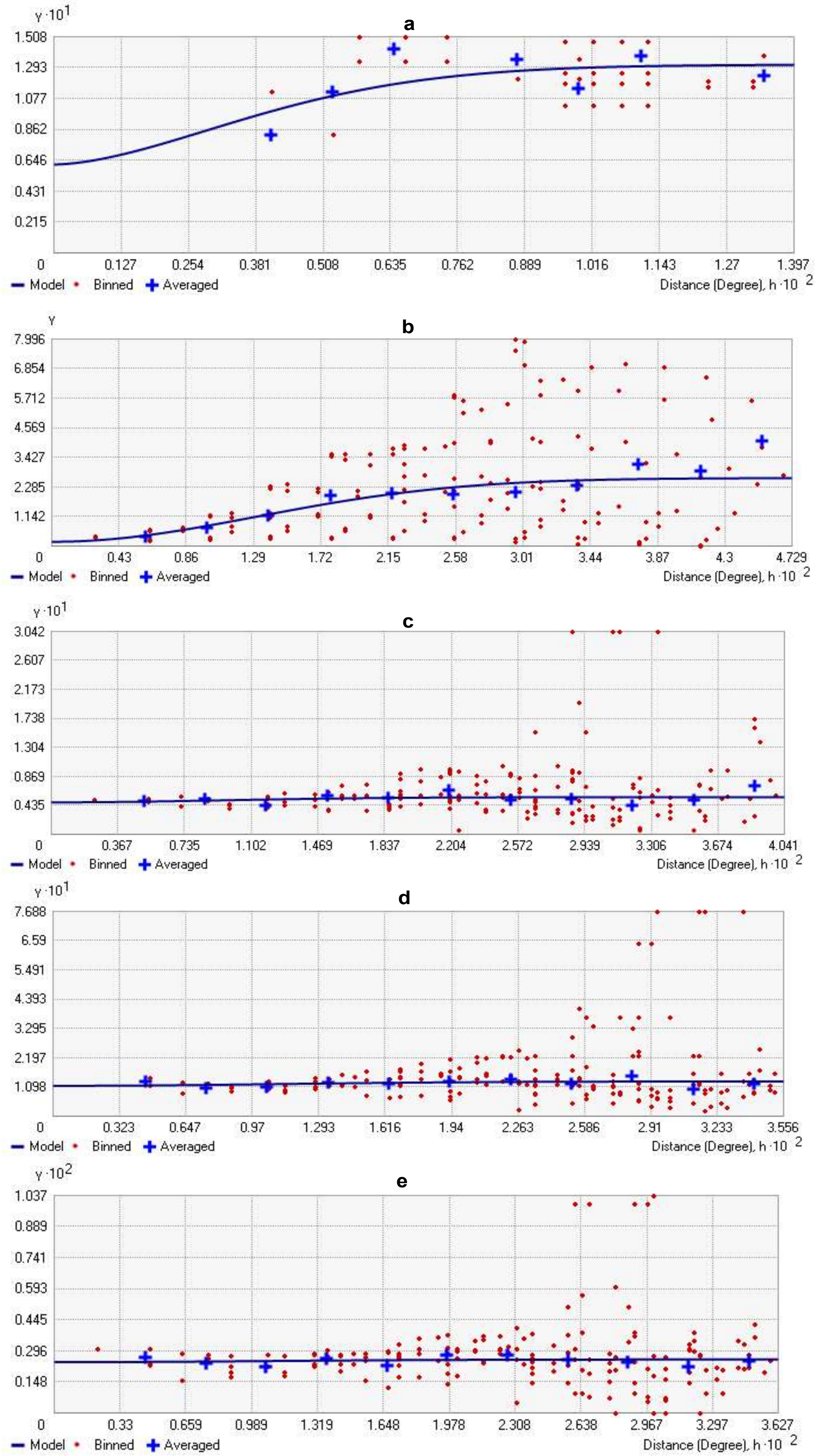

Fig. 1. Semivariogram parameters of best-fitted theoretical model to predict soil properties, a) Cd, b) Cr, c) EC, d) soil OC, and e) pH

indicates that the spatial variability is primarily caused by stochastic factors, such as fertilization, human activities etc.

The lower ratio suggests that structural factors, such as climate, parent material, topography and other natural factors, play a significant role in spatial variability. If the ratio is less than 25%, the variable has strong spatial dependence; between 25% and 75%, the variable has moderate spatial dependence; and greater than 75%, the variable shows only weak spatial dependence (Chien et al 1997, Chang et al 1998). Therefore, Spatial dependence of Cr is strong, Cd is moderate and for EC, OC and pH are weak. These results indicate that the theoretical model was an adequate representation of the spatial structural properties of soil.

Semivariograms showed that soil Cd and Cr were best fitted for spherical model, organic carbon for Gaussian and other properties of soil which are electrical conductivity and pH were best fitted for an exponential model. Figure 2 shows the spatial distribution maps of soil properties using ordinary kriging. Cadmium availability range varies with the distance from the industrial zone. Near the industrial zone Cd has concentration 16.63 ppm and away from the industrial zone its concentration decreases to 4.54 ppm. In tannery industries, the bi-products generated is rich in chromium therefore, a very high concentration is noted near industrial zone which decreases with distance.

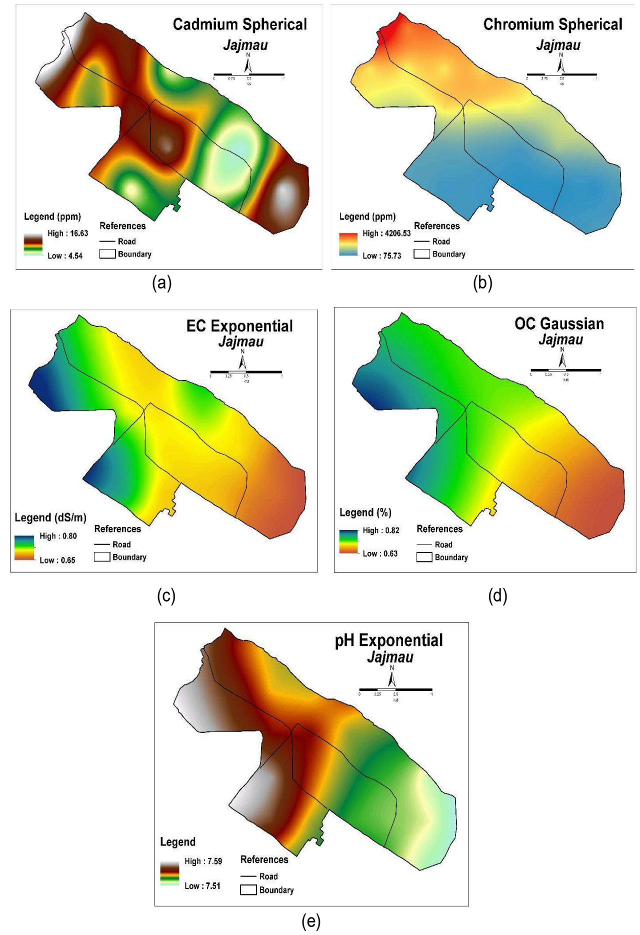

Fig. 2. Spatial distribution maps of soil properties, a) Cd, b) Cr, c) EC, d) soil OC, and e) pH

Table 1. Descriptive statistics of soil properties of industrial area

Parameters	Distribution	Minimum	Maximum	Mean	Median	Standard deviation	Skewness	Kurtosis
Cadmium (mg/kg)	Log	3.6	24	9.25	9	0.364	0.144	3.377
Chromium (mg/kg)	Log	44.6	4596	1066.8	942.2	1.242	-0.336	1.874
EC (dS/m)	None	0.41	1.230	0.719	0.620	0.231	0.738	2.446
OC (%)	None	0.2	1.54	0.722	0.73	0.352	0.663	2.725
pH (1:2.5)	Log	7.0	8.3	7.56	7.5	0.050	0.353	1.902

Table 2. Geo-Statistical parameters of the fitted semivariogram models for soil properties

Soil properties	Semivariogram model	Range (m)	Nugget (C_0)	Partial sill (C)	C_0+C	NS ratio	Spatial dependence
Cadmium (mg/kg)	Spherical	0.0091	0.0378	0.0922	0.13	0.290	Moderate
Chromium (mg/kg)	Spherical	0.0472	0.00	2.8431	2.8431	0.00	Strong
EC (dS/m)	Exponential	0.3459	0.0457	0.0108	0.0565	0.808	Weak
OC (%)	Gaussian	0.0264	0.1144	0.0165	0.1309	0.87	Weak
pH (1:2.5)	Exponential	0.0362	0.0024	0.0001	0.0025	0.96	Weak

CONCLUSION

The spatial variability of soil properties in tannery industrial zone is very important for environmental monitoring and planning remediation measures in this region. The spherical model was best fitted for cadmium and chromium, exponential for EC and pH and gaussian for soil organic carbon for prediction. Spatial variability maps of soil properties were prepared with best models using ArcGIS software. Future studies is required to analysis the environmental and human risk due to presence of high concentration of soil heavy metals.

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Validation of Derived Groundwater Potential Zones Using Well Yield Data through Agreement Scheme Approach with Geoinformatics in Ken River Basin

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***Abstract*:** This study focused on validation of derived groundwater potential zones (GPZ) map from well yield data using the Agreement Scheme approach in Ken River Basin with the help of geoinformatics. Total 100 random points were generated over the classified GPZ map of the study area. Information regarding different groundwater potential zones were extracted for each random point. Then, theses points were imported in to Bhujal-Bhuvan Portal of ISRO. In this portal, the “Ground Water Prospects” map represents different well depth and well yield ranges, which is developed by Rajiv Gandhi National Drinking Water Mission Project with collaboration of CGWB and NRSC, Hyderabad. In order to validate the groundwater potential zones map, the well yield data was classified into five classes namely, Very Poor (< 50 LPM), Poor (50-100 LPM), Moderate (100-200 LPM), Good (200-400 LPM), and Very Good (> 400 LPM). After that, 100 random points were superimposed over the Ground Water Prospects map and extracted well yield data. The accuracy of the GPZ was cross-validated with the well yield data using agreement scheme. The overall validation accuracy was about 84%, which shows a very good correlation between groundwater potential zones and the well yield. It proves that the applied approach provided significant reliable outcomes for the present study, allowing decision makers to create an effective plan.

***Keywords*:** Groundwater, Well yield, Validation, Ken River Basin, Geoinformatics

In present scenario of water crisis in the country and changing climate conditions, the groundwater resource management is essential for food, water security, and economic growth. Groundwater, a precious yet hidden resource, remains elusive to direct detection, making its mapping a daunting task. However, with increasing demand for water and depleting surface water resources, it is imperative to explore this underground natural resource. The Ken Basin's geological conditions are known to be highly variable, and as such, mapping the potential of its groundwater resources has posed a complex and challenging task that remains largely unexplored. An advanced remote sensing technique combined with GIS is proving to be a powerful tool for identifying and mapping groundwater potential zones in time and cost-effective manner (Chouhan et al 2014, Patle et al 2022).

Validation of the resulted data is one of the most important works after making any model to check the proficiency of the predicted results. Various methods are extensively used to validate groundwater potential zones maps such as receiver operating characteristics (ROC) approach, groundwater well yield data, net availability of groundwater and groundwater level fluctuation data etc. (Basavarajappa et al 2016, Arulbalaji et al 2019, Elubid et al 2020, Sajil et al 2022, Mahato et al 2022). Several studies have been conducted to validate the groundwater potential areas by implementing different statistical approaches in a GIS environment (Sharma et al 2012, Gajbhiye et al 2015, Patil et al 2017). Pradeep and Gopal (2022) studied in Mewat district of Haryana, to validate the groundwater potential zones using water level of test wells during pre-monsoon of 2019, and documented the satisfactory results. Validation of the result/ product shows the significance of the study and its practicability. To validate any model/ predicated result, the availability of field data is a challenging task. Hence, an attempt has been made in this study to validate the derived groundwater potential zones map through geoinformatics techniques in Ken Basin by using Agreement Scheme approach.

MATERIAL AND METHODS

Study area: The Ken River is one of the major rivers of the Bundelkhand region of central India. It originates from the Ahirgawan village in Katni district (MP) and confluence with the Yamuna River at Chilla village, Banda district (UP). Ken River travels a total distance of 427 km. Ken River Basin lies between 23°07'-25°51' N latitudes and 78°30'-80°38' E longitudes. Total geographical area of the Ken River basin is about 28,671 km^2, out of which 86.73% of this area lies in MP and 13.27% in UP. The basin covers a total of eleven districts, out of which eight districts from Madhya Pradesh (Katni, Sagar, Damoh, Chhatarpur, Panna, Satna, Narsinghpur, Raisen) of Madhya Pradesh and three districts of Uttar Pradesh (Hamirpur, Mahoba, and Banda). The location map of the study area was given in Figure 1.

The Ken Basin is a part of the Yamuna Basin (Lower Ganga Basin), is varied in its geological setting. The following types of hydro-geological formations are found in the Ken Basin: Alluvium supergroup (newer/ younger and older alluvium), Bundelkhand Granite-Gneiss supergroup (Bundelkhand granite and gneiss), Dharwar supergroup (Bijawar), Deccan supergroup (Malwa, Lameta and Laterite), and Vindhyan supergroup (Bhander, Kaimur, Rewa, and Semri). The northern portion of the basin was covered by the alluvium geologic group, southern eastern portion covered by bhander group, and, the southern western part covered by malwa group. In Ken River Basin, Alluvium group depicted in Banda, Hamirpur and Mahoba districts of Uttar Pradesh, having more than 2000 lpm aquifer yield. The Bhander and Laterite group consists 900-1250 lpm, Bijawar and Rewa groups refers 700-900 lpm, Malwa and Semri group states 400-600 and, Bundelkhand Granitoid Complex and Lameta group ranges less than 200 lpm aquifer yield. The hydraulic conductivity varies from 5-15 m/d. Similarly, specific yield is generally in the range of 5 to 15%. The wells are recorded to be generally up to 25 to 30 m in depth with water levels in the lean part of the year exceeding 10 m bgl.

Methodology: The Groundwater Potential Zones (GPZ) map of Ken River Basin was developed by integration of different nine thematic layers like geology, geomorphology, lineament density, land use/ land cover, soil texture, slope, drainage density, and rainfall through AHP (Analytical Hierarchical Process) which is widely used as a multi-criterion decision making approach. In this study, validation of the groundwater potential zones map of Ken River Basin was done through the "Ground Water Prospect Study" map available on Bhujal-Bhuvan portal (https://bhuvan-app1.nrsc.gov.in/gwis/gwis.php) which provides the spatial information on well yield. This geospatial platform was developed by the CGWB and NRSC under the Rajiv Gandhi National Drinking Water Mission Project. In the Agreement Scheme Approach (Patle 2022), random points (at least 100) generated over the Groundwater Potential Zones map of the Ken River Basin using ArcGIS 10.8 software (Fig. 2).

The information of different zones from the GPZ was extracted for each random point. Then, all the points (vector format file) were converted into km layer file so that it can be open in Bhujal-Bhuvan portal appropriately. All the random points were imported in Bhujal-Bhuvan portal (Fig. 3).

In Bhujal-Bhuvan portal, Madhya Pradesh selected in state option and checked the 'Ground Water Prospect' option.

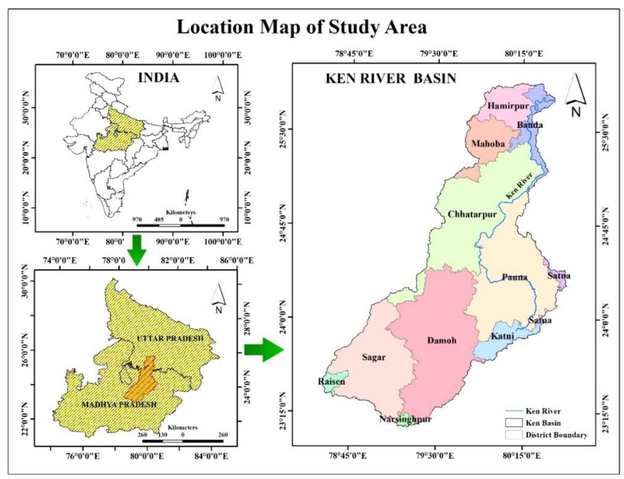

Fig. 1. Location of Ken River Basin

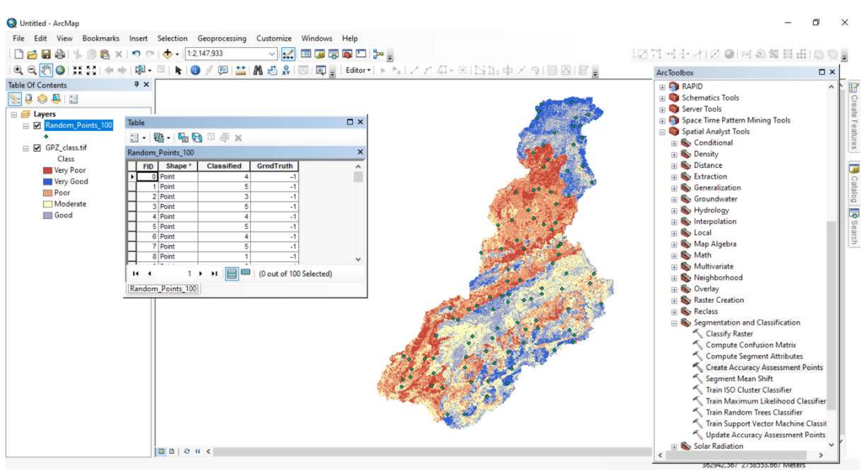

Fig. 2. Random point generation

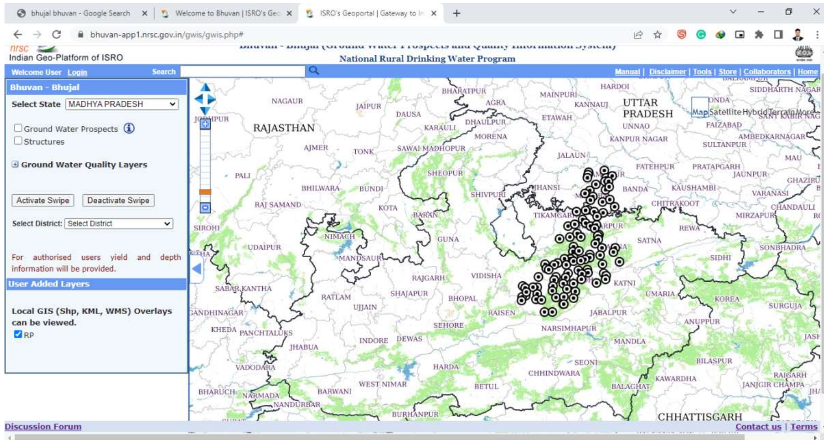

Fig. 3. Imported random points in Bhujal-Bhuvan Portal

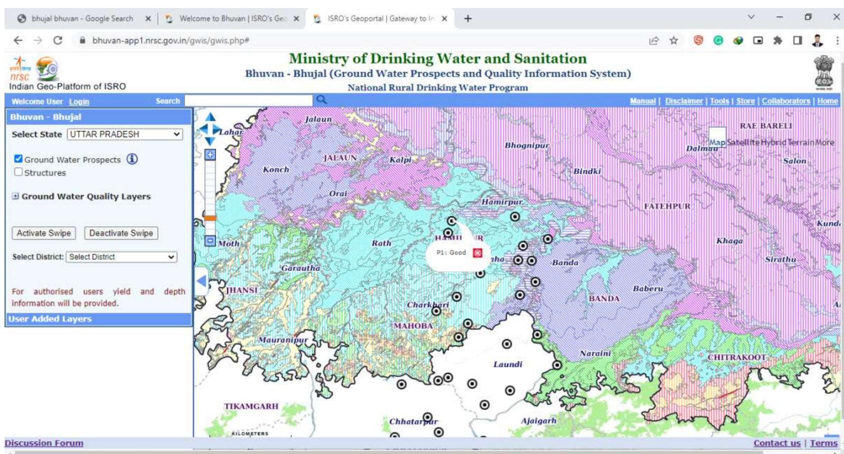

Fig. 4. Information extraction from the map

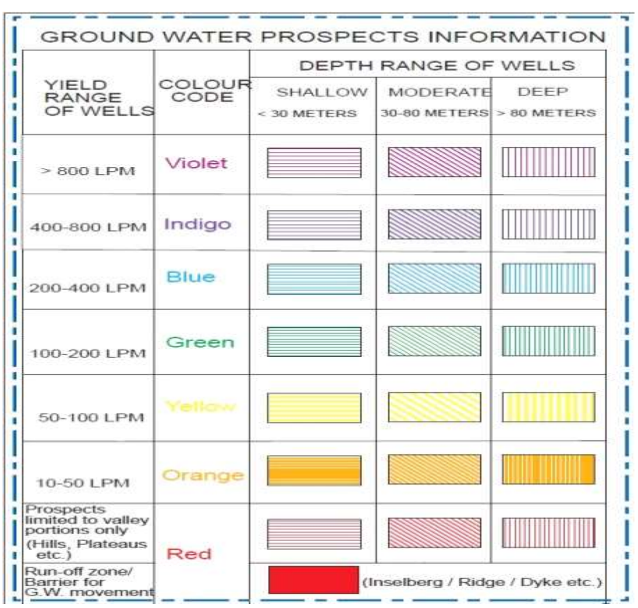

Fig. 5. Colour coding given in user manual of groundwater prospect

Afterward, clicked on each point and zoom-in it. Then, identified the *colour* code and *lining* pattern of existing polygon (Fig. 4). Classification of well yield ranges was given in the User manual of "Groundwater Prospect Mapping" (NRSA, 2011) (Fig. 5). The available yield ranges of well are classified into six classes from 10-50 LPM to > 800 LPM. These ranges of well yield are regrouped into five categories from < 50 LPM to > 400 LPM. The well yield ranges extracted for all the random points, by clicking on each point manually using zoom-in & zoom-out option in Bhujal-Bhuvan portal. This information was obtained based on colour code and lining pattern of existing polygon below the particular point. Both the data, well yield classes and GPZ classes were categorized into five categories like very good to very poor (Table 1).

The Random Points containing info of GPZ class was compared with the Well Yield ranges and prepared a table having point no., longitude, latitude, GPZ, yield, and agreements. Overall accuracy was estimated based on "agree condition (agree, agree-less, and agree-excess)" and

Table 1. Classification of well yield

Yield range of wells	Class
> 400 LPM	Very good
200 - 400 LPM	Good
100 - 200 LPM	Moderate
50 - 100 LPM	Poor
< 50 LPM	Very poor

"disagree" statement between well yield class and GPZ classes.

Accuracy (%) = No. of points in agree condition / total no. of points x 100

The validation accuracy can be classified into the following categories: 0.5 - 0.6 (poor) 0.6 - 0.7 (average); 0.7 - 0.8 (good); 0.8 - 0.9 (very good); and 0.9 – 1.0 (excellent) (Hosmer and Lemeshow 2000).

RESULTS AND DISCUSSION

The Groundwater Potential Zones (GPZ) map of Ken River Basin was derived through the Analytical Hierarchical Process (AHP) by integration of nine thematic parameters in GIS environment. The major portion (55%) of the study area is covered with gentle slope to moderate slope which reflects good to moderate groundwater potential. The Bhander geology group (45%) is dominated and represents poor potential because of sandstone and shale rocks with low aquifer yield. The pediment pediplain complex (58%) geomorphological unit is dominated in the study area which indicates moderate potential for groundwater. The loamy soil (48%) and clayey soil (47%) were majorly found in Ken Basin which depicts moderate to poor groundwater prospective due to infiltration and percolation properties. A major part of the basin was found about 24.85% in good groundwater potential zones (Fig. 6). The moderate and poor zones also contribute almost an equal share of the basin which is 23.32 and 23.03% respectively. The very poor zones also contribute 18.30% area of the basin. Least area found in the very good potential zones which is about 10.50%. However, this study seeks to break new ground by utilizing advanced remote sensing and GIS techniques to identify and demarcate varying groundwater potential areas within the Ken River Basin in India. It is providing valuable insights into the region's water resources and paving the way for more informed management and conservation efforts.

The main purpose of the study was to provide a scientific systematic manner to validate the groundwater potential zones map. The appropriate dataset for validation of groundwater potential zones map is well yield of an area. The Bhujal-Bhuvan portal provides easy access to get spatial information on well yield. In Agreement Scheme approach, cross validation between GPZ classes and well yield ranges were done based on statements given in Table 2. Groundwater potential zones was verified with well yield data which shown in below given Table 3. In this method of validation, results also revealed that numbers and percentage of points (with concerning yield ranges) are correctly classified in all the zones of groundwater potential over the entire area. Numbers of random points were identified in different zones of groundwater potential map with different agreements represented in Table 4.

The 45% of points were classifed under the agreement condition and only 16% of points found in disagreement category (Fig. 7). Rest of the points found under the

Table 2. Agreement for cross validation between GPZ classes and well yield ranges

Well yield class	GPZ Class	Agreement	Well yield class	GPZ Class	Agreement
Very good	Very good	Agree	Moderate	Poor	Agree - Less
Very good	Good	Agree - Less	Moderate	Very poor	Disagree
Very good	Moderate	Disagree	Poor	Very good	Disagree
Very good	Poor	Disagree	Poor	Good	Disagree
Very good	Very poor	Disagree	Poor	Moderate	Agree - Excess
Good	Very good	Agree - Excess	Poor	Poor	Agree
Good	Good	Agree	Poor	Very poor	Agree - Less
Good	Moderate	Agree - Less	Very poor	Very good	Disagree
Good	Poor	Disagree	Very poor	Good	Disagree
Good	Very poor	Disagree	Very poor	Moderate	Disagree
Moderate	Very good	Disagree	Very poor	Poor	Agree - Excess
Moderate	Good	Agree - Excess	Very poor	Very poor	Agree
Moderate	Moderate	Agree			

Table 3. Comparison analysis of derived GPZ map and actual well yield data

Random point/ validation point	Longitude	Latitude	Well yield (LPM)	Well yield class	GPZ class	Agreement
1	80.297	25.838	100 - 200	Moderate	Good	Agree - Excess
2	79.954	25.822	100 - 200	Moderate	Very Good	Disagree
3	80.151	25.815	50 - 100	Poor	Moderate	Agree - Excess
4	80.208	25.807	200 - 400	Good	Moderate	Agree - Excess
5	79.903	25.798	50 - 100	Poor	Moderate	Agree - Excess
6	80.300	25.787	< 50	Very Poor	Poor	Agree - Less
7	80.286	25.766	< 50	Very Poor	Moderate	Disagree
8	80.089	25.755	50 - 100	Poor	Moderate	Agree - Excess
9	80.335	25.744	100 - 200	Moderate	Moderate	Agree
10	79.923	25.724	> 400	Very Good	Good	Agree - Less
11	79.972	25.713	100 - 200	Moderate	Poor	Agree - Less
12	80.380	25.703	50 - 100	Poor	Poor	Agree
13	80.460	25.701	> 400	Very Good	Good	Agree - Less
14	79.865	25.675	200 - 400	Good	Moderate	Agree - Excess
15	80.111	25.674	> 400	Very Good	Very Good	Agree
16	80.253	25.669	200 - 400	Good	Poor	Disagree
17	79.965	25.665	50 - 100	Poor	Moderate	Agree - Excess
18	80.332	25.645	> 400	Very Good	Moderate	Disagree
19	80.165	25.639	50 - 100	Poor	Moderate	Agree - Excess
20	79.836	25.631	100 - 200	Moderate	Good	Agree - Excess
21	79.934	25.594	200 - 400	Good	Moderate	Agree - Less
22	79.764	25.587	50 - 100	Poor	Good	Disagree
23	79.751	25.579	50 - 100	Poor	Moderate	Agree - Excess
24	79.917	25.542	200 - 400	Good	Good	Agree
25	80.301	25.532	200 - 400	Good	Moderate	Agree - Less
26	79.880	25.525	200 - 400	Good	Moderate	Agree - Less
27	79.755	25.491	> 400	Very Good	Good	Agree - Less
28	79.951	25.464	< 50	Very Poor	Very Poor	Agree
29	79.762	25.456	100 - 200	Moderate	Moderate	Agree
30	80.212	25.454	< 50	Very Poor	Moderate	Disagree
31	80.208	25.387	50 - 100	Poor	Moderate	Agree - Excess
32	79.946	25.362	50 - 100	Poor	Poor	Agree
33	80.108	25.361	< 50	Very Poor	Very Poor	Agree
34	79.762	25.355	< 50	Very Poor	Very Poor	Agree
35	79.907	25.350	50 - 100	Poor	Very Poor	Agree - Less
36	80.375	25.344	200 - 400	Good	Good	Agree
37	79.927	25.327	< 50	Very Poor	Very Poor	Agree
38	80.390	25.311	100 - 200	Moderate	Moderate	Agree
39	79.807	25.305	100 - 200	Moderate	Poor	Agree - Less
40	79.807	25.305	100 - 200	Moderate	Poor	Agree - Less
41	80.408	25.285	> 400	Very Good	Very Good	Agree
42	80.431	25.259	> 400	Very good	Very good	Agree
43	80.439	25.251	> 400	Very good	Very good	Agree
44	79.964	25.244	< 50	Very poor	Very poor	Agree

Cont...

Table 3. Comparison analysis of derived GPZ map and actual well yield data

Random point/ validation point	Longitude	Latitude	Well yield (LPM)	Well yield class	GPZ class	Agreement
45	79.905	25.233	< 50	Very poor	Very poor	Agree
46	80.293	25.233	< 50	Very poor	Moderate	Disagree
47	80.426	25.231	200 - 400	Good	Good	Agree
48	80.047	25.226	< 50	Very poor	Very poor	Agree
49	80.454	25.209	100 - 200	Moderate	Moderate	Agree
50	80.054	25.194	< 50	Very poor	Very poor	Agree
51	79.879	25.133	< 50	Very poor	Ver poor	Agree
52	79.942	25.104	100 - 200	Moderate	Poor	Agree
53	80.188	25.074	50 - 100	Poor	Poor	Agree
54	79.697	25.051	< 50	Very poor	Poor	Agree - Less
55	80.297	25.048	> 400	Very good	Good	Agree - Less
56	79.721	24.994	50 - 100	Poor	Poor	Agree
57	79.909	24.973	200 - 400	Good	Poor	Disagree
58	80.276	24.976	100 - 200	Moderate	Very poor	Disagree
59	79.597	24.909	< 50	Very poor	Poor	Agree - Excess
60	79.520	24.908	100 - 200	Moderate	Moderate	Agree
61	80.245	24.900	100 - 200	Moderate	Poor	Agree - Less
62	79.942	24.847	100 - 200	Moderate	Poor	Agree - Less
63	79.604	24.834	100 - 200	Moderate	Poor	Agree - Less
64	79.833	24.813	50 - 100	Poor	Moderate	Agree - Excess
65	79.881	24.781	50 - 100	Poor	Very poor	Agree - Excess
66	79.963	24.779	50 - 100	Poor	Very poor	Agree - Excess
67	79.826	24.772	50 - 100	Poor	Very poor	Agree - Excess
68	79.910	24.773	200 - 400	Good	Poor	Disagree
69	79.494	24.621	50 - 100	Poor	Poor	Agree
70	80.135	24.621	< 50	Very poor	Very poor	Agree
71	79.611	24.604	200 - 400	Good	Moderate	Agree - Less
72	79.656	24.582	200 - 400	Good	Good	Agree
73	80.264	24.561	200 - 400	Good	Moderate	Agree - Less
74	80.175	24.548	100 - 200	Moderate	Moderate	Agree
75	80.084	24.513	200 - 400	Good	Moderate	Agree - Less
76	80.028	24.506	200 - 400	Good	Good	Agree
77	80.028	24.506	200 - 400	Good	Good	Agree
78	79.709	24.479	> 400	Very good	Good	Agree - Less
79	80.282	24.406	200 - 400	Good	Poor	Disagree
80	79.853	24.394	< 50	Very poor	Very poor	Agree
81	80.472	24.384	< 50	Very poor	Very poor	Agree
82	79.774	24.362	< 50	Very poor	Very poor	Agree
83	80.050	24.351	200 - 400	Good	Good	Agree
84	80.296	24.333	> 400	Very good	Very good	Agree
85	79.693	24.307	50 - 100	Poor	Very good	Disagree
86	79.648	24.287	< 50	Very poor	Poor	Agree - Less
87	80.047	24.262	100 - 200	Moderate	Poor	Agree - Less
88	79.825	24.241	200 - 400	Good	Good	Agree
89	79.660	24.224	100 - 200	Moderate	Moderate	Agree
90	79.964	24.179	100 - 200	Moderate	Moderate	Agree
91	80.304	24.174	200 - 400	Good	Good	Agree
92	79.454	24.104	50 - 100	Poor	Good	Disagree
93	79.511	24.070	< 50	Very Poor	Very Poor	Agree
94	79.640	24.062	100 - 200	Moderate	Very Good	Disagree
95	79.259	24.047	50 - 100	Poor	Poor	Agree
96	79.148	24.034	100 - 200	Moderate	Moderate	Agree
97	78.929	24.010	100 - 200	Moderate	Very Poor	Disagree
98	79.042	24.012	100 - 200	Moderate	Very Poor	Disagree
99	80.166	24.020	> 400	Very Good	Very Good	Agree
100	79.180	23.976	50 - 100	Poor	Moderate	Agree - Excess

Table 4. Validation of derived GPZ with well yield

Groundwater prospect zones / Well yield points	Very good	Good	Moderate	Poor	Very poor	Total
Number of points under agreement	6	9	9	7	14	45
Number of points under agreement with less yield	0	5	6	10	1	22
Number of points under agreement with excess yield	0	2	11	1	3	17
Number of points under disagreement	3	2	4	4	3	16
No. of points under different zones	9	18	30	22	21	100

agreement with less and excess yields about 22%, 17% respectively. Figure 7 illustrated that the well yields points with the agreement are mostly observed in entire zones of the groundwater potential zones. The overall accuracy of groundwater potential zones was found 84% which is denotes very good accuracy. One of the most important criteria for evaluating a system/ model/ approach is its validation. The validation of Groundwater Potential Zones

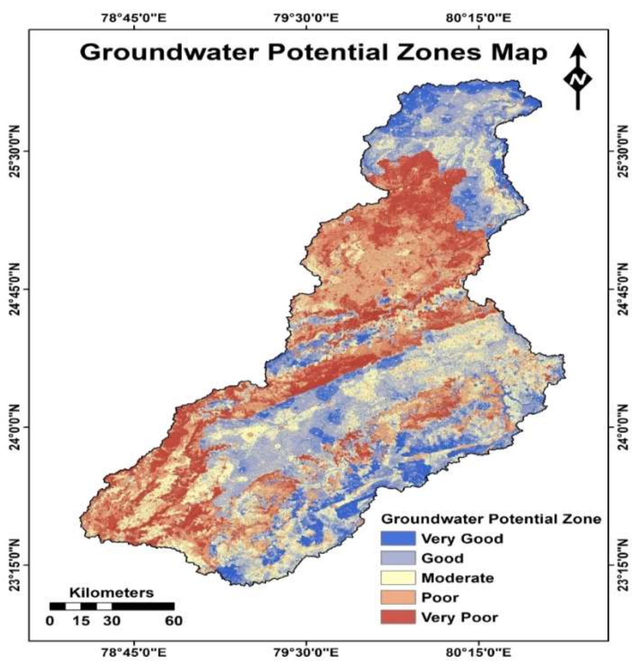

Fig. 6. Groundwater Potential Zones (GPZ) map of Ken River Basin derived by AHP

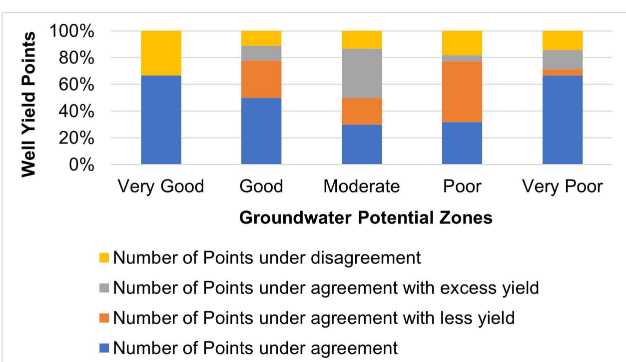

Fig. 7, GPZ with well yield

map is an essential step in defining its authenticity. An important aspect of validating GPZ maps is the availability of data. Collection of validation data such as water level (pre & post monsoon), well yield, groundwater availability, groundwater recharge, etc. on random locations is a typical task. Similarly, a few or limited samples of data using for the validation of GPZ may be causing inappropriate results. It may affect the accuracy of the groundwater potential zones map. Keeping this in mind, the validation of groundwater potential zons map was done using well yield data collected from the Bhujal-Bhuvan portal through the agreement scheme approach.

CONCLUSIONS

The main purpose of study was to provide an easy and scientific way to validate the groundwater potential zones map. Generally, the data collection for validation of GPZ is a hectic task. Many Researchers are used well yield data and groundwater level fluctuation data. These data are not freely available on village, block, and district level. These data must also be acquired from different government agencies, which is time consuming. So, the Bhujal-Bhuvan portal may be used for the validation purpose which is open access portal developed by NRSC and CGWB. In some studies, ROC (relative operating characteristics) curve method was used to validate the GPZ map using different datasets. The ROC curve plots between the true positive rates (sensitivity) and false positive rates (1-specificity). This statistical method is difficult to recognize and execute. Accuracy Scheme approach was used in this study. The data availability and the validation approach are simple, accurate, and easy to implement. This approach will be helpful to validate the different water resource management and prediction models.

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GIS Based Groundwater Quality Mapping along Banks of River Noyyal in Tiruppur District of Tamil Nadu

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Abstract: Due to the rapid economic and industrial growth in the Tiruppur district after globalization has adversely affected the quality of the environment. The major source of ground water pollution in Tiruppur is due to the domestic, agricultural and industrial activities. In this study, it has been evaluated the extend of the ground water contamination in Tiruppur district due to the Agricultural and Industrial activities. Forty sampling stations were selected along the banks of the river Noyyal on both sides in the Tiruppur district. The samples were analyzed for various physico-chemical parameters. From this study, it was found that the underground water was contaminated more at few sampling sites due to the Industrial and agricultural activities in the Tiruppur District. The sampling sites namely Samalapuram, Velayudhapalayam, Agraharapudur, Sulthanpettai, SR Nagar, MGR Nagar, Segudanthali and Vanjipalayam shows notable variation in the physio-chemical parameters. This study concludes that the groundwater quality in the entire region shows variation in the parameters for the monsoon period of July to October 2021 due to seasonal variation. Hence, it is important to take periodical monitoring of the groundwater quality in these regions for our future sustainability.

Keywords: Groundwater, Physio-chemical parameters, Correlation Matrix, GIS, Mapping

Tiruppur has become one of the country's largest hosiery manufacturing industrial cluster. This region emerged as a garment producing cluster because it is located in the cotton belt of Tamil Nadu, India. The first automatic ginning factory was established at Tiruppur in 1901 (Ajith Babu et al 2017). The post first world war era saw the mushrooming of hosiery factories in the region and it gained momentum since 1930. In textile and garment production, a large quantity of effluents is generated mainly due to the processes of dyeing and bleaching. The largest polluting industry in the Noyyal river basin are the dyeing and bleaching industries, particularly those units located in Tiruppur district. The growth of dyeing and bleaching units corresponds to the growth of export garment units. According to the most recent figures available, there are 800 dyeing and bleaching companies in Tiruppur district, involved in export-oriented garment production. The small-scale industries located at the entire river basin are in unorganized manner. These industries often dump their wastes into nearby water bodies that are assumed as dumping yards for the wastes. The cotton textile and hosiery industries are clustered more in Coimbatore, Sulur, Avinasi, Palladam, and Tiruppur. Metal and machinery product industries are higher at Coimbatore in PN Palayam and Palladam. Groundwater is the main source for all the industries located at Tiruppur district. Hence, this study was focussed to identify the groundwater quality of Noyyal River basin in Tiruppur district during the periods of July 2021 and October 2021.

MATERIAL AND METHODS

Study area: River Noyyal is considered as one of the major source of water for both domestic and agricultural activities for the districts of Coimbatore, Tiruppur, Erode and Karur. It has started its journey from the vellingiri hills of Western Ghats in the Coimbatore district and joins to Kaveri River at the place called Noyyal in Karur District. It is a Non-Perennial River which flows in the regions from Coimbatore and Karur through Tiruppur and Erode districts. In this project work, the area along the banks of the Noyyal River in the Tiruppur District is studied for the period of July 2021 and October 2021 by taking groundwater samples at forty locations along the banks of the river (Table 1).

Identification of source of wastewater: The major source of wastewater in the Tiruppur district were identified through the field survey and consists of domestic wastewater collected through sewer called sewage; industrial wastewater during the process of dyeing and bleaching process; surface runoff water from agriculture field during irrigation and rainfall period. (Babunath and John 2017, Selvakumara et al 2017).

Site selection and collection of ground water sample: The site for the collection of the groundwater sample was selected based on the distance between the two locations and distance between the site and Noyyal River. The distance between the two sampling sites are selected such that it should not exceed 2 km. (Siva Dharshini et al 2018) and the distance between the sampling site and the Noyyal River is selected such that it should not exceed 1 km, because the study area contains cluster of industrial sector. The sampling bottles for the collection of groundwater samples were made of plastic, usually polythene. The groundwater samples were collected from the open wells and bore wells along the banks of the Noyyal River in plastic bottles of 1 litre capacity after rinsing it with distilled water and with the groundwater sample before collection of samples as mentioned in the standard procedure for method of collection.

RESULTS AND DISCUSSION

Analysis of groundwater sample: During the first phase of the study the forty groundwater samples were collected and analyzed for the various physio-chemical parameters such as electrical conductivity (EC), resistivity, pH, turbidity, total dissolved solids (TDS), dissolved oxygen (DO), hardness and chlorides in the laboratory for July 2021 (Table 2).

Quality of the groundwater will be varying from season to season and from stratum to stratum. From the field investigation it is observed that all the groundwater samples collected from all the location during July 2021 is free from physical impurities such as colour and odor (Natarajan and Sekaran, 2019). The collected groundwater sample is tested for other physico-chemical parameters in the Environmental Engineering laboratory. The quality of groundwater samples were compared with the water quality standards prescribed in IS10500-2012 for drinking and IS11624-2009 for irrigation purposes (Irfan Jamila and Yousuf, 2018). The observed values of electrical conductivity (EC) of groundwater samples during July 2021 varies from minimum of 398 µS/cm at Mangalam bore well location to maximum of 9418 µS/cm at Agraharapudur bore well location. The acceptable limit of electrical conductivity for drinking purpose is 2000 µS/cm and for irrigation purpose in semi-tolerant and tolerant crops are 8000 µS/cm and 10000 µS/cm respectively. Among 21 out of 40 groundwater samples were exceeding the acceptable limit of electrical conductivity for drinking purpose and all the groundwater samples EC values are within the limit for irrigation purpose. The seven groundwater samples tested at Velayuthapalayam open well, Agraharapudur bore well, Bavani nagar bore well, MRG nagar bore well, Vanjipalyam bore well, Veliyampalayam bore well and Anaipalayam Pirivu has electrical conductivity more than 5000 µS/cm. The resistivity value of the groundwater sample varies between 107 Ω at Agraharapudur bore well location and maximum of 3150 Ω at Mangalam bore well location. The highest value recorded at the bore well groundwater sample located at the place Mangalam bore well.

The observed pH of groundwater samples during July 2021varied from minimum of 7.01 at Sivasakthi nagar bore well to maximum of 8.36 at Tiruppur Old bus stand open well. Anaipalayam bore well and Sivasakthi nagar bore well groundwater samples has a pH value more 8. But all the 40 groundwater samples were within the acceptable limit of 6.5-8.5 as per drinking water quality standards. The turbidity of groundwater samples during July 2021 varies from minimum of 1.10 NTU at Vijayapuram bore well to maximum of 4.25 NTU at Kavilpalayam bore well. The groundwater samples collected at Bavani nagar bore well, Kavilpalayam bore well, Kurukkapalayam bore well and Semmandampalayam bore well have the turbidity values of more than 4 NTU even though all the samples were within the permissible limit of 5 NTU. The total dissolved solids of the ground water samples during July 2021 varied between minimum of 150 mg/L at Mangalam bore well and maximum at 4767 mg/L Agraharapudur bore well location. From the groundwater quality analysis study the TDS values at 11 different sampling locations such as Samalapuram bore well, Velayuthapalayam open well, Agraharapudur bore well, Sulthanpettai open well, Parmasivampalayam bore well, Bavani nagar bore well, MRG nagar bore well, Sirupooluvapatti bore well, Kavilpalayam bore well, Veliyampalayam bore well and Anaipalayam Pirivu bore well exceeded the permissible limit of 2000 mg/L. The dissolved oxygen of the groundwater samples during July 2021 varied between 0.9 mg/L and 3.10 mg/L, but all the samples are below the acceptable limit of 4 mg/L.

The hardness of the ground water sample during July 2021 varied between 275 mg/L at Mangalam bore well and 2350 mg/L at Agraharapudur bore well. From the water quality analysis study, the groundwater samples at 24 out of 40 locations exceeded the permissible limits of 600 mg/L. The eight locations such as Samalapuram bore well, Velayuthapalayam open well, Agraharapudur bore well, Bavani nagar bore well, MRG nagar bore well, Vanjipalyam bore well, Veliyampalayam bore well and Anaipalayam Pirivu bore well has shown the hardness values of more than 1000 mg/L. The chloride values of the groundwater sample during July 2021 varies between 223 mg/L at Semmandampalayam bore well location and 3613 mg/L at Agraharapudur bore well location. The Chlorides at 15 different locations such as Samalapuram bore well, Velayuthapalayam open well, Agraharapudur bore well, Sulthanpettai open well, Kozhipannai open well, Mundalipalayam bore well, Parmasivampalayam bore well, Bavani nagar bore well, VSA nagar bore well, MRG nagar bore well, Sirupooluvapatti bore well, Pudur bore well, Segudanthali bore well, ACS modern City bore well and Veliyampalayam bore well has exceeded the permissible limit of 1000 mg/L. In order to identify the

Table 1. Locations of wells along the banks of river Noyyal in Tiruppur District

Sample No.	Sampling location	Type of well	Latitude	Longitude
1	Samalapuram	Bore well	11° 4' 23.27"N	77° 11'40.31" E
2	Pallapalayam	Bore well	11° 4' 57.47"N	77° 12'27.69" E
3	Velayuthapalayam	Open Well	11° 5' 33.68"N	77° 14'02.87" E
4	Agraharapudur	Bore well	11° 06' 05.8"N	77° 15'01.10" E
5	Mangalam	Bore well	11° 6' 07.06"N	77° 16'07.46" E
6	Sulthanpettai	Open Well	11° 6' 05.47"N	77° 16'49.26" E
7	Koluthupudhur	Open Well	11° 6' 05.47"N	77° 17'45.56" E
8	Kozhipannai	Open Well	11° 5' 57.34"N	77° 18'15.77"E
9	Karuvampalayam	Bore well	11° 5' 45.42"N	77° 20'18.78"E
10	Old bus stand	Open Well	11° 6' 12.17"N	77° 21'01.87" E
11	Renukanagar	Bore well	11° 6' 24.12"N	77° 21'57.64" E
12	Mundalipalayam	Bore well	11° 7' 15.1"N	77° 24'25.27" E
13	Kavin garden	Bore well	11° 5' 23.68"N	77° 25'45.55"E
14	Parmasivam palayam	Bore well	11° 5' 19.68"N	77° 13'33.96" E
15	Chinnaputhur	Bore well	11° 4' 22.08"N	78° 8'58.56" E
16	SR nagar	Bore well	11° 5' 33.72"N	77° 19'21.72" E
17	Bavani nagar	Bore well	11° 6' 17.64"N	77° 21'43.56" E
18	Vijayapuram	Bore well	11° 5' 19.68"N	77° 24'24.12" E
19	VSA nagar	Bore well	11° 6' 45.36"N	77° 22'44.04" E
20	MRG nagar	Bore well	11° 6' 30.6"N	77° 20'29.76" E
21	Kathankanni	Bore well	11° 6' 36.83"N	77° 28'40.62" E
22	Tamma Reddy palayam	Bore well	11° 5' 38.54"N	77° 30'30.13" E
23	Savadipalayam	Bore well	11° 5' 27.71"N	77° 31'13.22" E
24	Rayapuram	Bore well	11° 6' 12.92"N	77° 19'50.88" E
25	Thiru VK nagar	Bore well	11° 6' 31.68"N	77° 19'34.68" E
26	Sirupooluvapatti	Bore well	11° 6' 44.5"N	77° 18'16.92" E
27	Kavilpalayam	Bore well	11° 7' 04.94"N	77° 18'00.32" E
28	Kurukkapalayam	Bore well	11° 7' 07" N	77° 14'55.82" E
29	Semmandampalayam	Bore well	11° 6' 29.74"N	77° 13'22.3" E
30	Segudanthali	Bore well	11° 6' 25.63"N	77° 12'28.76" E
31	Pudur	Bore well	11° 6' 41.08"N	77° 14'22.09"E
32	Vanjipalyam	Bore well	11° 6' 59.51"N	77° 16'34.57" E
33	Annapalayam	Bore well	11° 6' 31.75"N	77° 18'44.32" E
34	Sivasakthi nagar	Bore well	11° 6' 52.24"N	77° 22'25.75" E
35	Kolathupalayam	Bore well	11° 7' 26.94"N	77° 23'09.78" E
36	ACS modern City	Bore well	11° 8' 04.27"N	77° 24'40.68" E
37	Veliyampalayam	Bore well	11° 8' 31.34"N	77° 24'04.73" E
38	Jeravampalayam	Bore well	11° 8' 14.35"N	77° 26'03.26" E
39	Anaipalayam	Bore well	11° 7' 49.33"N	77° 27'14.83" E
40	Anaipalayam Pirivu	Bore well	11° 7' 05.23"N	77° 27'39.2" E

Table 2. Physico-chemical parameters of the ground water samples during July 2021

EC (μS/cm)	Resistivity (Ω)	pH	Turbidity (NTU)	TDS (ppm)	DO (ppm)	Hardness (ppm)	Cl (ppm)
4280	233	7.93	2.1	2138	1.1	1050	1650
955	1050	7.24	2.2	478	1.2	300	425
5118	193	7.93	3.6	2600	2.5	1050	1900
9418	107	7.18	1.9	4767	2.5	2350	3613
398	3150	7.83	1.7	150	1.5	275	308
4127	243	7.48	1.9	2053	1.3	900	1518
1037	965	7.37	2.5	518	1.3	375	318
2924	417	7.21	2.7	1207	1.4	750	1020
1236	1590	7.33	2	317	2.6	300	350
1404	1692	8.36	3.5	276	1.7	325	258
1343	748	7.41	2.1	665	2.5	350	335
3254	501	7.08	2.8	1001	0.9	825	1250
1029	1360	7.11	2.7	366	2.7	300	358
4097	221	7.42	2.7	2106	1.5	900	1520
1697	1269	7.81	3.1	384	1.9	475	373
2369	721	7.05	3.6	702	3	600	380
5243	183	7.62	4.1	2598	1.6	1025	2105
4108	236	7.43	1.1	1994	1.5	850	815
2411	409	7.23	1.9	1198	0.9	750	1023
5298	169	7.18	1.9	2698	1.7	1050	1923
1249	1002	7.21	2.2	598	1.2	350	318
1665	1261	7.49	2.5	376	0.9	475	293
1896	1377	7.4	2.8	387	1.8	450	613
3215	498	7.39	1.8	997	2	825	625
1726	598	7.63	1.9	867	1.8	600	463
3002	179	7.82	1.3	2883	1.9	725	1025
3319	164	7.1	4.5	2902	2	775	805
2042	735	7.21	4.2	382	2.4	550	420
1456	706	7.29	4	796	2.2	650	223
1794	1260	7.22	1.2	395	1.8	900	255
3826	262	7.41	1.5	1922	1.4	750	1590
5197	943	7.07	1.6	1040	2	1600	383
1896	715	7.82	1.8	699	2.7	625	428
738	1350	7.01	1.9	372	3.1	500	285
1067	955	7.54	2.8	527.4	0.9	750	378
3175	327	7.4	2.9	1570	1.4	750	1115
5418	183	7.32	2.8	2763	1.6	1475	1863
1375	728	7.09	3.4	687	1.2	325	330
1720	584	8.01	3.4	855	2.4	625	703
5715	174	7.69	2.9	2895	1.3	1225	1940

variations of water quality parameters and to check the consistency of groundwater quality parameters at the above 40 locations the repeated sampling was done in October 2021 and was tested for the above parameters (Table 3).

Table 3. Physico-chemical parameters of the groundwater samples during October 2021

EC (μS/cm)	Resistivity (Ω)	pH	Turbidity (NTU)	TDS (ppm)	DO (ppm)	Hardness (ppm)	Cl (ppm)
4386	226	8.01	2.2	2198	1.2	1125	1775
1214	694	7.21	2.2	608	1.3	350	600
5263	186	7.82	3.5	2677	2.2	1100	1993
9718	103	7.68	1.8	4910	2.8	2425	3635
428	2868	7.79	1.9	169	1.3	325	325
1118	890	7.52	2.1	2155	1.1	925	1675
1089	912	7.87	2.6	546	1.6	400	438
3028	405	7.45	2.7	1250	1.5	775	1268
1489	1312	7.27	2.2	382	1.9	350	425
1629	1458	8.45	3.6	320	1.8	375	293
1539	653	7.49	2.4	762	2.6	400	378
3459	481	7.18	2.9	1064	1.2	850	1478
1038	1345	7.22	2.8	369	2.4	300	380
4179	217	7.35	2.6	2148	1.8	900	1595
1630	1269	7.76	3	384	2	475	395
2466	689	7.01	3.8	740	3.2	600	413
5324	179	7.9	4	2644	1.1	1030	2213
4201	232	7.35	1.7	2046	1.3	856	878
2426	409	7.48	1.5	1206	1.1	754	1083
5309	188	7.15	1.8	2705	1.5	1052	2015
1605	784	7.29	2.2	780	1.5	450	335
1927	1102	7.58	2.6	455	1.2	550	308
2001	1319	7.31	2.4	412	1.5	475	648
3409	459	7.59	1.9	1079	1.9	875	680
1726	608	7.61	1.9	889	1.9	600	450
3209	169	7.92	1.5	3089	2	775	1080
3640	142	7.05	4	3183	2.5	850	815
2093	1369	7.34	4.1	384	2.2	600	445
1521	712	7.39	4.1	833	1.9	675	248
1901	1159	7.18	1.9	426	1.9	975	260
3899	245	7.49	2.1	1802	1.2	800	1540
5365	924	7.11	2.2	1040	2.4	1650	398
1987	701	7.9	1.9	732	2.9	700	450
812	1317	7.19	2.2	391	3.2	550	303
1124	916	7.51	2.1	561	1.2	775	395
3259	367	7.39	1.9	1620	1.5	725	1095
5591	162	7.34	1.6	2805	1.9	1425	1998
1459	701	7.06	2.8	718	1.3	400	390
1755	542	7.94	3.5	877	2.5	650	760
5824	153	7.75	3.6	2946	1.6	1300	1993

The observed values of electrical conductivity (EC) of groundwater samples during October 2021 varied from minimum of 428 µS/cm at Mangalam bore well location to maximum of 9718 µS/cm at Agraharapudur bore well location. During this period also 21 out of 40 groundwater samples were exceeding the acceptable limit of electrical conductivity for drinking purpose but all the groundwater samples EC values were within the limit for irrigation purpose. The seven groundwater samples tested at Velayuthapalayam open well, Agraharapudur bore well, Bavani nagar bore well, MRG nagar bore well, Vanjipalyam bore well, Veliyampalayam bore well and Anaipalayam Pirivu has electrical conductivity values more than 5000 µS/cm and have moderate variation during October 2021. The resistivity value of the groundwater sample during October 2021 varied between 103 Ω at Agraharapudur bore well location and maximum of 2868 Ω at Mangalam bore well location. The highest value also recorded at the bore well groundwater sample located at the place Mangalam.

The observed values of pH of groundwater samples during October 2021 varied from minimum of 7.01 at S R nagar bore well to maximum of 8.45 at Tiruppur Old bus stand open well. Samalapuram bore well and Tiruppur old bus stand open well groundwater sample has a pH value more than 8. But all the 40 groundwater samples were within the acceptable limit of 6.5-8.5 as per drinking water quality standards. The turbidity value of groundwater samples during October 2021 varied from minimum of 1.5 NTU at two locations VSA nagar bore well and Sirupooluvapatti bore well to maximum of 4.1 NTU at Kurukkapalayam bore well and Semmandampalayam bore well and all the samples were within the limit of 5 NTU.

The total dissolved solids of the ground water samples during October 2021 varied between minimum of 169 mg/L at Mangalam bore well and maximum at 4910 mg/L at Agraharapudur bore well location. During this period also the TDS values at 11 different sampling locations such as Samalapuram bore well, Velayuthapalayam open well, Agraharapudur bore well, Sulthanpettai open well, Parmasivam palayam bore well, Bavani nagar bore well, MRG nagar bore well, Sirupooluvapatti bore well, Kavilpalayam bore well, Veliyampalayam bore well and Anaipalayam Pirivu bore well exceeded the permissible limit of 2000 mg/L. The dissolved oxygen of the groundwater samples during October 2021 varied between 1.1 and 3.2 mg/L, and all the samples were below the acceptable limit of 4 mg/L.

The hardness of the ground water sample during October 2021 varies between 325 mg/L at Mangalam bore well and 2425 mg/L at Agraharapudur bore well. During this period also the groundwater samples at 24 out of 40 locations exceeded the permissible limits of 600 mg/L. The same eight locations such as Samalapuram bore well, Velayuthapalayam open well, Agraharapudur bore well, Bavani nagar bore well, MRG nagar bore well, Vanjipalyam bore well, Veliyampalayam bore well and Anaipalayam Pirivu bore well have shown the hardness values of more than 1000 mg/L. The chloride values of the groundwater sample during October 2021 varies between 248 mg/L at Semmandampalayam bore well location and 3635 mg/L at Agraharapudur bore well location. During this periods also the values of chlorides at 15 different locations such as Samalapuram bore well, Velayuthapalayam open well, Agraharapudur bore well, Sulthanpettai open well, Kozhipannai open well, Mundalipalayam bore well, Parmasivampalayam bore well, Bavani nagar bore well, VSA nagar bore well, MRG nagar bore well, Sirupooluvapatti bore well, Pudur bore well, Segudanthali bore well, ACS modern City bore well and Veliyampalayam bore well have exceeded the permissible limit of 1000 mg/. But for continuous monitoring of water quality parameters the groundwater sampling and testing are to be done in all the observed locations at various seasons. The monitoring of groundwater quality sample will be helpful in

Table 4. Pearson correlation matrix among the groundwater quality parameters

Parameters	pH	Electrical conductivity	Resistivity	Turbidity	Total dissolved solids	Dissolved oxygen	Hardness	Chlorides
pH	1							
EC	-0.0632	1						
Resistivity	-0.1341	-0.6276	1					
Turbidity	0.0632	-0.0547	-0.0707	1				
TDS	-0.0316	0.8966	-0.7368	-0.001	1			
DO	-0.0948	-0.0025	-0.0836	-0.184	-0.001	1		
Hardness	-0.0447	0.9203	-0.5576	-0.155	0.7918	0.0447	1	
Chlorides	-0.1095	0.8966	-0.6387	-0.045	0.8848	-0.118	-0.798	1

identification of the exact variation of groundwater quality at different seasons (Kumar and Balamurugan 2018) as well as to identify the consistency of records.

Formulation of correlation matrix: Correlation matrix for the groundwater quality parameters is formulated to identify the relationship between any two parameters. It is a statistical method used to measure how the water quality parameters were related to each other. It was developed by Karl Pearson

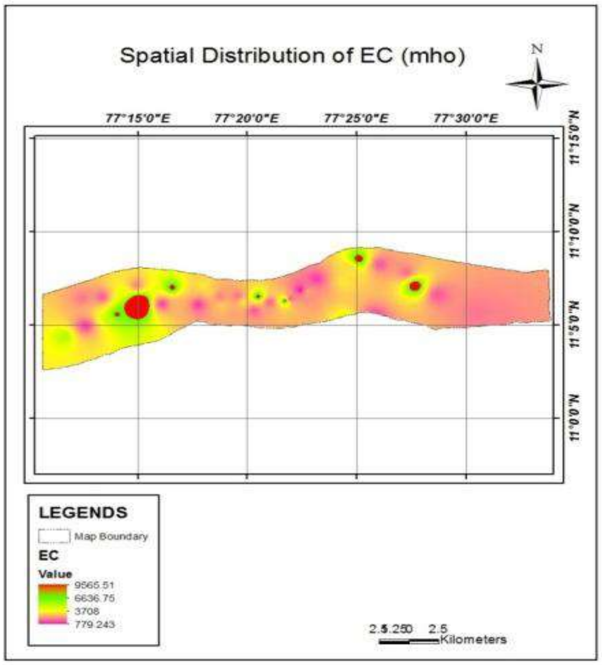

Fig. 1. Spatial distribution of EC

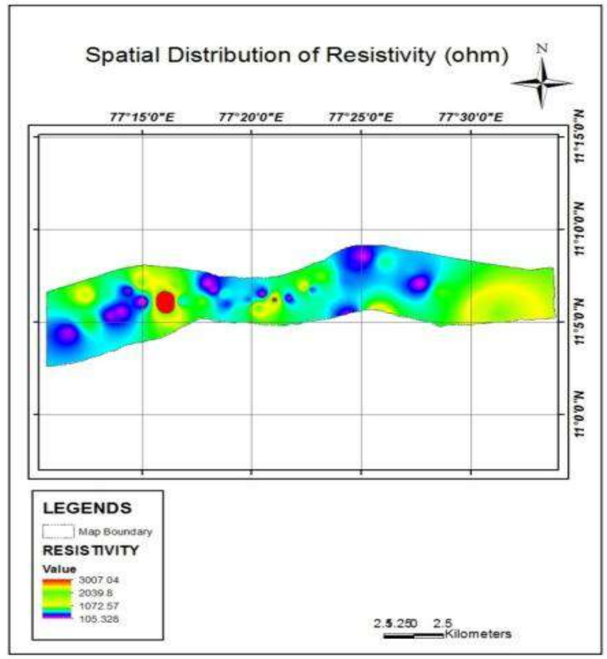

Fig. 2. Spatial distribution of resistivity

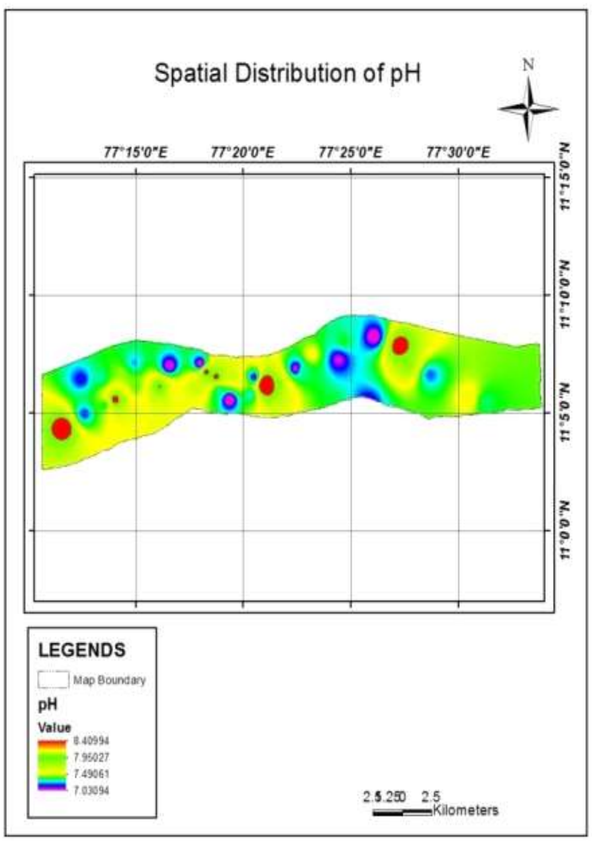

Fig. 3. Spatial distribution of pH

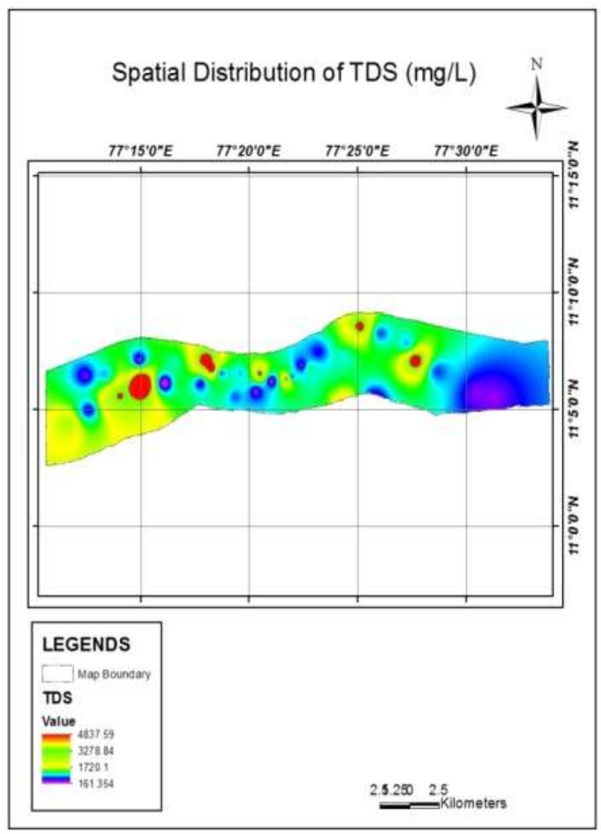

Fig. 4. Spatial distribution of TDS

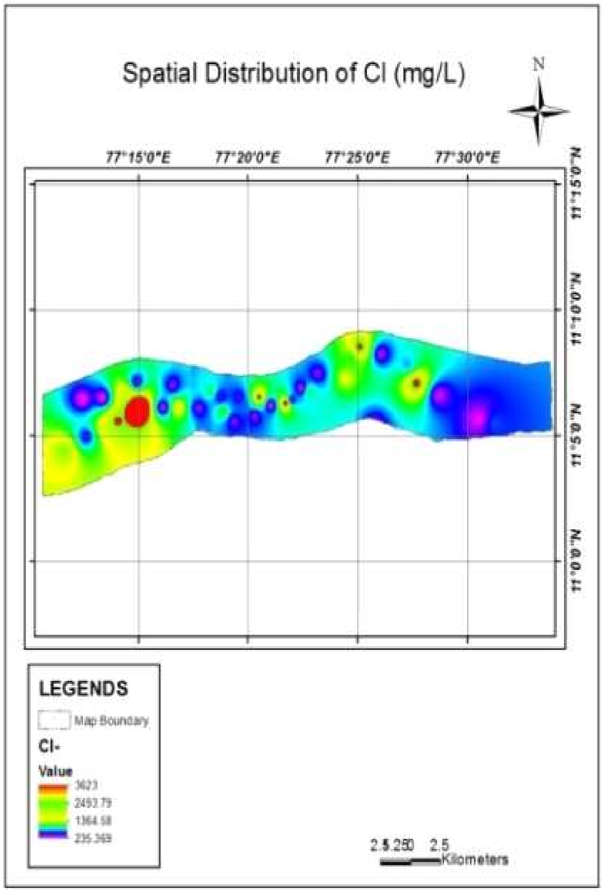

Fig. 5. Spatial distribution of chlorides

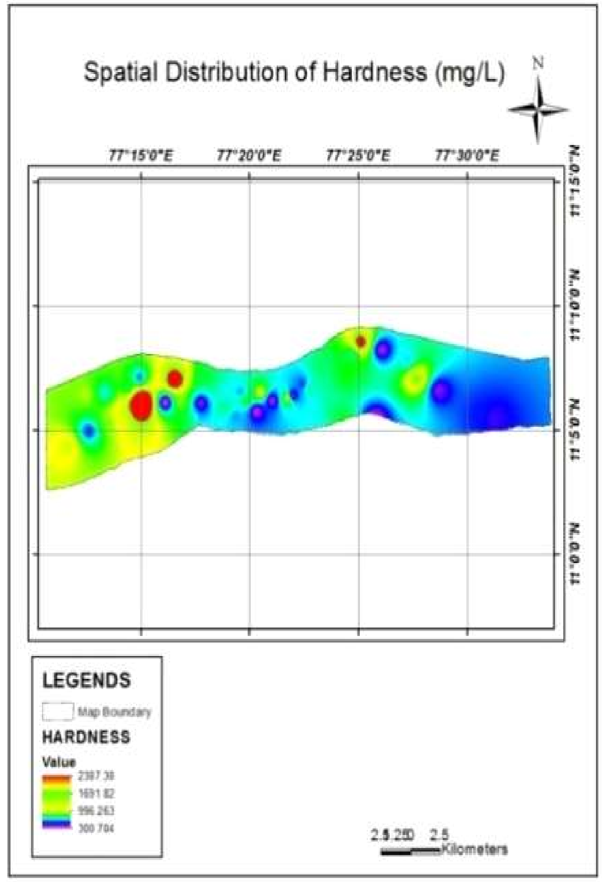

Fig. 6. Spatial distribution of hardness

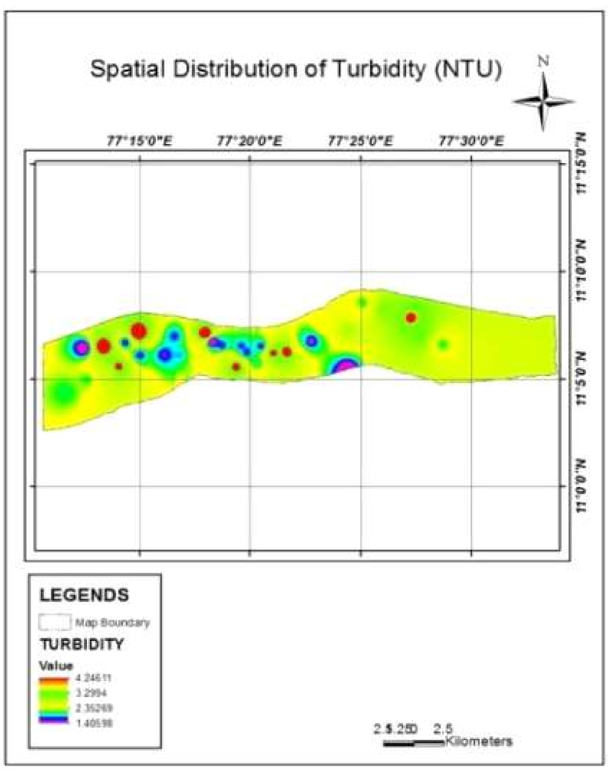

Fig. 7. Spatial distribution of turbidity

in 1880s (Samantray et al 2009, Sidhardhan and Adish Kumar 2019). From the correlation analysis, most of the parameters were negatively correlated to each other and some parameters were positively correlated to other parameters (Table 4).

GIS based water quality mapping: In this project Arc-GIS software is used to plot the spatial distribution of the various physico-chemical parameters for getting visual interpretation of the consistent values of groundwater quality parameters (Jebastina and Arulraj 2017, Subbaiah et al 2022). The calculated concurrence values of the water quality parameters during July 2021 and October 2021 at different well locations were presented in the mapping format using GIS software (Fig. 1 to 7).

CONCLUSION

Thee most of the groundwater source is contaminated in the selected sites due to the poor effluent treatment methods and poor agricultural practices in the Tiruppur district. The range of the physico-chemical parameters exceeds the permissible limits in most of the samples except at the three locations such as at Pallapalayam bore well, Mangalam bore well and Sivasakthi nagar. The pH and turbidity values of all the groundwater samples are well within the permissible limits as per IS codes. The other physico-chemical parameter of most of the regions along the banks of the Noyyal River is more than the permissible limits. The bore well located at Agraharapudur is need to be monitored continuously due to its higher level of contamination compared to other wells. Hence, continues monitoring of groundwater samples at the selected locations facilitate in improves the quality of groundwater and helps in sustainability in water management practices.

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Effect of Size Reduction and Packaging Materials on Storage Stability of Dried Stevia under Ambient Conditions

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Abstract: Experiments were conducted to study the effect of particle size of dried stevia leaves and packaging material on storage stability under ambient conditions. Three forms of dried stevia - Fraction A (<180 µm) in powder, Fraction B (>180 µm and <350 µm) in powder and dried leaves were packed in different packaging materials viz. glass jars, PET jars and punnets, stored under ambient conditions and evaluated for quality attributes at regular intervals throughout the storage period. The quality assessment of various forms of dried stevia suggested that type of packaging material and form of dried stevia had significant effect on the quality and shelf life of dried product. The glass jars were the best packaging material followed by PET jars. Stevia stored in dried leaves retained better quality characteristics in comparison to stevia stored in powdered form during nine months of storage. Out of the two fractions of powder, stevia powder-Fraction B retained better quality characteristics throughout the storage period.

Keywords: Stevia, *Stevia rebaudiana*. Packaging materials, PET, Stevioside

Stevia, botanically known as *Stevia rebaudiana* Bertoni (Family- Asteraceae) is a sweet herb and leaves of stevia are the source of sweet glycosides. The chemical compound obtained from stevia is the best alternative source of sugar especially for diabetes patients. More importantly, stevia contains a high percentage of phenols, flavonoids, and antioxidants. There are eight groups of active compounds that are a source of sweetness in stevia that can be divided into: stevioside, steviobioside, ducloside and rebaudiosides A, B, C, D and E. The two main glycosides are stevioside (St) traditionally being 5-10% of the dry weight of the leaves and rebaudioside A (R-A) being 2-4% (Hossain et al 2017). Fresh stevia leaves are perishable in nature which leads to their easy spoilage due to climatic factors, handling, microorganisms, and structural and chemical changes during storage. Drying is an important step in post-harvest technology of stevia because every agricultural product in its natural state contains a certain amount of water called the moisture. To preserve the quality of the product and its storage life, this moisture content needs to be reduced to a level that is safe for storage. Drying of stevia needs to be done as soon as the crop is harvested to protect it from any kind of infestation. Shelf life of the dried product is very much dependent on the packaging materials and storage conditions under which the product is stored. Besides these, the form of the dried product is also an important parameter that determines the quality of the dried product during the storage as it relates to the surface area available for various losses to occur. The type of package, form of dried product and storage also affects the final quality of the product over time. The present study was planned to study the effect of size reduction and packaging materials on storage stability of dried stevia under ambient conditions.

MATERIAL AND METHODS

The leaves of stevia were dried in solar assisted mechanical tray dryer at temperature of 55°C. Once dried, half of the stevia leaves were grounded to powder in a grinder. The powder thus obtained, was then subjected to sieve analysis and two fractions of powder were obtained. Therefore, dried stevia was kept in three forms, viz, stevia powder- Fraction A (<180 µm), stevia powder-Fraction B (>180 µm and <350 µm) and dried leaves. The dried stevia leaves and powder were then packed in three containers namely, glass jars, punnets and PET jars and stored under ambient conditions over a period of nine months. The samples were tested for various physio-chemical parameters at regular intervals. The weights of dried stevia leaves and both fractions of stevia powder stored in all three containers were evaluated for gain in weight. The percentage gain in weight of various forms of dried stevia during storage was calculated by using the formula:

$$\text{Gain in weight (\%)} = \left(\frac{W_2 - W_1}{W_1}\right) * 100$$

Color was determined using Hunter Lab Miniscan XE-Plus Colorimeter. The instrument gives readings of three parameters namely, L*, a* and b*. Values of a, b closer to zero indicates grey color. L indicates the intensity of color i.e., lightness which varies from L=100 for perfect white to L=0 for black. The stevioside content from the stevia extract was estimated by method described by Kaur (2009). Steviol glycoside extract was hydrolyzed with 5N HCL at 70°C for 1 hour. The glucose units liberated from the stevioside upon hydrolysis took part in the reaction with 5% phenol and 95% sulphuric acid (H_2SO_4). The intensity of orange, brown color was read at 490 nm.

The flavonoid content was determined using method given by Balabaa et al (1974). Methanolic extract (3 ml) mixed with stevia extract was evaporated to dryness. The residue left was dissolved in 10 ml of 0.1 M methanolic solution of aluminium chloride. Intensity of yellow color so developed was read at 420 nm against blank. Protein content was determined by Lowry *et al* method (1951). The crude fibre method was determined using method given in (AOAC, 1980).

Statistical analysis: The data was analyzed for the effect of storage period, form of dried stevia and type of packaging material on the quality of dried stevia during storage using general linear model using Statistical Package for Social Sciences (SPSS).

RESULTS AND DISCUSSION

Gain in weight (%): Storage period and packaging material had significant effect on the gain in weight of dried stevia irrespective of its form during storage of nine months. The minimum gain in weight was for samples packed in glass jars while maximum for punnets (Fig. 1). This could be because of higher permeability of punnets as compared to glass and PET jars. Among the various forms of dried stevia, stevia powder-Fraction A showed the highest percentage gain in weight and dried stevia leaves had the lowest percentage gain in weight. This could be attributed to the fact that in dried leaves, lesser surface area was exposed and thus gain in moisture was comparatively less. The gain in weight of dried stevia was significantly affected by storage period, form of dried stevia and type of packaging materials.

Color: The L value, taken as a measurement of brightness, varied from 21.35 to 28.07 with storage period irrespective of the type of packaging material. Minimum L value was for stevia powder-Fraction A stored in punnets. The maximum 'a' value recorded for different forms of dried stevia i.e stevia powder-Fraction A, stevia powder-Fraction B and dried stevia leaves were -1.09, -1.18 and -1.23, respectively, when packed in punnets at storage of nine months. The increase in b value was also observed with storage period irrespective of the packaging material and storage period. The highest 'b' value for all the three forms of dried stevia viz. stevia powder-Fraction A, stevia powder-Fraction B and dried stevia leaves was 3.39, 3.42 and 3.61 respectively, for punnets. Moreover, the color change (ΔE) of dried stevia powder as well as leaves witnessed increasing trend with storage period throughout the storage period of nine months. The increase in color change was significantly affected by storage time and packaging materials and could be due to the absorption of moisture by all the forms of dried stevia caused by an inadequate barrier provided by the packaging materials resulting in higher color variation with storage. The maximum 'ΔE' value was 26.19, 27.91 and 27.83 of all three forms viz. stevia powder-Fraction A, stevia powder-Fraction B and dried stevia leaves, respectively. However, the least color change was observed for dried stevia stored in glass jars. This change in color might be due to the reduction of

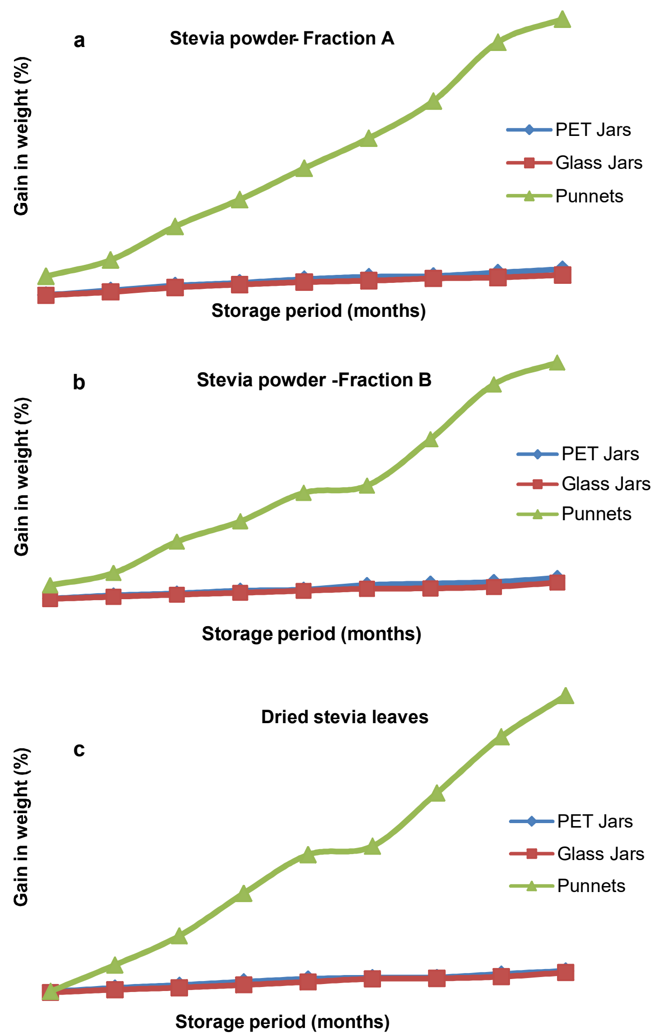

Fig. 1. Effect of packaging material and storage period on gain in weight of various forms of dried stevia. Stevia powder-Fraction A, (b) Stevia powder-Fraction B and (c) Dried stevia leaves

chlorophyll pigments as a result of photo oxidation reaction in the cells (Maskan et al 2002). The form of dried stevia and the type of packaging materials had significant effect on the color of dried stevia.

Stevioside content: The stevioside content varied from 5.15 to 13.61 % with the storage period irrespective of the type of packaging material (Fig. 3). The least stevioside content was observed in stevia powder-Fraction A when stored in punnets. The highest stevioside content at the end of storage period was in dried stevia leaves stored in glass jars. The decrease was significant and may be attributed to the moisture gain by all forms of dried stevia during the storage period that led to the deterioration of the stevioside content. Dried stevia leaves were observed to retain more stevioside content as compared to the two fractions of powder. This could be because lesser the surface area exposed; less are the losses from the surface. Since dried leaves had less exposed surface area as compared to the two fractions of powder, thus the losses in dried leaves were comparatively less. It was observed that punnets retained the least stevioside content out of all three packaging materials at the end of storage. It could be because of higher permeability of moisture and air in case of punnets as compared to PET and glass jars. The stevioside content of dried stevia was effected significantly by storage period, form of dried stevia and type of packaging materials.

Flavonoid content: The least flavonoid content was in stevia powder-Fraction A stored in punnets and maximum value of flavonoid content was observed in dried stevia leaves stored in glass jars after a storage period of nine months. The flavonoid content decreased with storage period (Fig. 4). This could be due to conversion of the natural constituents into other compounds as a result of chemical reactions with enzymes, oxygen and light during storage.

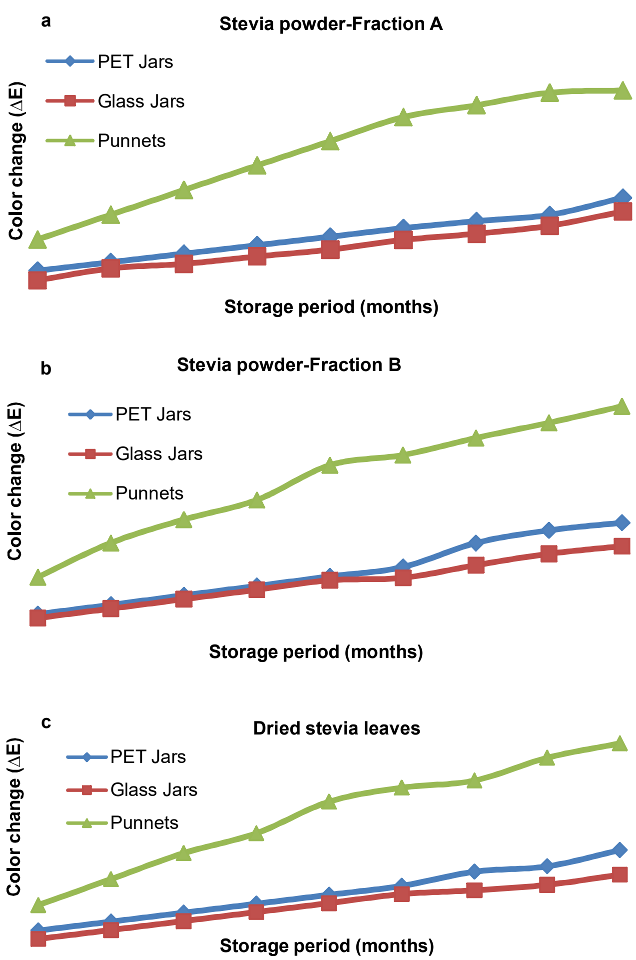

Fig. 2. Effect of packaging material and storage period on color change of various forms of dried stevia (a) Stevia powder-Fraction A, (b) Stevia powder-Fraction B and (c) Dried stevia leaves

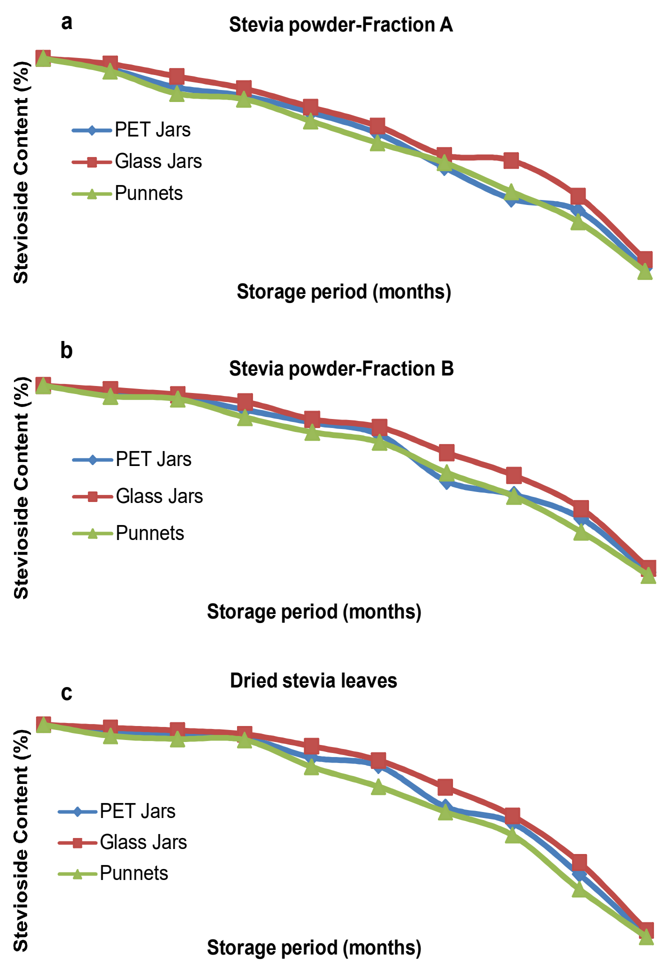

Fig. 3. Effect of packaging material and storage period on stevioside content of various forms of dried stevia (a) Stevia powder-Fraction A, (b) Stevia powder-Fraction B and (c) Dried stevia leaves

Some volatile compounds tend to escape away from the ground powder and leaves during storage time. Similar results were reported by Meghwal and Goswami (2014). The glass jars retained the highest flavonoid content irrespective of the form of dried stevia and punnets retain the minimum flavonoid content at the end of storage period. The dried leaves retained the flavonoid content better than both fractions of stevia powder. There was significant effect of storage period, form of dried stevia and type of packaging materials on the flavonoid content of the dried stevia.

Protein content: The least protein content was observed in stevia powder-Fraction A when stored in punnets and the maximum protein content was recorded in dried stevia leaves stored in glass jars (Fig. 5) for storage over nine months. The protein content of dried stevia leaves and both fractions of stevia powder followed a decreasing trend during the storage period i.e. the protein content for dried stevia decreased with an increase in the storage period, irrespective of the type of packaging materials. The decrease in protein content of dried stevia leaves and powder during storage period could be due to the fact that after drying, the process of protein synthesis stopped and denaturation of protein took place and thus the protein content either remained constant or decreased with storage period. The decrease was not much because during this time, denaturation of protein took place, thus the protein changed its form but was not lost completely (Zhang et al 2013). The maximum protein content was retained in dried stevia leaves in glass jars whereas, the least protein content was found in stevia powder-Fraction A in punnets at the end of nine months. The protein content of dried stevia was significantly affected by the storage period, form of stevia as well as the packaging material used.

Crude fibre content: The least crude fibre content was recorded in stevia powder-Fraction A during the storage period of nine months (Fig. 6). The crude fibre content decreased with increase in storage period in all three

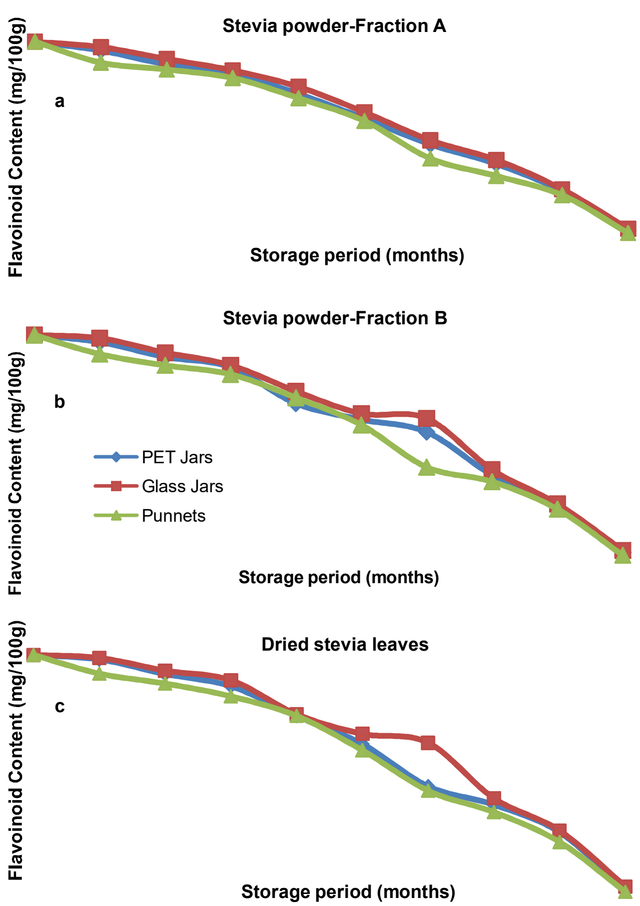

Fig. 4. Effect of packaging material and storage period on flavonoid content of various forms of dried stevia (a) Stevia powder-Fraction A, (b) Stevia powder-Fraction B and (c) Dried stevia leaves

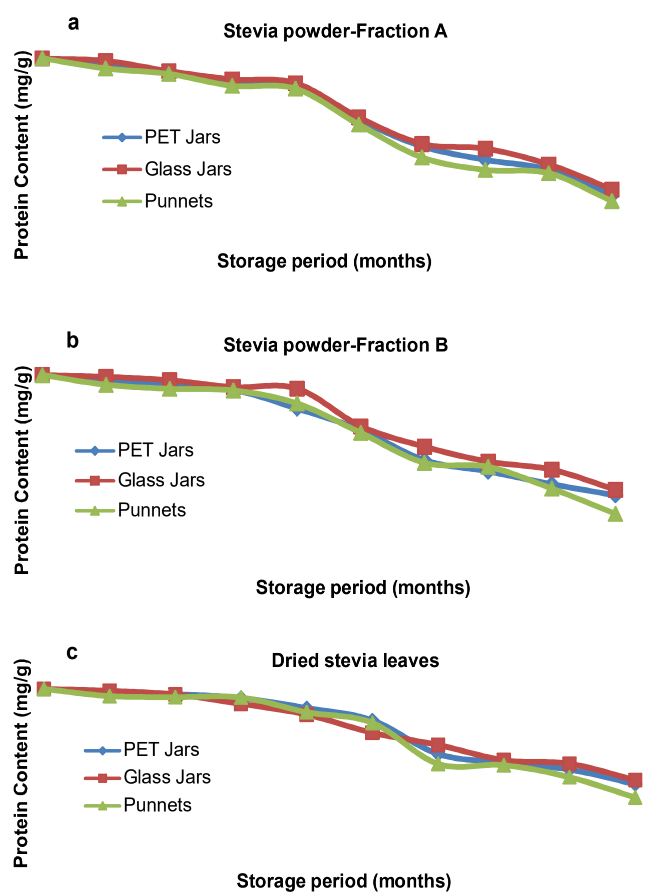

Fig. 5. Effect of packaging material and storage period on protein content of various forms of dried stevia (a) Stevia powder-Fraction A, (b) Stevia powder-Fraction B and (c) Dried stevia leaves

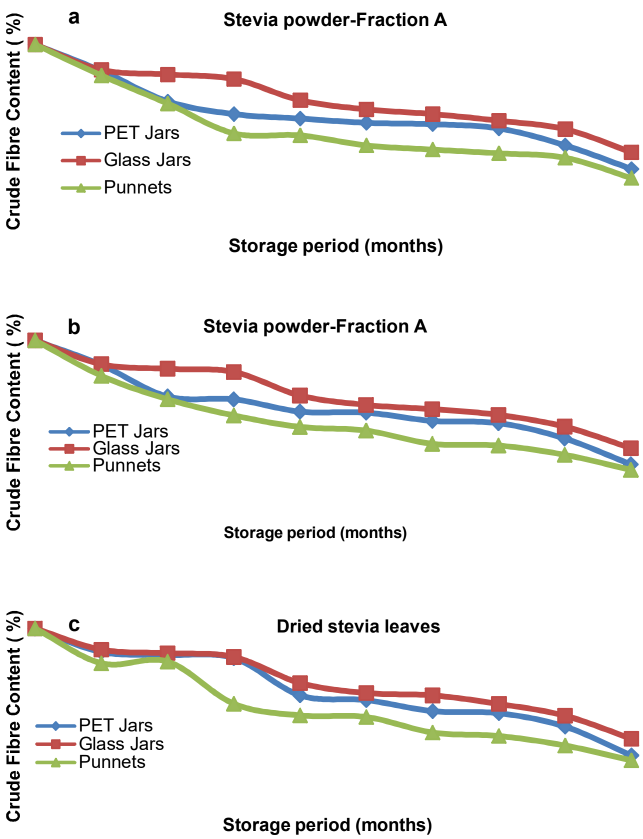

Fig. 6. Effect of packaging material and storage period on crude fibre content of various forms of dried stevia (a) Stevia powder-Fraction A, (b) Stevia powder-Fraction B and (c) Dried stevia leaves

packaging materials viz. PET jars, glass jars and punnets during storage. This might be because of the activity of lipase enzyme which increased during ambient conditions leading to more loss of fibrous content during storage (Kalim et al 2016). The least amount of crude fibre content was retained in stevia powder-Fraction A while the maximum was in dried stevia leaves. This could be attributed to the fact that the powder fractions were subjected to physical and chemical deterioration at the time of grinding. The storage period had significant effect on the quality of dried stevia irrespective of the packaging materials and form of stevia.

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CONCLUSIONS

The quality assessment of various forms of dried stevia suggested that storage period, type of packaging material and the form of dried stevia significantly affected the keeping quality of dried stevia. In order to store the dried stevia, the glass jars were the best packaging materials followed by PET jars. The stevia stored in form of dried leaves retained better quality characteristics throughout the storage in comparison to stevia in powdered form. Stevia, in powder (>180 µm and <350 µm)form retained better quality characteristics in comparison to powder with <180 µm size throughout the storage of 9 months.

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Rooting Pattern and Biomass Potential of Henna (*Lawsonia inermis* L.) in Legume Based Intercropping Systems Under Rainfed Condition of Hot Semi-Arid Region of Rajasthan, India

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Abstract: The knowledge of rooting pattern and structural development of roots are prerequisite to improve and optimize the productivity of any agroforestry systems. The present study was conducted to observe the rooting pattern and distribution of henna (*Lawsonia inermis*) roots in leguminous based intercropping combinations in relation to leaf production under hot semi-arid region Rajasthan, India. The experiment plot was laid out in a Randomized Block Design with three replications. Different combination of cluster bean and henna were taken and Sole henna was taken as control. The mean of horizontal root length increased from 76.66cm (H: CB 1:1) to 111.6 cm (Alley cropping (6m)) while vertical root length varied from 62.33 cm (H: CB 1:2) to 99.66 cm (Sole henna (C)). The maximum root spread was recorded in Alley cropping (6m) (98.88 cm) and minimum root spread was in H: CB 1:1 (61.22 cm) followed by Sole henna (C). The maximum above ground biomass was recorded in alley cropping (6m) while minimum in Alley cropping (3m). Maximum below ground biomass was recorded in H: CB (1:2) followed by strip cropping and sole henna (C) and minimum was in H: CB (1:1). Since considering economical parameters, alley cropping with cluster bean (6m) is the best intercropping system among the other systems in hot semi arid region of Rajasthan under rainfed condition.

Keywords: Henna, Hot arid and semi-arid zone, Cluster bean based intercropping systems, Rooting pattern and distribution

The hot semi-arid regions are highly dynamic, sensitive, fragile and are adaptable to human induced changes in climate as well as land use transitions. The large amount of food production cannot be achieved with agricultural enterprises alone with this uncertain climatic and edaphic condition in arid and semi-arid region. Moreover, water is often the most limiting resources and competition for water can impair the effectiveness of agroforestry systems in semi-arid region (Smith et al 1998). So that the integration of trees/ shrubs with the agricultural crops may serve the purpose of achieving the basic needs of farmer in terms of food, fodder and fuelwood in drought prone area. But the soil moisture and nutrient deficit and chances of crop failure may occur due to the adverse climatic factors in arid and semi-arid region when the new trees/shrubs are introduced along with the agricultural crops (Cai et al 2009).

The root depth of trees/ shrubs determines the competition between crops and trees/ shrubs for nutrients and soil moisture in a particular agroforestry system. The deep-rooted plants may be drawn the moisture and nutrients from the deeper layer of soil, which makes less competition with crops while the shallow rooted plants can compete with associated crops through their root system which may leads to yield depressions and may contribute the economic failure of the particular land use systems (Schroth 1995, Chauhan et al 2019).

Lawsonia inermis L. belongs to the family Lythraceae commonly called as Henna or Mehndi has been commercially cultivated promising dye yielding cash crop which is mainly used for dyeing hair, palm and feet since ancient times. (Singh et al 2015). Henna cultivation is profitable under low rainfall conditions and give assured income returns at low cost investment in drought prone arid and semi-arid regions. Due to its drought hardiness, deep root system and perennial nature, it can be cultivated on lands that are drought prone, marginal or unsuitable for arable cropping. Economic production of leaves starts from the third year onwards that continues for the next 15-30 years (Chand and Jangid 2007). Globally, India has exported 2,383 tons of henna to several countries in the year 2002-03 which indicates high demand in international export market.

Cluster bean is an important leguminous crop and mostly cultivated mostly on marginal and sub marginal lands of arid and semi-arid regions. Overall, India produces around 80% of global cluster bean production. It is cultivated on more than 4 m ha in India, Rajasthan alone accounts for around 80% of the area and production. It has gaining its importance for its gum named as guar gum which is used in multiple commercial applications (Bhatt et al 2017).

However, there was no study was undertaken to evaluate the integration of henna with agricultural crops. And also, integration of henna with leguminous crop may ensure the income and productivity of farmers in henna growing areas of India. Deep rooted trees/ shrubs are widely recommended to achieve the complementary in use of below ground soil resources in agroforestry systems (van Noordwijk et al 1996). In view of growing needs and for the better understanding of the rooting pattern, biomass and yield potential of henna in cluster bean based different intercropping systems under rainfed condition, the present study was conducted with different combinations of henna with leguminous crop and sole henna under hot semi-arid region Rajasthan, India.

MATERIAL AND METHODS

The study was conducted in henna intercropping experimental field, at ICAR-Central Arid Zone Research Institute (CAZRI), Regional Research Station (Pali-Marwar, Rajasthan) in hot semi-arid region of India during 2019-20. The experimental site of henna is located between 25°47′-25°49′N and 73°17′-73°18′E at 217-220 m msl and receives 460 mm annual average rainfall with annual maximum mean temperature of 42°C and minimum 7°C. The soils were shallow in depth (30-45 cm) with sandy clay loam to sandy loam texture, 1.35-1.5 Mg m^{-3} bulk density, 7.7-8.4 pH, 0.15-0.55 dSm^{-1} electrical conductivity and a dense underlying layer of murrum (highly calcareous weathered granite fragment coated with lime).

Experimental design and site management: The henna plants were planted at 60X 30 cm in seven cluster bean based different intercropping systems during 2003 and leguminous crop cluster bean was taken as inter crop during kharif season in second year onwards under rainfed condition at ICAR-Central Arid Zone Research Institute, Regional Research Station, Pali in Rajasthan, India. The experiment plot was laid out in a Randomized Block Design with three replications. Sole henna was taken as control. The treatment details were given in Table 1.

Demarcation and enumeration of plants: Uniform and healthy plants were selected randomly in each system from middle portion of the plantations. Since the root excavation is a very laborious process, three representative plants of henna from each system were selected for destructive sampling. Growth variables for *viz*., plant height, basal diameter and number of branches (primary and secondary) were measured before cutting the plants of henna.

Excavation of roots of henna: Plants were harvested during the month of September, 2019 at the experimental site of henna. After recording the above ground parameters of henna, the plants were harvested into 10cm above ground level which is usually followed by farmers. The roots of henna under different systems were excavated and complete recovery of roots were done from the base of plant. All categories of roots were carefully picked from soil during the excavation and rearranged. The below ground variables viz., root depth, root spread and horizontal root length were measured. Shoot and roots of henna were separated from uprooted plants and dry biomass for above ground and below ground were recorded for each component. All biomass estimates were based on oven dry weight. These measurements were recorded as per established procedure.

Data analysis and interpretation: Analysis of variance (ANOVA) followed by Duncan multiple range tests (DMRT) was performed at 95% confidence level for comparing means of above and below ground growth parameters and biomass among the different systems of henna plantations.

Table 1. Treatment details of henna under different intercroppings

Treatment code	Abbreviations	Remarks
H: CB 1:1	Henna: Cluster bean (1:1)	One row of henna was alternated with one row of legume and each crop component was spaced at 60 cm from each other.
H: CB 1:2	Henna: Cluster bean (1:2)	One row of henna was alternated with two rows of legumes at 40 cm distance
H: CB 1:3	Henna: Cluster bean (1:3)	One row of henna was alternated with three rows of legumes
H: CB 1:5	Henna: Cluster bean (1:5)	One row of henna and five rows of legumes. Each row whether of henna or legume are spaced at 60cm from the other one.
Strip cropping	2.4m Strip cropping	A 2.4m wide strip of henna was alternated with 2.4m wide strip of legumes. In this system proportion is 50:50.
Alley (3m)	Alley cropping (3m wide)	Two rows of henna were planted in 60 cm rows at 3m distance. Four rows of legume were arranged in the open strip. Henna would be maintained in the form of hedge from third year onwards after the plantation.
Alley (6m)	Alley cropping (6m wide)	Paired rows of henna at 60cm are planted at 6m distance. Ten rows of legumes were maintained between the 6m space. Henna would be maintained in the form of hedge from third year onwards after the plantation.
Sole henna (C)	Sole henna (Control)	The only henna is planted with standard spacing with in the experiment.

RESULTS AND DISCUSSION

Above ground morphometric traits of henna under different intercropping systems: Among the different systems, the significant variation was observed in above ground and below ground morphometric parameters. The maximum plant height was observed in H: CB 1:2 followed by Alley cropping (6m) while minimum was in H: CB 1:5. The highest collar diameter was registered in H: CB 1:2 system and minimum in Sole henna (C). The primary branches were more in strip cropping followed by H: CB 1:1 while less in H: CB 1:2 and Alley cropping (3m). The maximum secondary branches were recorded in Alley cropping (6m) followed by H: CB 1:5 and minimum was recorded in H: CB 1:1 and Sole henna (C). The results indicated that maximum growth was attained with increased spacing (Table 2). Songyos et al., 2013 and Noor et al., 2018 also reported that the stems and branches are relatively more with increased spacing due to the higher availability of soil moisture, nutrients and light resources. And also, these results are supported with the findings of Hafeez and Hafeezullah (1993); Misra et al. (1996); Nissen et al. (2001).

Root distribution of Henna under different intercropping systems: Rooting depth determines to which extent the plants can use sub soil nutrients and water. The higher root depth of plants may use sub soil resources viz., water, nutrients, etc., by nutrient pumping and hydraulic lifting and made less competition for the resources with associated agricultural crops which produces the shallow root system in the top layer of the soil (Emerman and Dawson 1996).

Root length is one of the best parameters relating to the uptake of water and nutrients. The length and spread of henna roots were showed a wide range of variation among the systems (Table 2). The mean of horizontal root length increased from 76.66cm (H: CB 1:1) to 111.6 cm in Alley cropping (6m) while vertical root length varied from 62.33 cm (H: CB 1:2) to 99.66 cm (Sole henna (C)). There was no significant difference were observed in root spread among the systems. But the maximum root spread was recorded in Alley cropping (6m) (98.88 cm) followed by strip cropping (94.66 cm) and minimum root spread was in H: CB 1:1 (61.22 cm) followed by Sole henna (C) (Table 2).

Deeper zone of soil has less number of lateral roots when compared with upper zones. The accumulation of more root biomass in the upper layers of soil gives access to more moisture and nutrients available in the top soil. Similar observations on the root distribution of five multipurpose tree

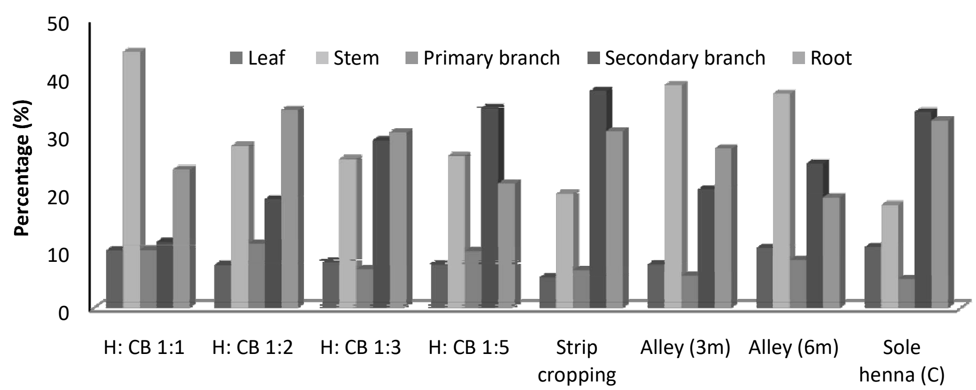

Fig. 1. Percentage distribution of biomass in henna under different intercropping systems

Table 2. Above ground and below ground morphometric characteristics of henna under different intercropping systems

Treatment	Plant height (cm)	Collar diameter (cm)	Primary branches	Secondary branches	Vertical root length (cm)	Horizontal root length (cm)	Root spread (cm)
H: CB 1:1	129.0[abc]	0.395[a]	5.33[ab]	10.00[a]	77.33[abc]	76.66[a]	61.22[a]
H: CB 1:2	156.0[c]	1.000[d]	3.00[a]	19.00[cd]	62.33[a]	108.6[a]	75.44[a]
H: CB 1:3	133.6[abc]	0.466[ab]	4.33[ab]	17.33[bcd]	63.66[ab]	107.3[a]	76.11[a]
H: CB 1:5	105.6[a]	0.682[bc]	5.00[ab]	21.00[d]	87.00[abc]	98.66[a]	73.00[a]
Strip cropping	112.6[ab]	0.948[cd]	6.00[b]	18.00[bcd]	67.66[ab]	109.6[a]	94.66[a]
Alley (3m)	114.6[ab]	0.519[ab]	3.00[a]	11.66[ab]	95.00[bc]	92.00[a]	75.22[a]
Alley (6m)	141.6[bc]	0.904[cd]	4.33[ab]	23.66[d]	78.00[abc]	111.6[a]	98.88[a]
Sole henna (C)	121.6[abc]	0.321[a]	4.00[ab]	10.00[a]	99.66[c]	88.66[a]	69.00[a]

*Mean value followed by same alphabet (superscript) in a column are insignificantly different (according to DMRT at P = 0.05)

Table 3. Above ground and Below ground biomass of Henna under different intercropping systems

Treatment	Leaf wt. (kg plant^{-1} year^{-1})	Stem wt. (kg plant^{-1} year^{-1})	Primary branch wt. (kg plant^{-1} year^{-1})	Secondary branch wt (kg plant^{-1} year^{-1})	Root wt. (kg plant^{-1} year^{-1})
H: CB 1:1	0.093^{a}	0.413^{a}	0.094^{a}	0.106^{a}	0.223^{a}
H: CB 1:2	0.095^{a}	0.358^{a}	0.142^{a}	0.240^{abcd}	0.437^{c}
H: CB 1:3	0.093^{a}	0.302^{a}	0.078^{a}	0.340^{bcd}	0.356^{bc}
H: CB 1:5	0.088^{a}	0.309^{a}	0.115^{a}	0.407^{de}	0.253^{ab}
Strip cropping	0.074^{a}	0.277^{a}	0.092^{a}	0.527^{e}	0.429^{c}
Alley (3m)	0.064^{a}	0.327^{a}	0.047^{a}	0.174^{ab}	0.234^{a}
Alley (6m)	0.128^{b}	0.458^{a}	0.102^{a}	0.309^{bcd}	0.236^{a}
Sole henna (C)	0.116^{a}	0.196^{a}	0.055^{a}	0.373^{cde}	0.356^{bc}

*Mean value followed by same alphabet (superscript) in a column are insignificantly different (according to DMRT at P = 0.05)

species were recorded by Dhyani et al (1990). Similarly, the plants exhibited spreading root parallel to the soil surface was exploited water and nutrients and increased below ground completion in *C. mopane* and *Cordia myxa* based agri horti silvi system (Bilas Singh et al 2013) and same trend was observed in other studies also (Dhyani et al 1990, Toky and Bisht 1992, Akinnifest et al 2004).

The present study indicated that the more root depth might be resulted in sole henna due to unavailability of nutrients in top layer of soil and which might be drawn from the sub soil in the system. And also, the alley cropping (6m) and other systems produced more horizontal roots and less vertical roots indicated that availability of nutrients and water from top layer of soil due to less competition among the plants.

Biomass potential of henna under different intercropping systems: The results on above and below ground biomass of henna showed the significant difference among the systems. But the differences were non-significant among the different intercropping systems for stem weight and number of primary branches (Table 3). The percentage distribution of biomass in henna under different intercropping systems also given in Figure 1. The maximum dry leaf (0.128 kg) and stem biomass (0.458 kg) was produced in Alley cropping (6m) while minimum in Alley cropping (3m) (0.64 kg) for dry leaf and sole henna (C) (0.196 kg) for stem weight respectively (Table 3). Since the economic part of the henna is ultimately dry leaf yield, Alley cropping (6m) followed by sole henna produced more dry leaf yield per plant. But the Alley cropping (6m) was having more sub surface root spread and less root depth than sole henna which may lead to competition between the agriculture crops for soil moisture and nutrients. It may reduce the yield of agriculture crop. The other researchers also suggested the similar results that the deep primary roots and moderate secondary root length of plants are less competitive with the companion crops (Das and Chaturvedi 2008; Makhumba et al. 2009; Chauhan et al. 2012).

The significant differences were observed among the systems for root weight. Maximum root weight was recorded in H: CB (1:2) followed by strip cropping and sole henna (C) and minimum in H: CB (1:1) (Table 3 and 4). Generally, trees allocate more biomass to root system with increased spacing due to less competition for uptake of nutrients, soil moisture and resources. In the present study, more root biomass was observed in henna with cluster bean-based system under H: CB (1:2) followed by strip cropping but there was less root biomass in sole henna which was planted closely with standard spacing. The similar results are observed by Swamy et al. (2003). Wani et al (2014) also reported that trees produce large root system that needed for uptake of soil resources which resulting in higher values in higher diameter. The same trend was observed in H: CB1:2 and strip cropping which resulted the more root biomass produced higher collar diameter and less in sole henna. Several other workers also support this finding (Yadava 2010, Uma et al 2011) who reported that root biomass is more in higher diameter class as compared to lower diameter class.

The lower nutrient availability from the deeper zone may affect the growth and biomass production in the sole plant

Table 4. Biomass potential of henna under different intercropping systems

Treatments	Above ground biomass (Kg/ Plant/Year)	Below ground biomass (Kg/ Plant/Year)	Total biomass (Kg/ Plant/Year)
H: CB 1:1	0.707	0.223	0.930
H: CB 1:2	0.837	0.437	1.275
H: CB 1:3	0.814	0.356	1.170
H: CB 1:5	0.920	0.253	1.174
Strip cropping	0.971	0.429	1.401
Alley (3m)	0.613	0.234	0.847
Alley (6m)	0.998	0.236	1.234
Sole henna (C)	0.741	0.356	1.098

and relatively greater availability of soil resources from the sub surface soil in alley cropping system facilitated more growth and biomass production. But wider spread of root in Alley cropping system may be the reason for competing the resources with agricultural intercrops.

CONCLUSION

The present study suggested that the increased availability of space facilitated the development of henna roots to confine mostly in upper layer of soil which may compete with agriculture crops for nutrient and soil moisture. Since the dry leaf yield is economical part in henna, alley cropping (6m) produced more dry leaf yield per plant followed by sole henna. So, the study suggests that alley cropping (6m) with cluster bean was best intercropping system considering other comparative factors. Further, the study may extend with evaluation of crops with different intercropping combination in henna may leads to select the potential combination of henna intercropping system for hot arid and semi-arid zone of Rajasthan, India and this study will serve as a base for future henna-based agroforestry studies.

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Effect of Supplemental Irrigation on Growth, Physio-biochemical and Yield Responses of Mothbean (*Vigna aconitifolia L.*) Genotypes under Rainfed Condition in Semi-arid Regions of Rajasthan

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Abstract: Mothbean cultivation in arid and semi-arid regions is practiced mainly under rainfed condition but increasing temperature and irregular rainfall pattern lead to drought conditions and substantially decreasing the yield. Supplemental irrigation at critical crop growth stage can play crucial role under water deficit situations in such regions. The field experiment was conducted to assess growth, physio-biochemical and yield responses of seven contrasting mothbean genotypes, viz. RMO-257, RMO-40, RMB-25, RMO-2251, CZM-45, RMO-435 and RMO-225 under rainfed (RF, drought condition) and supplemental irrigation (SI, irrigation applied at flowering stage i.e. 30 DAS) conditions. SI significantly improved plant growth attributes and water status which ultimately enhanced yield up to 35% as compared to RF condition. The water stress conditions significantly increased activities of antioxidative enzymes i.e. ascorbate peroxidase (APOX) and guaiacol peroxidase (GPOX) especially in tolerant genotypes. The correlation matrix and principal component analysis emphasized that there is positive relationship between growth attributes, water indices and yield of the genotypes whereas antioxidative enzymes showed negative relationship with yield. Among the genotypes studied, RMO-257, RMO-40 and RMB-25 performed well, whereas RMO-435 is more susceptible to drought conditions, as also demonstrated by a heat map of drought tolerance indices.

Keywords: *Vigna aconitifolia*, Drought stress, Rainfed, Supplemental irrigation, Antioxidative enzymes

Mothbean [*Vigna aconitifolia* (Jacq.) Marechal] is an important pulse crop in Rajasthan's arid and semi-arid zones (cultivated on 1 million hectares, with 0.2 million tons produced and an average productivity of 228 kg/ha). It is a rainfed crop and requires less humidity, high temperature (24-32°C) and rainfall of around 50-75 cm. Climate change with increasing temperature, low average annual rainfall, erratic rainfall, and dry atmospheric conditions fulfills only 25-30% of the crop water requirements during the growing season thus water shortage is becoming a key challenge resulting in quantitative and qualitative yield losses in mothbean, especially in rainfed agriculture system (Kumar and Chander, 2020, Overpeck and Udall 2020). Although there is sufficient rainfall to enhance yield under rainfed farming system but it is not available during the critical stages of crop growth causing dry spells.

Drought stress has a negative impact on plant growth, reducing leaf area, other physio-biochemical processes such as membrane stability index (MSI), relative water content (RWC), water potential (WP), and photosynthesis, limiting development to achieve maximum yield (Vujanovic and Germida 2017). It also causes the production of reactive oxygen species (ROS) such as superoxide, peroxide, hydroxyl radical, singlet oxygen, and alpha oxygen, which cause a variety of detrimental events such as lipid peroxidation of cell membranes, oxidation of proteins and nucleic acid, and ultimately cell death. Antioxidative enzymes such as ascorbate peroxidase (APOX), guaiacol peroxidase (GPOX), catalase (CAT) and superoxide dismutase (SOD) play an important role in regulation of these ROS under water stress conditions. Under drought stress, the level of normal metabolic enzymes such as nitrate reductase (NR) decreases while antioxidative enzymes increase to maintain the plant's overall (Hasanuzzaman et al 2020).

To maintain sustainable crop yields while dealing with the additional challenge of drought stress, there is an increasing need to replace rainfed cropping systems with irrigated systems, which has been shown to be an effective strategy for increasing up to 43% of global agricultural production (Okada et al 2018). Supplemental irrigation during the most sensitive stages of the crop growth, such as flowering and grain filling will help to increase survival and yield under rainfed conditions (Farooq et al 2017). Irrigation scheduling, which includes providing water that matches crop evapotranspiration and providing irrigation at critical growth stages, improves field crop water use efficiency. Water conservation by using a limited amount of water during critical crop growth stages result in a significant increase in yield and an improvement in the livelihoods of smallholder farmers in dry rainfed areas (Molla et al 2021).

The information pertaining to adoption of supplemental irrigation under water stress conditions in mothbean genotypes under agro-climatic conditions of arid North-western India are meager. Therefore, the objective of the current study was to evaluate the effect of supplemental irrigation on physio-biochemical traits and yield of seven mothbean genotypes widely grown in semi arid region.

MATERIAL AND METHODS

Site description: The study was conducted on the experiment area of the Central Arid Zone Research Institute, Regional Research Station, Bikaner (28°4' N; 74°3' E; 238.3 m above mean sea level), Rajasthan. The experiment was executed from August to October, 2020 (Table 1.The soil of experimental site was loamy sand, having 8.5 pH, 0.15 % organic carbon, 85 kg ha^{-1} available N, 96 kg ha^{-1} available P and 256 kg ha^{-1} available K.

Experimental design and treatment: Seven mothbean genotypes i.e. RMO-257, RMO-40, RMB-25, RMO-2251, CZM-45, RMO-435 and RMO-225 were sown in a randomized complete block design (RCBD) in lines with line to line distance of 40 cm and plant to plant distance of 15cm under two irrigation treatments of rainfed production (RF) and supplemental irrigation (SI). The main plots contained rainfed and supplemental irrigation condition and sub plots had seven mothbean genotypes with three replicates. Size of each plot was 4m x 2m with 2m gap in between and there were 5 rows in each replication. Seed rate was @10kg/ha and sowing was done on 8^{th} August, 2020 after the rain. A basal dose of 10 kg N ha^{-1} (as urea) and 20 kg P ha^{-1} (as single superphosphate) was applied at sowing. For SI treatment, irrigation was applied before flowering (40% of soil available water was depleted at this stage). Soil available water was monitored using soil moisture probe (Profile Probe PR2), which monitors soil moisture content at 10, 20, 30, 40, 60, and 100 cm soil depth. The amount of supplemental irrigation (SI) was calculated by I = 10.γ.H.(FC-βj) (Shang et al 2020), where I is the amount of SI, γ (1.37 g.cm3) is the soil bulk density, H (7.35 cm) is the soil depth of the wetting layer, FC (30%) is the field capacity, and βj (5%) is the soil water content before irrigation. Observations were recorded after 10 days of irrigation treatments in three replicates.

Plant growth characteristics: Ten plants were randomly selected from the central 2 × 2 m area of each plot to determine dry matter (DM) accumulation per plant. The plants were oven dried at 65 °C ± 5 °C till constant dry weight following which the shoots dry mass was recorded and expressed as g $dwplant^{-1}$. Chlorophyll and carotenoid contents were extracted by the non-maceration method (Hiscox and Israelstam 1979). The total leaf area per plant was measured by portable leaf area meter model (Systronics leaf area meter 211) and expressed as cm^2.

Plant water status: Plant water relation parameters i.e. RWC, MSI and WP were observed by taking three replications of each genotype. RWC of leaf samples was determined as described by Barrs and Weatherley (1962). The MSI of leaf samples was determined following the procedure described by Sairam et al (2002). WP of fully expanded youngest leaves was measured during 9.30-11.30 h by WP 4 Dew-Point Potential Meter.

Enzymatic activity: *In vivo* leaf NR activity was assayed according to the procedure of Hageman and Hucklesby (1971) with slight modifications. NR was measured in 200 mg of finely chopped leaves that were incubated in a medium containing 5ml of 0.1 M phosphate buffer, 0.02M $KNO_{3,}$ 5% propanol and two drops of chloramphenicol (0.5mg/ml). After incubation of samples for 2 h in the dark at 30C a mixture of 1 ml each of 1.0% sulphanilamide in 1N-HCl and 0.025% N-(1-Napthyl)-ethylene diammonium dichloride (NEDD) were added. The absorbance was read at 540 nm, after 30 min using UV-Vis spectrophotometer (model Specord Bio-200, AnalytikJena, Germany). The calibration curve was prepared using sodium nitrite solution. The enzyme activity was expressed as μmol NO_2 g-^{1}fw h^{-1}.

APOX activity was assayed by following the decrease in absorbance at 290 due to ascorbate oxidation (ε = 2.8 mM^{-1} cm^{-1}) in a reaction mixture (1 ml) contained 530 μl of 50 mM phosphate buffer (pH 7.0), 200 μl of 0.5 mM ascorbic acid, 200 μl of 0.1 mM H_2O_2, 50 μl of 0.1 mM EDTA and 20 μl of enzyme extract for 1 min following the method of Nakano and Asada (1981). Protein content was determined by the method of Bradford (1976) using bovine serum albumin as the standard and used for the calculation of APOX enzyme. APOX enzyme specific activity is expressed as μmol (ascorbate oxidized) min^{-1} (mg protein) $^{-1}$.

GPOX activity was assayed, was measured by following the increase in absorbance due to the oxidation of guaiacol at 470 nm (ε = 26.6 mM^{-1} cm^{-1}) for 1 min. The assay mixture (1 ml) contained 530 μl of 50 mM phosphate buffer (pH 7.0), 50 μl of 0.1 mM EDTA, 200 μl of 10 mM guaiacol and 200 μl of 10 mM H_2O_2 and 20 μl of enzyme extract for 1 min as described by Chance and Maehly (1955). Protein content was determined by the method of Bradford (1976) using bovine serum albumin as the standard and used for the calculation of GPOX enzyme. GPOX activity is expressed as μmol (tetraguaiacol formed) min^{-1} (mg protein) $^{-1}$.

Yield and yield attributes: Yield (Y) and its attributes i.e. branches $plant^{-1}$(BP), pod length (PL), number of pods $plant^{-1}$

(PP), number of seeds pod^{-1} (SP) and test weight (TW) of seeds were recorded from each plot by manual harvesting of plants 3 cm above the ground and allowed to dry in the field.

Drought tolerance indices: Drought tolerance indices were calculated using the following equations (Fischer and Mourer 1978, Grzesiak et al 2019)

1. Stress Susceptibility Index (SSI) = 1 - [(Ys) / (Yp)] / 1 - [(Ȳs) / (Ȳp)]
2. Stress Tolerance (TOL) = (Yp - Ys)
3. Stress Tolerance Index (STI) = [(Yp) × (Ys)] / (Ȳp)^2
4. Yield index (YI) = Ys/Ȳs
5. Yield Stability Index (YSI) = Ys / Yp
6. Sensitivity drought index (SDI) = (Yp - Ys) / Yp
7. Drought resistance index (DI) = Ys × (Ys / Yp) / Ȳs
8. Relative drought index (RDI) = (Ys / Yp) / (Ȳs / Ȳp)
9. Stress susceptibility percentage index (SSPI) = (Yp - Ys) / (2 × Yp) × 100
10. Geometric Mean Productivity GMP = [(Yp) × (Ys)]$^{0.5}$
11. Mean Productivity MP = (Yp + Ys) / 2

In the above formulas, Ys, Yp and Ȳs, Ȳp represent yield in stress (RF) and non-stress (SI) conditions for each genotypes, and yield mean in stress and non-stress conditions for all genotypes, respectively.

Statistical analysis: Before analysis, the Shapiro Wilk test at 0.05 was conducted using R software (v. 4.1.0) to test the normality of the data and fitting data transformation was performed for any data that was not normally distributed. Analysis of variance (ANOVA) was also performed using the same software. Correlation (Pearson) analysis, Principal component analysis and box plot were performed using “R v. 4.1.0” in Rstudio 1.3.1039. “Pheatmap” package of R program was used to create heat map and hierarchical clustering for various stress indices.

RESULTS AND DISCUSSION

Plant growth characteristics: Plant growth parameters showed significant increase under SI condition as compared to RF condition in all the genotypes (Table 2). Irrespective of treatments, plant biomass was estimated maximum in RMO-40 followed by RMO-257 and minimum in CZM-45 and maximum under SI (6.7 g plant^{-1}) condition which was almost double than biomass under RF (3.1 g plant^{-1}) condition. The interaction between genotypes and treatments revealed that plant biomass was maximum in RMO-40 followed by RMO-257 under SI condition and minimum in RMO-225 under RF condition. Chen et al (2018) also showed that supplemental irrigation increased the above ground biomass in sorghum and cotton plants. Irrespective of treatments, no significant variation was observed in plant height among the genotypes. Plant height was maximum in SI condition (26.6 cm) which was 49 % higher than RF (17.9 cm) condition. The interaction between genotypes and treatments was non significant for plant height (Table 5). Souza et al (2020) observed similar results in which varied irrigation regimes had no significant effect on plant height.

Total chlorophyll was estimated maximum in RMB-25 followed by RMO-40 irrespective of treatments (Table 2). Total chlorophyll under SI (2.4 mg g^{-1} fw) condition was 24.4% higher than RF (1.9 mg g^{-1} fw) condition. The total chlorophyll was maximum in RMO-40 in SI condition and minimum in CZM-45 in RF condition. Similarly carotenoid content was maximum in SI (0.67 mg g^{-1} fw) condition as compared to RF (0.55 mg g^{-1} fw) condition (Table 2). Carotenoid content was maximum in RMO-40 with par value in RMB-25 under SI condition while minimum in CZM-45 under RF condition. The main reason for decrease in chlorophyll and carotenoids content as affected by water stress is that during drought stress the plant tends to produce reactive oxygen species which can lead to lipid peroxidation and chlorophyll and carotenoid destruction (Mafakheri et al 2010, Hu et al 2023).

The leaf area was maximum in SI (470.9 cm^2) condition which was almost double than RF (229.9 cm^2) one (Table 2). Irrespective of treatments, was highest in RMO-40 followed by RMO -2251 and minimum in RMO-25. Perusal of data pertaining to the interaction between genotypes and treatments revealed that leaf area was maximum in RMO-40 under SI condition while minimum in RMO-225 under RF condition. The genotypes, treatments difference and interaction were significant for chlorophyll, carotenoids and leaf area (Table 5). Supplemental irrigation increased the chlorophyll content that in turn increased the photosynthetic activity and leaf area of the plants (Liao et al 2022), while

Table 1. Weather data for the growing period of mothbean at the CAZRI (RRS), Bikaner

Months	Relative humidity (%)	Temperature		Total rainfall (mm)
		Minimum (°C)	Maximum (°C)	
August	44.4	37.0	27.5	99.2
September	34.9	38.4	25.4	16.4
October	28.0	35.7	18.6	0.0

Source: Meteorological station, CAZRI (RRS),Bikaner water limiting conditions caused reduction in leaf area due to inhibition of cell expansion by declining rate of cell division and loss of cell turgidity to minimize transpiration losses (Bangar et al 2019). Furthermore, the variation in the growth attributes among the genotypes might be due to the genotypic variations associated with the different genotypes under the present investigation.

Plant water status: Plant water status is the basic criteria for drought tolerance measurement. RWC, MSI and WP were significantly improved under SI condition as compared to RF condition (Table 3). Irrespective of treatments, RWC was maximum in RMO-257 with non-significant variation with RMO-40 while was minimum in RMO-435 with par value in RMO-225. Regardless of genotypes, SI (84%) treatment improved RWC of plant which was 26.12% higher than plants under RF (66.6%) condition. The interactive effect of genotypes and treatments showed that RWC was maximum for CZM-45 under SI condition followed by RMO-257 whereas minimum RWC was recorded in RMO-435 under RF condition.

Similarly, regardless of treatments, MSI and WP were estimated maximum in RMO-40 were at par with RMO 225and minimum in RMO-225. MSI and WP were significantly improved under irrigated condition i.e. 22.9% and 39.5% higher than respective RF genotypes. Irrigated RMO-40 genotype had maximum MSI and WP values with minimum in rainfed RMO-225 genotype. Genotypic variability, treatment difference and the interaction of genotypes and treatments was found to be statistically significant for RWC, MSI and WP) (Table 5). Chowdhury et al

Table 2. Plant growth parameters of mothbean genotypes grown under rainfed and supplemental irrigation conditions

Treatment		Plant biomass (g)	Plant height (cm)	Total chlorophyll (mg g^{-1} fw)	Carotenoids (mg g^{-1} fw)	Leaf area (cm^2)
Genotypes						
RMO-257		5.7a	22.6a	2.0d	0.56c	336.6cd
RMO-40		5.8a	21.8a	2.3ab	0.64ab	396.7b
RMB-25		4.8bc	22.2a	2.4a	0.66a	326.2d
RMO-2251		4.9b	22.1a	2.0cd	0.63ab	362.6b
CZM-45		4.4c	22.1a	2.0d	0.55c	351.1bc
RMO-435		4.6bc	22.0a	2.3ab	0.64ab	350.7bc
RMO-225		4.4c	22.9a	2.2bc	0.60bc	328.9d
Treatments						
Rainfed (RF)		3.1b	17.9b	1.9b	0.55a	229.9b
Supplemental irrigation (SI)		6.7a	26.6a	2.4a	0.67b	470.9a
Genotypes x Treatments						
RMO-257	RF	4.3d	18.6bc	1.7hi	0.51ef	253.0ef
	SI	7.1b	26.7a	2.2cd	0.61bcd	420.2d
RMO-40	RF	3.9d	18.4bc	2.0fgh	0.56de	262.4e
	SI	7.7a	25.1a	2.7a	0.72a	531.1a
RMB-25	RF	3.1e	16.4c	2.2cdef	0.61cd	220.5ghi
	SI	6.5bc	28.0a	2.6a	0.72a	431.9d
RMO-2251	RF	3.1e	16.1c	2.0efg	0.58cd	237.7efg
	SI	6.7bc	28.1a	2.1def	0.68ab	487.4bc
CZM-45	RF	2.6ef	17.6bc	1.7i	0.49ef	231.0fgh
	SI	6.1c	26.6a	2.3cd	0.62bcd	471.1bc
RMO-435	RF	2.6ef	18.0bc	2.2cde	0.63bc	207.80hi
	SI	6.6bc	25.9a	2.4bc	0.64bc	493.5b
RMO-225	RF	2.3f	20.1b	1.8ghi	0.48f	196.5i
	SI	6.5bc	25.7a	2.6ab	0.72a	461.2c
CV%		7.8	9.1	6.4	6.6	4.7

Data with different alphabet, are significantly different ($p < 0.05$) as analyzed by Duncan's multiple comparison tests for post hoc analysis
CV: coefficient of variation

(2017) also showed that water stress condition significantly decreased the RWC, MSI and WP of plants. Loss of water from plant tissues under drought conditions decreases WP and RWC in plants and also impairs the membrane structure and function thus more membrane electrolyte leakage (Buchanan et al 2015). Different genotypes showed different RWC and WP which may be due to differences in ability of genotypes to absorb water from soil or the ability to accumulate osmolytes to maintain tissue turgor. Based on RWC, WP and MSI, the genotypes RMO-257 and RMO-40 were showing higher values and thus more tolerance to drought conditions and RMO-435 and RMO-225 were showing lesser values thus more susceptible to drought.

Enzymatic activities: Irrespective of treatment, NR activity was estimated maximum in RMB– 25 with at par value in RMO -40 and RMO-257, however, was minimum in RMO-435 and was at par with RMO-225 (Table 3). NR activity was calculated significantly higher in irrigated mothbean plants as compared to rainfed one (53.6 %). The interaction between genotypes and treatments revealed that NR activity was maximum in irrigated RMB-25 and minimum in rainfed RMO-225. This might be due to increased total chlorophyll content which had a positive relationship with the NR activity. In previous studies with mothbean, the NR activity of mothbean decreased by around 80% at 10 days after drought stress treatment and resulted in altered nitrogen metabolism (Garg et al 2001).

The activity of antioxidative enzymes APOX and GPOX

Table 3. Plant water status and enzymatic activities of mothbean genotypes grown under rainfed and supplemental irrigation conditions

Treatment		RWC (%)	MSI (%)	WP (-MPa)	NR (µmoles g^{-1} fw h^{-1})	APOX (µmoles min^{-1} (mg protein $^{-1}$)	GPOX (µmoles min^{-1} (mg protein $^{-1}$)
Genotypes							
RMO-257		80.0a	81.7a	-3.6ab	1.3a	228.9a	1280.1a
RMO-40		79.4a	82.6a	-3.4a	1.3a	210.4b	1176.8b
RMB-25		74.3bc	70.4b	-3.9b	1.4a	185.2c	912.1c
RMO-2251		73.3bc	71.1b	-.3.8b	1.2bc	173.9c	821.2d
CZM-45		77.2ab	70.8b	-4.3c	1.2b	201.6b	757.4e
RMO-435		71.3c	73.7b	-4.6cd	1.1c	143.3d	715.4e
RMO-225		71.7c	66.3c	-4.9d	1.1c	141.3d	764.7de
Treatments							
Rainfed (RF)		66.6b	66.2b	-5.1b	1.0b	233.5a	1058.9a
Supplemental irrigation (SI)		84.0a	81.4a	-3.1a	1.5a	133.6b	777.6b
Genotypes x Treatments							
RMO-257	RF	72.7c	76.9cd	-4.0de	1.2fg	282.8a	1517.2a
	SI	87.4ab	86.6a	-3.3bc	1.5cd	175.2gh	1043c
RMO-40	RF	74.8c	78.0cd	-4.3ef	1.1gh	264.1ab	1325.9b
	SI	84.6ab	87.1a	-2.5a	1.6abc	156.7h	1027.7c
RMB-25	RF	66.1de	58.0f	-4.9g	1.1gh	234.2cd	1068.3c
	SI	82.5ab	82.9ab	-2.8ab	1.7a	136.2i	755.9e
RMO-2251	RF	64.3de	62.3ef	-4.6fg	1.0h	248.1bc	897.2d
	SI	82.2ab	79.8bc	-3.0bc	1.3ef	99.9j	745.2e
CZM-45	RF	66.6d	66.4e	-5.5h	1.0h	218.1de	882.2d
	SI	87.8a	75.2cd	-3.1bc	1.4de	184.9fg	632.7f
RMO-435	RF	60.5e	63.6e	-5.9hi	0.7i	182.9g	850.3d
	SI	82.0b	83.8ab	-3.2bc	1.5bcd	103.7j	580.6f
RMO-225	RF	61.6de	57.9f	-6.2i	0.6i	204.ef	871.3d
	SI	81.7b	74.6d	-3.6cd	1.6ab	78.5k	658.1f
CV%		4.5	3.9	-7.6	6.6	6.3	5.3

Data with different alphabet, are significantly different ($p < 0.05$) as analyzed by Duncan's multiple comparison tests for post hoc analysis
CV: coefficient of variation

were estimated maximum in RMO-257 followed by RMO-40 (Table 3). APOX and GPOX in rainfed plants were 42.8 and 26.6% higher than respective irrigated genotypes. Furthermore, it was observed that rainfed RMO-257 had maximum APOX and GPOX activity were minimum for APOX in irrigated RMO-225 followed by RMO-435 and for GPOX in irrigated RMO-435 which was at par with irrigated RMO-225. The difference between genotypes, treatments and the interaction effect was statistically significant for NR, APOX and GPOX (Table 5). Antioxidative enzyme activity was increased more under drought condition in tolerant genotype as compared to susceptible genotype (Sarker and Oba 2018). This increased in antioxidative activity is a defense response against the generated ROS to cope up with the stress.

Yield and yield attributes: The results showed that irrespective of treatment, yield and its all attributes were estimated maximum in RMO-257 and BP, PP and SP were recorded minimum in CZM-45, while PL and seed yield were recorded minimum in RMO-435 and RMO-225, respectively (Table 4). SI improved BP, PL, PP, SP, TW and yield which is 30.5, 14.2, 82.9, 13.3, 7.6 and 34.3%, higher than RF one respectively. The genotypes and treatments interaction revealed that all the yield parameters except BP were maximum in RMO-257 under RF condition. The values for BP, PP and SP were minimum in RMO-435 genotype and TW and Y were observed minimum in RMO-225. The effect of genotype and treatment was statistically significant for almost all the yield components but the interaction between genotype and treatment was non-significant (Table 5). The

Table 4. Yield attributes of mothbean genotypes grown under rainfed and supplemental irrigation conditions

Treatment		Branches per plant	Pod length (cm)	Pods per plant	Seeds per pod	Test weight (g)	Seed yield (kg/ha)
Genotypes							
RMO-257		4.5a	4.1a	40.1a	5.7a	36.3a	757.1a
RMO-40		4.2b	4.0ab	33.8b	5.4abc	35.9ab	648.7cd
RMB-25		4.3ab	4.09ab	38.0a	5.6ab	34.1bcd	649.5cd
RMO-2251		4.3ab	4.0ab	31.9bc	5.1c	32.3d	696.1abc
CZM-45		3.7c	4.0ab	29.8c	5.1c	34.5abc	729.3ab
RMO-435		3.8c	3.9b	32.9bc	5.3bc	34.0bcd	690.2bc
RMO-225		3.8c	4.0ab	31.1bc	5.4abc	33.3cd	613.4d
Treatments							
Rainfed (RF)		3.5b	3.7b	24.0b	5.0b	33.1b	583.4b
Supplemental irrigation (SI)		4.6a	4.3a	43.9a	5.7a	35.6a	783.6a
Genotypes x Treatments							
RMO-257	RF	4.1ef	3.9b	29.5e	5.3bcde	34.0bcd	649.1cd
	SI	4.9ab	4.3a	50.8a	6.1a	38.5a	865.1a
RMO-40	RF	3.9f	3.7bc	24.4fg	5.0ef	35.1bc	599.6de
	SI	4.4cde	4.3a	43.2bcd	5.7abcd	36.8ab	697.8c
RMB-25	RF	3.4gh	3.7c	28.3ef	5.2def	33.1cd	593.2de
	SI	5.2a	4.3a	47.8ab	6.0a	35.1bc	705.8c
RMO-2251	RF	3.8fg	3.8bc	23.4fg	4.9ef	31.9d	586.9de
	SI	4.8abc	4.3a	40.5d	5.4bcde	32.7cd	805.3ab
CZM-45	RF	3.3h	3.8bc	21.3g	5.0ef	32.8cd	606.7de
	SI	4.2def	4.3a	38.3d	5.3cdef	36.3ab	852.0a
RMO-435	RF	3.0h	3.6c	19.9g	4.8f	33.0cd	552.3e
	SI	4.6bcd	4.2a	45.8abc	5.9ab	35.0bc	828.2a
RMO-225	RF	3.4gh	3.7bc	21.2g	5.0ef	31.6d	496.2f
	SI	4.3cde	4.2a	41.1cd	5.7abc	34.9bc	730.7bc
CV%		6.2	3.7	9.0	5.9	5.2	7.8

Data with different alphabet, are significantly different ($p < 0.05$) as analyzed by Duncan's multiple comparison tests for post hoc analysis
CV: coefficient of variation

reduction in seed yield and test weight under RF condition is thought to be caused by a decrease in photosynthate assimilation and poor carbohydrate partitioning to the developing grain because of drought stress (Nathawat et al 2018). Improving the status of water through irrigation at the reproductive stage helps to sustain reproductive success and the partition of assimilates for optimum yields in water-limited conditions (Molla et al 2021).

Pearson correlation matrix plot, principal component analysis and box plot: The results of the correlation analysis for the yield and different traits in mothbean genotypes under rainfed and irrigated condition revealed the variegated strengths and directions of the relationships (Fig. 1). Positive correlations were found between the Y and BM, PH, LA, RWC, BP, PL, PP, WP, MSI and NR. Low significant positive correlation was found between the Y and TC, CT, SP and TW. Similarly low significant negative correlation between the Y and APOX and insignificant negative correlation between Y and GPOX was observed.

The total contribution to the first two components of variation was 78.6% (Fig. 2). The first principal component (PC1) contributed to the variations by 68% and similar to the

Table 5. Mean squares and degree of freedom of all parameters of mothbean plants

Variation source	*df*	BM	PH	TC	CT	LA	RWC
Genotypes (G)	6	2.16 *** (0.000)	0.95 ns (0.962)	0.18*** (0.000)	0.01*** (0.000)	3535*** (0.000)	76.80*** (0.000)
Treatments (T)	1	137.03*** (0.000)	793.01*** (0.000)	2.37*** (0.000)	0.15*** (0.000)	610043*** (0.000)	3205.10*** (0.000)
G X T	6	0.30 ns (0.090)	8.56 ns (0.089)	0.11*** (0.000)	0.01** (0.004)	2433*** (0.000)	24.12 ns (0.090)
Error	26	0.15	4.09	0.02	0.00	266	11.61
Variation source	*df*	MSI	WP	NR	APOX	GPOX	BP
Genotypes (G)	6	224.72*** (0.000)	1.68*** (0.000)	0.08***(0.000)	6615***(0.000)	297812***(0.000)	0.55*** (0.000)
Treatments (T)	1	2450.42*** (0.000)	41.66*** (0.000)	2.83***(0.000)	104724***(0.000)	831031***(0.000)	12.26*** (0.000)
G X T	6	58.52*** (0.000)	0.70*** (0.000)	0.11***(0.000)	1998***(0.000)	15237***(0.000)	0.280**(0.003)
Error	26	8.29	0.09	0.01	135	2406	0.06
Variation source	*df*	PL	PP	SP	TW	Y	
Genotypes (G)	6	0.03 ns (0.233)	85.40*** (0.000)	0.28*(0.027)	11.76**(0.008)	15007**(0.001)	
Treatments (T)	1	2.95***(0.000)	4159.13***(0.000)	4.83***(0.000)	67.30***(0.000)	420538***(0.000)	
G X T	6	0.01 (0.842)	14.01 ns (0.214)	0.09 ns (0.475)	2.44 ns (0.603)	6905 (0.051)	
Error	26	0.02	9.30	0.09	3.19	2811	

"***",and "**" are significance codes at 0.001 and 0.001, respectively and "ns" is not significant
BM (biomass), PH (plant height), TC (total chlorophyll), CT (carotenoids), LA (leaf area), RWC (relative water content), WP (water potential), MSI (membrane stability index), NR (nitrate reductase), APOX (ascorbate peroxidase), GPOX (guaiacol peroxidase), BP (branches per plant), PL (pod length), PP(pods per plant), SP (seeds per pod), TW (test weight) and Y (yield).

Table 6. Drought tolerance indices calculated for seed yield of seven mothbean genotypes under rainfed (RF) and supplemental irrigation (SI) condition

Genotypes	Drought indices (Seed yield)												
	Ys	Yp	SSI	TOL	STI	YI	YSI	SDI	DI	RDI	SSPI	GMP	MP
RMO-257	649.1	865.1	0.98	216.0	0.915	1.11	0.75	0.25	0.83	1.01	13.8	749.4	757.1
RMO-40	599.6	697.8	0.55	98.1	0.682	1.03	0.86	0.14	0.88	1.15	6.3	646.9	648.7
RMB-25	593.2	705.8	0.62	112.6	0.682	1.02	0.84	0.16	0.85	1.13	7.2	647.1	649.5
RMO-2251	586.9	805.3	1.06	218.4	0.770	1.01	0.73	0.27	0.73	0.98	13.9	687.5	696.1
CZM-45	606.7	852	1.13	245.3	0.842	1.04	0.71	0.29	0.74	0.96	15.7	719.0	729.4
RMO-435	552.3	828.2	1.30	275.9	0.745	0.95	0.67	0.33	0.63	0.90	17.6	676.3	690.3
RMO-225	496.2	730.7	1.26	234.5	0.591	0.85	0.68	0.32	0.58	0.91	15.0	602.1	613.5

Ys (Yield under stress condition), Yp (Yield under irrigated condition), SSI (Stress susceptibility index), TOL (Stress Tolerance), STI (Stress tolerance index), YI (Yield index), YSI (Yield stability index), SDI (Sensitivity drought index), DI (Drought resistance index), RDI (Relative drought index), SSPI (Stress susceptibility percentage index), GMP (Geometric mean productivity) and MP (Mean productivity)

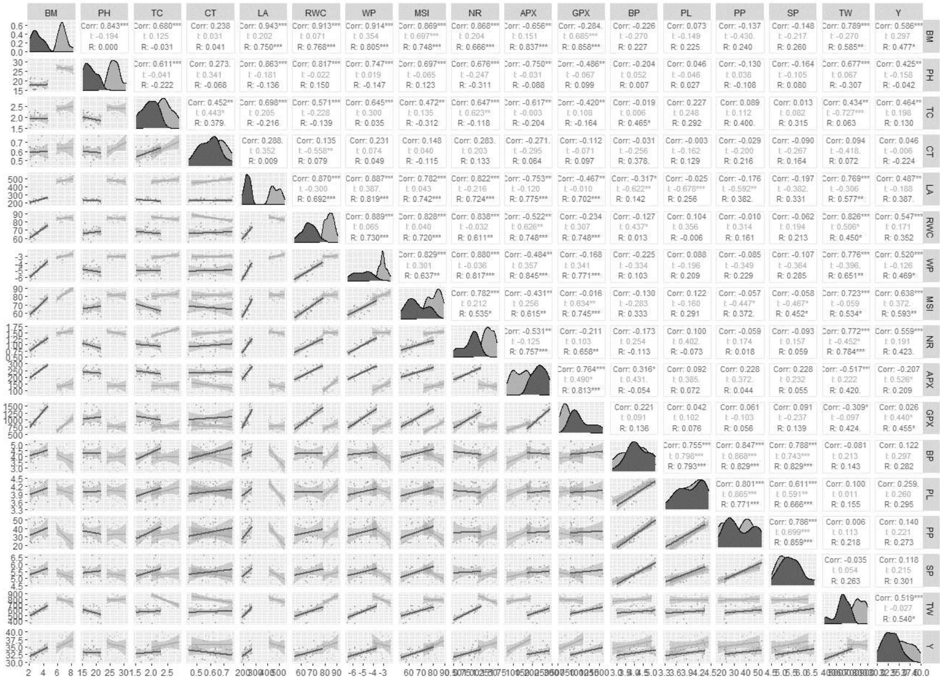

Fig. 1. Correlation matrix plot among all evaluated traits in seven mothbean genotypes studied under rainfed (R) and supplemental irrigation (I) conditions. The tested variables included. BM (biomass), PH (plant height), TC (total chlorophyll), CT (carotenoids), LA (leaf area), RWC (relative water content), WP (water potential), MSI (membrane stability index), NR (nitrate reductase), APX (ascorbate peroxidase), GPX (guaiacol peroxidase), BP (branches per plant), PL (pod length), PP(pods per plant), SP (seeds per pod), TW (test weight) and Y (yield).

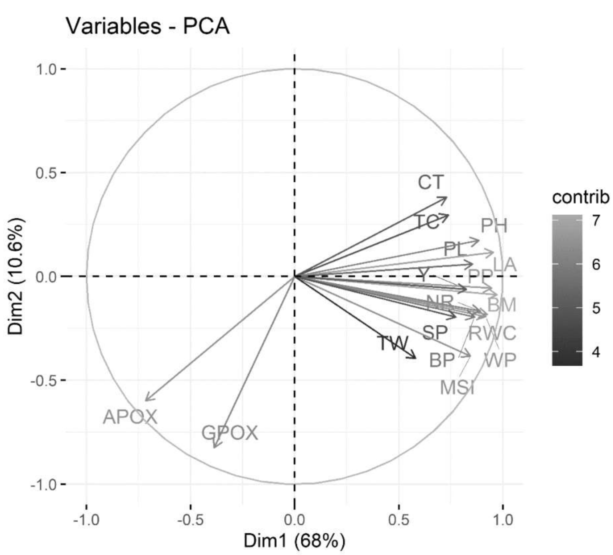

Fig. 2. Principal component analysis of all evaluated traits in seven mothbean genotypes studied under rainfed and supplemental irrigation conditions. The tested variables included. BM (biomass), PH (plant height), TC (total chlorophyll), CT (carotenoids), LA (leaf area), RWC (relative water content), WP (water potential), MSI (membrane stability index), NR (nitrate reductase), APOX (ascorbate peroxidase), GPOX (guaiacol peroxidase), BP (branches per plant), PL (pod length), PP(pods per plant), SP (seeds per pod), TW (test weight) and Y (yield)

results of correlation matrix plot indicated a strong correlation between Y and BM, PH, LA, MSI, RWC, WP, NR, BP, PL, PP while weak correlation with SP, TC, CT and TW. The second principal component (PC2) contributed to the variations by 10.6%, and it had a strong correlation with the APOX and GPOX.

Box plots for descriptive statistic parameters were also constructed (Figure 3). From the box plot representation it was observed that the values for almost all the traits increased under SI condition except APOX and GPOX, which showed an decrease under SI condition.

Drought tolerance indices: Drought tolerance indices indicate the ability of the genotypes to survive in drought stress conditions. Drought tolerance indices for individual genotypes were estimated based on seed yield and were varied significantly indicating genotypic variability (Table 4). STI, YI, DI, GMP and MP were calculated highest in RMO-257 followed by RMO-40 and RMB-25 whereas SSI, TOL, SDI and SSPI were observed highest in RMO-435 genotype. RMO-2251, CZM 45 and RMO-225 were showing intermediate range of drought tolerance indices. The selection of genotypes based on drought tolerance indices were done by many researchers in which GMP and STI were found to be suitable genotype tolerance indices under non stresses and stressed conditions (Kumar et al 2008, Raman et al 2012).

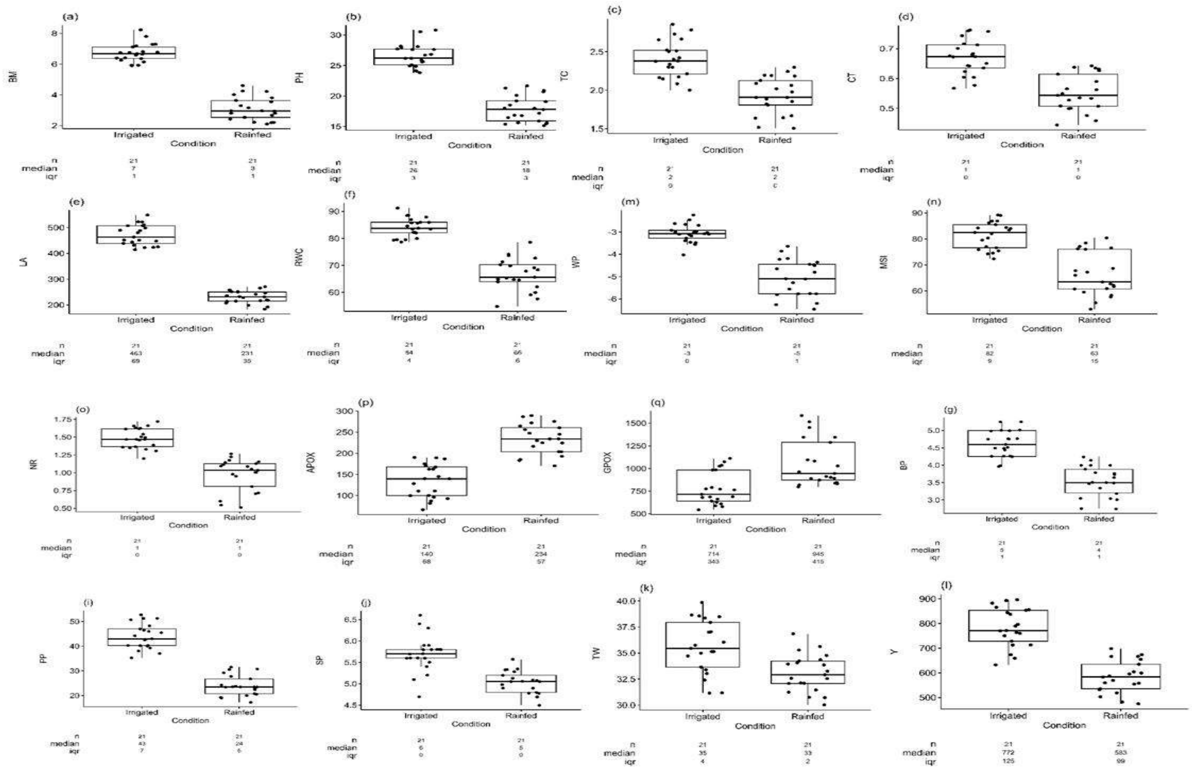

Fig. 3. Box plot of all evaluated traits in seven mothbean genotypes studied under rainfed and supplemental irrigation conditions. The tested variables included. BM (biomass), PH (plant height), TC (total chlorophyll), CT (carotenoids), LA (leaf area), RWC (relative water content), WP (water potential), MSI (membrane stability index), NR (nitrate reductase), APOX (ascorbate peroxidase), GPOX (guaiacol peroxidase), BP (branches per plant), PP(pods per plant), SP (seeds per pod), TW (test weight) and Y (yield)

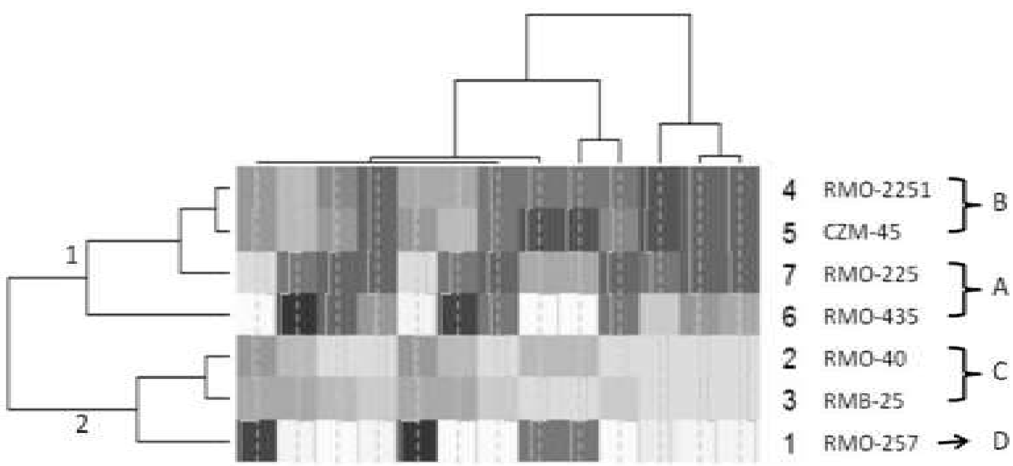

Fig. 4. Heatmap of stress indices among seven mothbean genotypes. Group 1 refers to stress susceptible genotypes, whereas group 2 refers to stress tolerant genotypes. Subgroup A is stress susceptible; subgroup B is moderately stress tolerant; subgroup C is stress tolerant; whereas D is highly stress tolerant. Black to white range is according to lower to higher correlation among genotypes and indices. SDI (Sensitivity drought index), YSI (Yield stability index), DI (Drought resistance index), STI (Stress tolerance index), SSI (Stress susceptibility index), RDI (Relative drought index), YI (Yield index), SSPI (Stress susceptibility percentage index), TOL (Stress Tolerance), Ys (Yield under stress condition), Yp (Yield under irrigated condition), GMP (Geometric mean productivity) and MP (Mean productivity)

Genotypic classification based on stress tolerance indices: Drought stress tolerance indices were studied for hierarchical clustering using a heat map (Fig. 4) and seven mothbean genotypes were classified in two major groups and four subgroups based on their stress responses. Group 1 was categorized as stress susceptible and group 2 as stress tolerant. Subgroup A consisted of two genotypes i.e. RMO-225 and RMO-435 with lowest grain yield and stress tolerance indices under RF condition, so these were considered as stress susceptible genotypes. Subgroup B consisted of two genotypes i.e. RMO-2251 and CZM-45 with intermediate values of yield and stress indices so considered as moderately stress tolerant. Subgroup C consisted of two genotypes i.e. RMO-40 and RMB-25 with higher yield and stress indices values so considered as stress tolerant. Genotype D i.e. RMO-257 had highest values for yield and stress indices so it was highly stress tolerant. Similar relationship between the drought tolerance indices and genotypes were also reported by Hussain et al (2021). Therefore, the drought tolerance indices were rapid selection criteria for selection of suitable genotypes under water stress conditions.

CONCLUSIONS

SI before flowering in areas where water availability is low under RF condition is beneficial to overcome the water stress conditions in mothbean genotypes. This helps the crop to improve its physiological and biochemical processes such as increase in photosynthetic pigments, water relation parameters such as WP, RWC and MSI, enzymes such as NR and growth traits which ultimately favors high yield as compared to the RF condition. Genotypes such as RMO-257, RMO-40 and RMB-25 having higher drought tolerance capacity can also be useful to compensate the yield losses under water limiting conditions. This study may help farmers to give sustainable yield of mothbean under anticipated water deficit conditions and improve the livelihood of farming community of hot arid region. The knowledge will also help in the identification of suitable genotypes of mothbean for achieving sustainable yield under water-deficit conditions.

AUTHORS CONTRIBUTIONS

VS and NSN initiated and designed the experiment. VS performed the experiments, collected the data and wrote the manuscript. MKB and CKJ analyzed the data. NSN revised the manuscript.

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Assessment of Pearl millet (*Pennisetum glaucum* L.) Legume Intercropping System under Dryland Condition

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Abstract: Field experiment was carried out at CCS Haryana Agricultural University, Hisar during *kharif* season of 2020 for suitable pearl millet-legume intercropping system for enhancement of yield and economics. There were eleven treatments *viz*., pearl millet, green gram and cluster bean sole at 45 cm, pearl millet in combination with green gram and cluster bean at variable ratio at 45 and 30 cm with four replications. The highest yield parameters of pearl millet were in pearl millet sole at 45 cm which was closely followed by pearl millet + green gram (8:4) at 30 cm. Yield attributes of intercrops were higher under sole cropping of intercrops followed by pearl millet + green gram/cluster bean (8:4) at 30 cm. Pearl millet + green gram (8:4) at 30 cm recorded highest pearl millet equivalent yield (3109 kg/ha) with higher net returns (₹ 41256/ha) and benefit: cost ratio (2.61). Higher yield indices under pearl millet + green gram (8:4) at 30 cm showed the superiority over other intercropping systems.

Keywords: Cluster bean, Dryland, Green gram, Intercropping, Pearl millet, Yield

Pearl millet is major coarse grain grown as rainfed crop on marginal lands under low input management conditions. Being inherent drought-escaping mechanism and adaptation to drier and low fertile conditions, it occupies a prime place in dryland agriculture and contributing significantly to country's food security. It is normally cultivated in those areas where annual rainfall ranges from 150 to 600 mm. Its sole cultivation is often risky and to avoid risks in rainfed/dryland areas, generally farmers grow green gram, cowpea, moth bean, black gram and cluster bean in mixed stands. Instead of sole and mixed cropping, intercropping of pearl millet with legumes has been reported to be more stable and profitable. In intercropping system, selection of compatible crops with different growth parameters and their suitable planting geometry are very significant because it helps to minimize the inter and intra specific competition for resources, thereby maximizing the production potential of the system (Sharma and Singh 2008). The suitable intercropping system might increase the total production through efficient utilization of production factors like space, moisture, nutrients etc. Short duration crops have ample scope to grow with other crops for introducing some compatible intercrops to increase the productivity. The complementarity effect and productivity increases are highest when the component crops have diverse growing habitat to meet their significant resource demands at different times (Maitra et al 2021). The selection of crops which will show complementarity among them is a key consideration to ensure efficient utilization of available resources (Huss et al 2022). Green gram and cluster bean with deep fast penetrating root system in combination with drought avoidance capabilities can survive and thrive for a considerable period in open field, exhibiting fast depletion of soil moisture with very high atmospheric temperature. The multi adaptive and adjusting nature of these crops have enabled them to become an integral part of different types of cropping and farming system of the arid and semi-arid regions. The information regarding intercropping systems of pearl millet-legume with varying row ratios is meagre under dryland conditions, therefore, the present study was undertaken.

MATERIAL AND METHODS

Field experiment was conducted during rainy (*kharif*) season of 2020 at Dryland Agriculture Research Farm, Chaudhary Charan Singh Haryana Agricultural University, Hisar, India ($29^0$10' N, $75^0$46' E and 215.2 m above mean sea-level). The average annual precipitation of the experimental site estimated to 425.5 mm and most of which is received from South-Western monsoon during July to September. The soil of the experimental field was sandy loam, low in organic carbon (0.29%) and in available nitrogen (112 kg/ha), medium in available phosphorus (15.5 kg/ha) and potassium (235 kg/ha). The experiment was laid out in randomized block design with four replications comprising of eleven intercropping treatments (Table 1). Hybrid 'HHB 67 Improved' pearl millet, 'MH 421' green gram and 'HG 2-20' cluster bean were sown on 14 July 2020. The fertilizer dose of 40 kg N + 20 kg P_2O_5/ha to pearl millet and 20 kg N + 40 kg P_2O_5/ha to legumes was applied at sowing. The other agronomic practices were followed as per package of practices during the crop growth period. The number of dry spells of more than 10 days experienced by the crop was 2 during the crop season. Pearl millet, green gram and cluster bean were harvested at 73, 57 and 87 days after sowing.

Observations on plant height and dry-matter accumulation/plant were recorded manually on 5 random plants from each plot of each replication separately as well as yield and yield-attributing characters were recorded as per the standard method. The grain yield of all the crops in sole as well as in intercropping systems were subjected to statistical analysis only after conversion into the pearl millet equivalent yield taking into consideration the average market prices of the grain (pearl millet ₹ 2150/100 kg, green gram ₹ 7196/100 kg and cluster bean ₹ 4000/100 kg). To find out the most profitable treatment, economics of different treatments were worked out in terms of net returns of the crop. Treatment-wise benefit: cost (B: C) ratio was calculated to ascertain economic viability. All the results were analyzed statistically for drawing conclusion using online statistical analysis tools (OPSTAT).

Land equivalent ratios (LER) = La + Lb, La = Yab/Yaa, Lb = Yba/Ybb where, La and Lb are land equivalent ratio of main and intercrops, respectively. Yaa and Yab are yields of main crop while Ybb and Yba are the yields of intercrops in sole stands and in intercropping, respectively. Area time equivalent ratio (ATER) = (LaTa + LbTb)/T where La and Lb, are partial LERs of main and intercrops, Ta and Tb are duration of main and intercrops and T is the total duration of the whole intercropping system. Income equivalent ratio (IER) = income from both main and intercrops in intercropping system/income from sole main crop. Monetary advantage index (MAI) = Net returns from combined produce (₹/ha) × (LER-1)/LER. Aggressivity of main crop (Aab) = {(Yab/Yaa × Zab) - (Yba/Ybb × Zba)} and of intercrop (Aba) = {(Yba/Ybb × Zba) - (Yab/Yaa × Zab)}. Relative crowding coefficient of main crop (Kab) = (Yab × Zba)/(Yaa-Yab) Zab and of intercrop (Kba) = (Yba× Zab)/(Ybb – Yba) Zba, and product of both (K) = Kab × Kba. Competitive ratio of main crop (Cra) = (LERa/LERb) (Zba/Zab) and of intercrop (Crb) = (LERb/LERa) (Zab/Zba) where Zab, proportion of intercrop area allocated to main crop and Zba, proportion of intercrops area allocated to intercrop.

RESULTS AND DISCUSSION

Weather and climate: The data on rainfall were recorded at the meteorological observatory of CCS Haryana Agricultural University, Hisar (Fig. 1). The total rainfall received was 151.9, 94.2 and 34.7 mm during July, August and September, respectively. However, total amount of rainfall received during the crop growth period was 239.4 mm. The mean weekly maximum and minimum temperatures ranged from 32.6 to 38.7°C and 16.3 to 27.9°C respectively during crop growing period. The weekly mean relative humidity ranged from 79 to 94% in morning and 28 to 77% in evening hours. The weekly mean wind speed fluctuated between 2.9 to 8.7 km/hour. The bright sun-shine hours ranged from 5.1 on a cloudy day to 8.7 on a clear day. Evaporation from open pan evaporimeter ranged between 3.5 to 7.6 mm/day in 36[th] to 27[th] standard weeks, respectively.

Pearl millet: Sole pearl millet recorded significantly higher plant height (182.22 cm) than that intercropping with green gram/cluster bean which is due to competition for sunlight among the plants (Table 1) and was at par with pearl millet + green gram (8:4) at 30 cm and pearl millet + cluster bean (8:4)

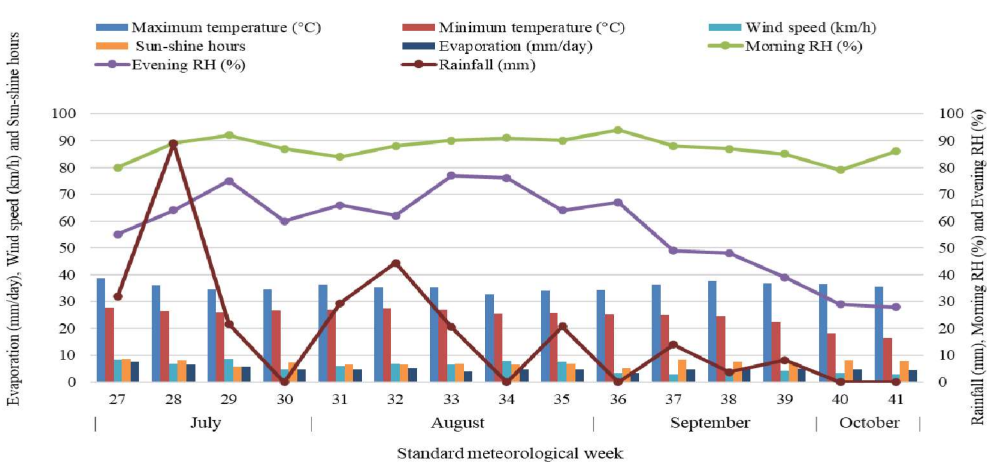

Fig. 1. Weather parameters during crop season

at 30 cm. The shorter plants of pearl millet were observed when intercropped at different row ratios with legumes. This was due to interspecies and cooperative interaction of intercrops with pearl millet for non-renewable resources like water, nutrients and light. The increase in plant height is a function of cell division and cell enlargement which depends on availability of nutrients in a balanced form especially N, P and K. Since soil of the experimental field was low in N, medium in P and K, therefore, sole stands of pearl millet might have faced less competition for growth and yield attributing characters as compared to intra-species competition in between pearl millet and intercrops (green gram and cluster bean). That may lead to establishment of better nutritional environment in root zone for growth and development. The number of total tillers/plant at harvest was significantly influenced by intercropping treatments. Sole pearl millet produced the maximum number of total tillers/plant (5.05) and was at par with pearl millet + green gram (8:4) at 30 cm, pearl millet + green gram (6:6) at 45 cm, pearl millet + cluster bean (8:4) at 30 cm, pearl millet + cluster bean (6:6) and pearl millet + green gram (4:4) both at 45 cm. These results corroborated with the finding of Suman et al (2021).

The significant increase in number of effective tillers/plant at harvest was observed in pearl millet sole at 45 cm over intercropping treatments. However, it was at par with pearl millet + green gram (8:4) at 30 cm, pearl millet + green gram (6:6) at 45 cm, pearl millet + cluster bean (8:4) at 30 cm and pearl millet + cluster bean (6:6) at 45 cm. This was due to less competition for resources by the intercrops during growth and development of the crop. Similar results were obtained by Renu et al (2018). Sowing of sole pearl millet at 45 cm produced significantly higher ear head length and ear head girth superior to all other intercropping treatments. However, it was at par with pearl millet + green gram (8:4) at 30 cm, pearl millet + green gram (6:6) at 45 cm and pearl millet + cluster bean (6:6) at 45 cm. The higher length and girth of earhead may be due to lower number of pearl millet density and wider space available for more growth and development of pearl millet. Suman et al (2021) had similar observations regarding yield-attributing characters of pearl millet. Seed index of pearl millet was not affected significantly with different intercropping treatments.

Intercrops: Sole green gram at 45 cm recorded significantly higher plant height (49.80 cm) than its intercropping with pearl millet except pearl millet + green gram (8:4) at 30 cm (Table 2). Yield- attributing characters of green gram, viz. number of branches/plant and pods/plant were higher under sole green gram at 45 cm which remained at par with pearl millet + green gram (6:6) at 45 cm and pearl millet + green gram (8:4) at 30 cm. Number of seeds/pod and seed index were not influenced significantly by intercropping treatments. Sole cluster bean at 45 cm being at par with pearl millet + cluster bean (8:4) at 30 cm recorded significantly higher plant height than other intercropping treatments. Cluster bean sole at 45 cm produced significantly higher number of pods/plant and seeds/pod compared to other intercropping treatments except pearl millet + cluster bean (8:4) at 30 cm. Yield attributes of cluster bean viz., number of branches/ plant and seed index were found to be non-significant with respect to different intercropping treatments. Similar results have also been reported by Kumar et al (2017).

Pearl millet-equivalent yield: The significant reduction in grain and stover yield was observed under intercropping treatments (Table 3). The maximum grain yield of pearl millet was found in sole pearl millet at 45 cm. The reduction in yield of pearl millet in the intercropping system was mainly due to reduction in plant stands and replacement and additive type

Table 1. Effect of intercropping on yield attributes of pearl millet

Treatments	Plant height (cm)	Total tillers/ plant	Effective tillers/ plant	Ear head length (cm)	Ear head girth (cm)	Seed index (g)
Pearl millet sole at 45 cm	182.22	5.05	4.15	23.15	9.02	8.97
Pearl millet + green gram (2:2) at 45 cm	172.52	4.45	3.44	22.12	8.08	8.72
Pearl millet + cluster bean (2:2) at 45 cm	169.56	4.00	3.05	22.16	7.94	8.74
Pearl millet + green gram (4:4) at 45 cm	173.08	4.50	3.47	22.37	8.52	8.79
Pearl millet + cluster bean (4:4) at 45 cm	171.09	4.30	3.35	22.81	8.48	8.72
Pearl millet + green gram (6:6) at 45 cm	176.36	4.80	3.75	22.94	8.84	8.91
Pearl millet + cluster bean (6:6) at 45 cm	173.95	4.60	3.70	23.03	8.82	8.89
Pearl millet + green gram (8:4) at 30 cm	179.03	4.90	4.03	23.09	9.11	8.85
Pearl millet + cluster bean (8:4) at 30 cm	178.40	4.63	3.71	22.71	8.72	8.85
CD (p=0.05)	4.17	0.56	0.46	0.40	0.44	NS

of intercropping system was followed under the present study. Sharma and Singh (2008) also recorded the maximum grain and stover yields of pearl millet in sole system over inter and strip cropping systems. The highest grain and stover yield of intercrops was found in the sole crops of green gram and cluster bean, respectively. The grain yield of intercrops was highest in their sole stands which decreased by 48.0, 46.3, 44.8 and 23.6% in case of green gram and 41.5, 39.3, 37.0 and 24.1% in cluster bean with 2:2, 4:4, 6:6 and 8:4 intercropping systems at 45 cm. Variation in the grain and straw yield of both intercrops (green gram & cluster bean) among different intercropping treatments were recorded. It might be due to less competition for resources by the other crops during growth and development of the crop. Similar trend was observed by Yadav et al (2015). Intercropping treatments significantly influenced the pearl millet equivalent yield (Table 3). The pearl millet equivalent yield was highest under pearl millet + green gram (8:4) at 30 cm which decreased by 32.3, 27.7 and 24.7% in case of green gram and 36.3, 33.5 and 24.7% in cluster bean with 2:2, 4:4 and 6:6 intercropping systems at 45 cm. These results corroborated with the finding of Sharma and Singh (2008). Among replacement series of intercropping treatments, highest pearl millet equivalent yield (2340 kg/ha) was obtained under pearl millet + green gram (6:6) at 45 cm. Lowest pearl millet equivalent yield (1654 kg/ha) was observed under pearl millet sole at 45 cm.

Economics: Among various intercropping treatments, pearl

Table 2. Effect of intercropping on yield attributes of intercrops

Treatments	Plant height (cm)	Branches/ plant	Pods/plant	Seeds/ pod	Seed index (g)
Green gram					
Green gram sole at 45 cm	49.80	5.60	25.79	8.93	4.58
Pearl millet + green gram (2:2) at 45 cm	41.75	5.01	23.65	8.83	4.12
Pearl millet + green gram (4:4) at 45 cm	42.70	5.20	24.44	8.85	4.14
Pearl millet + green gram (6:6) at 45 cm	43.21	5.35	24.84	8.88	4.28
Pearl millet + green gram (8:4) at 30 cm	47.80	5.28	24.72	8.90	4.31
CD (p=0.05)	2.93	0.35	1.25	NS	NS
Cluster bean					
Cluster bean sole at 45 cm	85.98	5.25	37.01	6.52	2.21
Pearl millet + cluster bean (2:2) at 45 cm	80.73	5.05	33.19	5.85	2.16
Pearl millet + cluster bean (4:4) at 45 cm	81.81	4.60	33.36	5.90	2.11
Pearl millet + cluster bean (6:6) at 45 cm	82.83	4.73	34.34	6.11	2.12
Pearl millet + cluster bean (8:4) at 30 cm	83.88	4.83	35.82	6.37	2.17
CD (p=0.05)	2.46	NS	2.35	0.19	NS

Table 3. Pearl millet-equivalent yield as affected by different intercropping treatments

Treatments	Grain yield (kg/ha)		Stover yield (kg/ha)		Pearl millet-equivalent yield (kg/ha)
	Pearl millet	Legume	Pearl millet	Legume	
Pearl millet sole at 45 cm	1409	-	2927	-	1654
Green gram sole at 45 cm	-	704	-	1141	2410
Cluster bean sole at 45 cm	-	942	-	942	1960
Pearl millet + green gram (2:2) at 45 cm	722	366	1563	597	2105
Pearl millet + cluster bean (2:2) at 45 cm	715	551	1541	551	1981
Pearl millet + green gram (4:4) at 45 cm	782	378	1671	631	2247
Pearl millet + cluster bean (4:4) at 45 cm	745	572	1595	572	2067
Pearl millet + green gram (6:6) at 45 cm	861	388	1807	639	2340
Pearl millet + cluster bean (6:6) at 45 cm	825	593	1777	593	2207
Pearl millet + green gram (8:4) at 30 cm	1079	538	2220	904	3109
Pearl millet + cluster bean (8:4) at 30 cm	1065	715	2139	715	2730
CD (p=0.05)	68	-	143	-	192

millet + green gram in 8:4 at 30 cm showed the maximum net returns of ₹ 41256/ha and B: C ratio of 2.61 (Table 4). The highest net returns and B: C ratio were associated with its higher grain and stover yields per unit of added cost. The minimum net returns were noticed in sole pearl millet at 45 cm and pearl millet + cluster bean (2:2) at 45 cm because cluster bean might be more competitive than green gram. These findings are in the vicinity with those reported by Kuri (2012) and Suman et al (2021).

Yield indices: Land equivalent ratio (LER) of all intercropping treatments varied from 1.05 to 1.55 (Table 5). The intercropping treatment of pearl millet + green gram (8:4) at 30 cm showed the highest LER (1.55), closely followed by pearl millet + cluster bean (8:4) at 30 cm whereas the lowest value of LER (1.05) was observed in pearl millet + green gram (2:2) at 45 cm. Higher values of LER in pearl millet + green gram (8:4) at 30 cm reflect development of complimentarily with least competition in this system. Higher land equivalent ratio in intercropping system under rainfed conditions was also reported by Sharma et al (2015). Highest value of MAI was recorded in pearl millet + cluster bean (8:4) at 30 cm followed by pearl millet + green gram (8:4) at 30 cm. Area time equivalent ratio (ATER) ranged from 0.78 to 1.40. The highest area time equivalent ratio (ATER) of 1.40 was obtained in pearl millet + cluster bean (8:4) at 30 cm followed by pearl millet + green gram (8:4) at 30 cm (1.15) while the minimum ATER was obtained in pearl millet + green gram (2:2) at 45 cm (0.78). The intercrops had negative values of aggressivity, representing the low competitiveness of crop when grown as intercrop with pearl millet. The aggressivity of intercrops ranged from -1.04 to -2.30. Pearl millet + green gram (2:2) at 45 cm had greater value of aggresivity (-1.04) which did offer less competition to pearl millet as compared to pearl millet + green gram (8:4) at 30 cm. The lowest competition ratio (0.50) of pearl millet was under pearl millet + green gram (8:4) at 30 cm while highest value was under pearl millet + green gram (6:6) at 45 cm. Green gram showed the highest competitive ratio when intercropped with pearl

Table 4. Effect of intercropping on economics of crops

Treatments	Gross returns (₹/ ha)	Cost of cultivation (₹/ ha)	Net returns (₹/ ha)	Benefit: cost ratio
Pearl millet sole at 45 cm	35561	23695	11866	1.50
Green gram sole at 45 cm	51815	23630	28185	2.19
Cluster bean sole at 45 cm	42140	20763	21378	2.03
Pearl millet + green gram (2:2) at 45 cm	45258	25033	20225	1.81
Pearl millet + cluster bean (2:2) at 45 cm	42592	23600	18992	1.80
Pearl millet + green gram (4:4) at 45 cm	48311	25033	23278	1.93
Pearl millet + cluster bean (4:4) at 45 cm	44441	23600	20841	1.88
Pearl millet + green gram (6:6) at 45 cm	50310	25033	25278	2.01
Pearl millet + cluster bean (6:6) at 45 cm	47451	23600	23851	2.01
Pearl millet + green gram (8:4) at 30 cm	66844	25588	41256	2.61
Pearl millet + cluster bean (8:4) at 30 cm	58695	24633	34063	2.38

Table 5. Yield indices under pearl millet-legume intercropping systems

Treatments	LER	MAI	ATER	A		CR		K		
				A_P	A_i	CR_P	CR_i	K_P	K_i	K_t
PM + GG (2:2) at 45 cm	1.05	0.53	0.78	1.06	-1.04	1.02	0.98	1.13	1.08	1.22
PM + CB (2:2) at 45 cm	1.10	1.11	1.02	1.02	-1.17	0.87	1.15	1.03	1.41	1.45
PM + GG (4:4) at 45 cm	1.10	1.11	0.82	1.11	-1.10	1.01	0.99	1.25	1.22	1.52
PM + CB (4:4) at 45 cm	1.14	1.60	1.05	1.06	-1.22	0.87	1.15	1.12	1.55	1.74
PM + GG (6:6) at 45 cm	1.16	1.74	0.87	1.22	-1.10	1.11	0.90	1.57	1.23	1.93
PM + CB (6:6) at 45 cm	1.21	2.50	1.12	1.17	-1.26	0.93	1.07	1.41	1.70	2.39
PM + GG (8:4) at 30 cm	1.55	5.63	1.15	1.15	-2.30	0.50	2.00	1.63	6.50	10.61
PM + CB (8:4) at 30 cm	1.52	6.09	1.40	1.14	-2.28	0.50	2.01	1.55	6.32	9.78

PM-Pearl millet, GG-Green gram, CB-Cluster bean, LER-Land equivalent ratio, MAI-Monetary advantage index, ATER-Area time equivalent ratio, A-Aggressivity, CR-Competitive ratio, K (K_t)
-Total relative crowding coefficient, K_P-Relative crowding coefficient of pearl millet, K_i-Relative crowding coefficient of intercrops

millet in 8:4 at 30 cm while green gram showed the lowest competitive ratio with pearl millet in 2:2 at 45 cm. In general, the competitive ability of pearl millet with green gram in 8:4 at 30 cm was better than other ratios. Relative crowding coefficient values of pearl millet were lower than that of all the intercrops, indicating the dominance of all the intercrops over pearl millet. The RCC values of intercrops were always >1. This indicates that all the intercrops yielded more than expected and had better competitive ability than pearl millet in the intercropping system. The total relative crowding coefficient (10.61) was observed highest in pearl millet + green gram (8:4) at 30 cm among all the intercropping treatments, indicating highest yield. Ram and Meena (2014) also observed the higher yield indices under pearl millet and green gram intercropping system in 1:7 rows in arid region of Rajasthan.

CONCLUSION

Pearl millet sown with green gram (8:4) at 30 cm proved beneficial for getting higher yield and profitability of pearl millet-legume intercropping system under dryland condition of sandy-loam soils in arid/semi-arid regions.

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Study on Highly Efficient Direct Shoot and Root Organogenesis from Cotyledon and *In vitro* Derived Root and Leaf of *Citrus jambhiri* Lush.

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Abstract: A protocol was developed for the direct regeneration of plantlets from *C. jambhiri* leaf explants that had undergone *in vitro* regeneration. The goal of the current investigation was to determine how well *C. jambhiri* seed cotyledons might be directly used to regenerate shoots. The cotyledons enlarged as the seeds initiated its germination.. In MS medium supplemented with casein hydrolysate, the highest response to cotyledon expansion was observed. The number of enlarged cotyledons cultured by the medium treated with 50 mg L^{-1} of casein hydrolysate was highest (96%) and was followed by 100 mg L^{-1} (84%) and 200 mg L^{-1} of casein hydrolysate (78%). On the synthetic medium supplemented with 50 mg L^{-1} of casein hydrolysate (1.628 g/cotyledon), 100 mg L^{-1} of casein hydrolysate (1.148 g/cotyledon), and 200 mg L^{-1} of casein hydrolysate (1.050 g/cotyledon), the largest cotyledons by weight were produced. When the seeds were inoculated on MS media supplemented with 1.0 mg L^{-1} of IAA and 1.0 mg L^{-1} of IBA, direct regeneration from the roots of germinating seeds was observed in *C. jambhiri.* On MS media supplemented with various combinations and quantities of plant growth regulators, leaves excised from axenic shoot cultures were utilised to stimulate organogenesis. Adding 0.50 mg L^{-1} of dicamba to the medium indicated minimum percentage of leaf callus. As the leaf gradually dried up, the callus began to regenerate on the callus induction medium. Depending on the particular Citrus species, the quality of the germplasm, and the tissue culture practitioner's experience, direct organogenesis results might vary. To obtain promising results, factors including sterilisation, culture medium composition, and ambient factors should be properly optimised.

Keywords: Direct regeneration, PGR's, Enlarged cotyledons, Casein hydrolysate, Conservation

Citrus is a genus of flowering trees and shrubs of the Rutaceae family, well known as the citrus fruit. It is one of the most frequently grown fruit tree crops in the world and is valued for its delectable flavour, brilliant colours, and invigorating perfume. Oranges, lemons, limes, grapefruits, and tangerines are just a few of the well-known fruits of the genus *Citrus*, each of which has unique qualities and culinary applications. One of the most significant commercial horticulture crops in the world is the citrus species, which is grown in more than 100 countries, mostly in the Mediterranean area (Pandey and Tamta 2016). It produces many, vivacious nucellar seedlings that are essentially identical to zygotic seedlings due to polyembryony in nature (Kour 2012). Genetic erosion occurs in citrus because it is nearly impossible to distinguish zygotic seedlings from nucellar seedlings *in vivo.* Although vegetative propagation has advanced to some level to address these issues, traditional techniques like as budding and grafting to maintain "true-to-type" are naturally linked to clonal degeneration, mostly occured by viral infections. Axillary vegetative portions used for long-term clonal replication produce genetic instability, disease vulnerability, and viral complexity (Chaturvedi et al 2001).

To reduce these constraints, a very effective *in vitro* procedure involving appropriate explants and cultures is required. In plant biotechnology, citrus *in vitro* micropropagation is a complex and successful method for growing citrus plants in carefully regulated lab environments. It entails the development of citrus plantlets from tiny explants, such as shoot tips, leaf segments, or meristematic tissues, in a culture medium that is nutrient-rich and fortified with growth regulators and other necessary ingredients. The *in vitro* method provides a useful and effective tool for the production of elite large-scale planting materials, genetic preservation, and citrus enhancement. Using a variety of tissues and organs, including shoot tips (Gereme et al 2018), nodal explants (Gereme et al 2018), epicotyl segments (Kour 2016, Sidhu) and cotyledons (Saini et al 2010) *in vitro* regeneration in *C. jambhiri* has been effectively shown. Additionally, explants taken from mature plants result in contamination and poor *in vitro* shoot and root development (Tallo et al 2013). In order to reduce contamination and get "true-to-type" plants, the commercial micropropagation methodology focused on axillary explants selection from in vitro grown seedlings (Shenoy and Vasil 1992). Moreover, compared to indirect regeneration via the intermediary process of callusing, direct shoot organogenesis offers reduced somaclonal variability among the regenerants (Savita et al 2012). Citrus rootstocks and root explants are among the explants that are best at withstanding biotic stressors, including viral complex. Although there aren't many literatures on Citrus shoot induction from root segments (Saini et al 2010), there aren't any reports on the possibility of entire root explants for *Citrus jambhiri* direct organogenesis.

Direct regeneration of plantlets from somatic tissues is crucial because it results in plantlets that are true to type. Indirect regeneration of plantlets by callus induction offers a good deal of somaclonal diversity. Therefore, mass-multiplication of true-to-type plant propagules may benefit from direct regeneration of plantlets from explant. Numerous studies have been conducted on citrus species' direct regeneration from nodal segments and shoot tips (Taye et al 2018, Sharma and Roy 2020). There are, however, few study findings on direct regeneration from *Citrus* spp. cotyledon, leaf, and root. On the other hand, a large number of promising research results on indirect regeneration through callus initiation and plantlet regeneration are available (Badr-Elden 2017, Fatonah et al 2018, Sharma and Roy (2020). As a result, an effort was made in this project to standardise a procedure for the direct regeneration of plantlets from the cotyledon, root, and leaf of *Citrus jambhiri* Lush. This is the first account of direct organogenesis from *C. jambhiri* Lush's cotyledons, root, and shoot.

Vitamin supplements and growth media are essential for *in vitro* morphogenesis. One of the most used media for citrus micropropagation (Ali and Mirza 2006) is MS medium (Murashige and Skoog 1962). Moreover, the beginning of dormancy and the establishment of shoot and root architecture are significantly influenced by plant growth regulators (PGRs) and vitamins in the basal media (Nongmaithem et al 2020). For improved adaption (Kazan and Manners 2009) of *in vitro* plants, auxins such NAA, IAA, and indole-3-butyric acid (IBA) play a crucial role in root modulation. While cytokinins encourage the growth and multiplication of shoots, auxins aid in the creation of roots. It is possible to regulate the growth and development of the citrus plantlets by adjusting the concentration and ratio of these growth regulators in the culture media. Agar, carbohydrates, and amino acids are among the other ingredients used to help the formation and growth of the plantlets.

The explants grow into tiny plantlets under regulated environmental parameters, such as temperature, light intensity, and photoperiod. To preserve the plantlets' vigour and avoid nutrient depletion, they are sub-cultured onto new medium at intervals as they grow. Citrus plants may be propagated quickly as a result of this ability to produce many plantlets from a single explant. The plantlets are moved to *ex vitro* settings for acclimatisation once they have reached the proper size and are showing good development. This entails exposing the plants to ambient conditions, lowering humidity, and supplying the right amount of water and nutrients to the plants so that they may gradually adjust to the external environment. The plantlets can either be transplanted into the field or used for additional study and reproduction after a successful acclimatisation. Thus, this method allows for the quick multiplication of superior cultivars with desirable features as well as the preservation and trade of endangered and uncommon citrus types.

MATERIAL AND METHODS

Direct Regeneration from Different Explants of *Citrus jambhiri* Lush.

The current research was conducted at the Synthetic Seed Laboratory in the Department of Seed Science and Technology, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar 736165, West Bengal, India, from 2018 to 2020. It focused on the direct regeneration of shoots from various explants of *Citrus jambhiri* Lush.

Source of plant material: Matured fruits of *Citrus jambhiri* Lush. collected from Indian Council of Agricultural Research (ICAR) Central Plantation Crop Research Institute, Kahikuchi, Guwahati, Assam, India was used for collection of seeds.

Preparation of explants: To collect the seeds, mature *Citrus jambhiri* Lush. fruits were brought from the Indian Council of Agricultural Research's (ICAR) Central Plantation Crop Research Institute in Kahikuchi, Guwahati, Assam, India.

Media preparation and culture conditions: On MS medium, all *in vitro* research was conducted (Murashige and Skoog, 1962). Exact proportions of each component of the specific medium were combined to produce the MS media. The medium's final volume (1.00 L) was created by mixing Mili-Q water with 3% sucrose. Either 1N HCl (Himedia) or 1N NaOH (Himedia) was used to bring the pH of the medium to 5.8. 0.8% agar (Himedia) was used to solidify the medium. To melt the agar, the MS medium was heated on a hot plate magnetic stirrer while being agitated. The medium was then autoclaved at 15 psi for 15 minutes at 121ºC. The culture bottles were placed beneath the laminar air flow cabinet, and the medium was then poured into them. The treatments included the following: (1) MS + Casein-hydrolysate (50, 100, and 200 mg L^{-1}); (2) MS + IBA (1.0 mg L^{-1}); (3) MS + IAA (1.0 mg L^{-1} + IBA (1.0 mg L^{-1}); (4) MS + BAP (1.0 mg L^{-1}); and (5) MS + BAP (1.0 mg L^{-1}).

Direct Regeneration from Cotyledon

Inoculation of explant: A sharp knife was used to cut mature fruits of *C. jambhiri* Lush, and the seeds were manually removed. Seeds were surface sterilized for 10 minutes with 0.1% $HgCl_2$ (Himedia) then washed 3-5 times with Mili-Q water. Surface sterilized seeds were de-coated in a laminar air flow cabinet before being inoculated onto a basal MS medium that had been enhanced with the various quantities and mixtures of plant growth regulators mentioned above. Then, cultures were put in a culture environment at 25°C with 16/8 hours of light and dark phases. The level of light was kept at 2500 lux

Inoculation for direct regeneration from root: Similar to this, IAA and IBA were added in various concentrations and combinations to MS media before the surface sterilized seeds were infected, as shown in Table 2. The cultures were subsequently contaminated for six weeks at 25±2ºC with 16/8 h light and dark phases in the culture chamber.

Inoculation for direct regeneration from leaf: On MS basal medium, surface sterilized seeds were cultured to promote germination and the establishment of seedlings. The culture environment was set at 25±2ºC with 16/8 h of light and dark phases for the seeds in culture bottles. Leaf explant source material was taken from *in vitro* grown seedlings that were six weeks old. For leaf explants, healthy *in vitro* seedlings were chosen. With the aid of a scalpel, the lower sides of the leaves of *in vitro* grown seedlings were cut off, and those *in vitro* grown dissected leaves were inoculated on MS medium that had been enhanced with the various concentrations and combinations of plant growth regulators listed in Table 3. The cultures were once more incubated in the culture chamber at 25±2°C and alternated between light and dark phases for 16/8 hours.

RESULTS AND DISCUSSION

Direct regeneration from cotyledon: The objective of the experiment was to determine how efficiently cotyledons of *C. jambhiri* could be used to regenerate shoots directly. The cotyledons enlarged as the seeds started to germinate (Table 1, Fig. 5 A). It ranged from 26% to 96%. In MS medium supplemented with casein hydrolysate, the highest response to cotyledon enlargement was observed. The number of enlarged cotyledons generated by the medium treated with 50 mg L^{-1} of casein hydrolysate was highest (96%) and was followed by 100 mg L^{-1} (84%) and 200 mg L^{-1} of casein hydrolysate (78%). The weight of enlarged cotyledons ranged from 0.517 to 1.628 g/cotyledon on average (Table 1, Fig. 5A). On the synthetic medium supplemented with 50 mg L^{-1} of casein hydrolysate (1.628 g/cotyledon), 100 mg L^{-1} of casein hydrolysate (1.148 g/cotyledon), and 200 mg L^{-1} of

Table 1. Effect of various combinations and concentrations of plant growth regulators on direct regeneration from *C. jambhiri* cotyledons on MS medium

Treatments	No. of seeds produced enlarged cotyledons	Mean wt. of enlarged cotyledons (g)	No. of cotyledon produced multiple shoots	No. of cotyledon produced multiple shoots	No. of multiple shoots/ cotyledon	
					Individual cotyledon	Mean
T1	48 (96%)	1.628^a	3.0	1	32.0^a	15.0^a
				2	12.0^b	
				3	1.0^e	
T2	42 (84%)	1.148^b	0.0	-	0.0^f	0.0^c
T3	39 (78%)	1.050^b	0.0	-	0.0^f	0.0^c
T4	28 (56%)	0.517^d	0.0	-	0.0^f	0.0^c
T5	32 (64%)	0.553^d	0.0	-	0.0^f	0.0^c
T6	37 (74%)	0.815^c	4.0	1	3.0^d	3.0^b
				2	1.0^e	
				3	7.0^c	
				4	1.0^e	
T7	13 (26%)	0.682^e	0.0	-	0.0^f	0.00
Total	239	-	7.0	-	-	-
Range	13-48 (96-26%)	0.517-1.628	0.0-4.0	-	1.0-32.0	3.0-15.0
Mean	34.14 (68.29%)	0.76	3.50	-	8.14	9.0

T1: Casein-hydrolysate @ 50 mg L^{-1}; T2: Casein-hydrolysate @ 100 mg L^{-1}; T3: Casein-hydrolysate @ 200 mg L^{-1}; T4: IAA @ 1.0 mg L^{-1}; T5: IBA @ 1.0 mg L^{-1}; T6: IAA @ 1.0 mg L^{-1} + IBA @ 1.0 mg L^{-1}; T7: BAP @ 1.0 mg L^{-1}.
*Values bearing same letter in the column are not significantly different at p = 0.05 of LSD

casein hydrolysate (1.050 g/cotyledon), the largest cotyledons by weight were produced. When MS media was supplemented with 50 mg L^{-1} of casein-hydrolysate and 1.0 mg L^{-1} + 1.0 mg L^{-1} of IAA + IBA, direct regeneration from larger cotyledons were observed (Fig. 1A, B, and C and Fig. 2A, B, and C). Only seven cotyledons formed direct shoots (Table 1, Fig. 5B), three on medium supplemented with 50 mg L^{-1} of casein-hydrolysate and four on medium supplemented with 1.0 mg L^{-1} of IAA + 1.0 mg L^{-1} of IBA, indicating that the direct regeneration from cotyledons was random. After three weeks of inoculation on the enlarged cotyledon, the seeds that were inoculated on the MS medium enriched with 50 mg L^{-1} of casein hydrolysate had indicated many globular growths (Fig. 1A, B). Few of the globular-growing cotyledons regenerated into rootless plantlets. In contrary to plantlets that were directly regenerated from the cotyledonary axis (Fig. 1D), regenerated plantlets' leaves were abnormal (Fig. 1A and B). Contrarily, the cotyledons that enlarged on the medium supplemented with 1.0 mg L^{-1} of IBA and 1.0 mg L^{-1} of IAA formed noticeable globular callus-like structures with light green coloring (Fig. 2A). These spherical objects gradually developed into plantlets (Fig. 2B, C, and D). Compared to plantlets regenerated from the cotyledonary axis, those on 1.0 mg L^{-1} of IAA + 1.0 mg L^{-1} IBA supplemented media were normal. On a media containing the same plant growth regulators, the medium with the highest number of shoots (32 shoots/cotyledon; Fig. 1B; Fig. 5B; Table1) was observed. This was followed by a medium with 12 shoots/cotyledon (Fig. 2D, Table 1).

Direct regeneration from root: When the seeds were inoculated on MS media supplemented with 1.0 mg L^{-1} of IAA and 1.0 mg L^{-1} of IBA, direct regeneration from the roots of germinating seeds was seen in *C. jambhiri* (Fig. 3A, B, and C). On the contrary, seeds developed into radicles and plumules concurrently (Fig. 3A [1]). Without contacting the medium, the tap root of seeds helped germination increased by about 2.50 cm (Fig. 3A [2]). When it made direct contact with the medium, shoots and roots immediately began to regenerate (Fig. 3B, C). Only two roots displayed direct regeneration (Table 2). According to the recommendations of (Sharma and Roy 2020), the direct *in vitro* regenerated shoots were transferred to the hardening chamber before being eventually transplanted to the field.

Direct regeneration from leaf: Simple protocol was developed for the direct regeneration of plantlets from *C. jambhiri* leaf explants that had undergone *in vitro* regeneration. On MS media that had been supplemented with various combinations and concentrations of plant growth regulators, leaves that were removed from axenic shoot cultures were utilized to stimulate organogenesis (Table 3). Adding 0.50 mg L^{-1} of dicamba to the medium indicated a few number of callus to appear on the leaf (Fig. 6). The callus gradually showed symptoms of regeneration on the callus induction media as the leaf gradually dried out (Fig. 4B). On medium enriched with 50 mg L^{-1} of dicamba, only 9.75% of the leaf callus had shown this kind of regeneration. Because

Table 3. Effect of various combinations and concentrations of plant growth regulators on *C. jambhiri* leaf regeneration into direct shoots

Treatments	Callus induction (%)	Regeneration on callus induction medium
2,4-D 1.0 mg L^{-1}	78.57	-
2,4-D 2.0 mg L^{-1}	64.51	-
2,4-D 1.0 mg L^{-1} + NAA 0.50 mg L^{-1}	100.00	-
2,4-D 2.0 mg L^{-1} + NAA 0.50 mg L^{-1}	100.00	-
Picloram 0.50 mg L^{-1}	88.88	-
Picloram 1.0 mg L^{-1}	90.91	-
Dicamba 0.50 mg L^{-1}	84.00	9.75%
Dicamba 1.0 mg L^{-1}	76.92	-
TDZ 0.25 mg L^{-1}	96.87	-
TDZ 0.50 mg L^{-1}	100.00	-

Table 2. Effect of plant growth regulators on direct shoot regeneration from roots of *C. jambhiri*

Treatment		No. of seed inoculated	No. of seedling responded to direct regeneration from root	% of response	Average no. of shoots per inoculated shoot
IAA	IBA				
0.50	0.50	60	0.0	0.00	0.00
1.00	0.50	60	0.0	0.00	0.00
0.50	1.00	60	0.0	0.00	0.00
1.00	1.00	60	2.0	3.33	4.50
1.00	1.50	60	0.0	0.00	0.00
1.00	2.00	60	0.0	0.00	0.00
1.50	1.00	60	0.0	0.00	0.00
2.00	1.00	60	0.0	0.00	0.00

it guarantees the highest genetic consistency of the emerging plants, direct regeneration of plantlets is frequently used for *in vitro* mass-multiplication of citrus. The innovative result of this work is direct regeneration from *C. jambhiri* cotyledons. Numerous studies on the indirect regeneration of citrus species' cotyledon-derived callus (via callus induction and shoot regeneration) have been conducted (Waghmare and Pandhure 2015, Badr-Elden 2017, Fatonah et al 2018). On the other hand, no literatures were found on the direct regeneration of shoots from the cotyledons of citrus species,

Fig. 1. When *C. jambhiri* cotyledons are inoculated on MS medium supplemented with 50 mg L^{-1} of casein-hydrolysate, direct regeneration results. A) Multiple buds on the cotyledon begin to form: A) Multiple buds that have sprouted, B) an enlarged cotyledon, C) an adult plantlet on the cotyledon: A multiple plantlet regeneration from the cotyledonary axis of germinating seeds when inoculated on MS medium supplemented with 50 mg L^{-1} of casein hydrolysate. 3] Plumule developed from the seed, 4] Radicle (root) developed from the seed, 5] Development of multiple plantlets; C) Developed multiple plantlets were separated from cotyledon and again cultured on MS basal medium

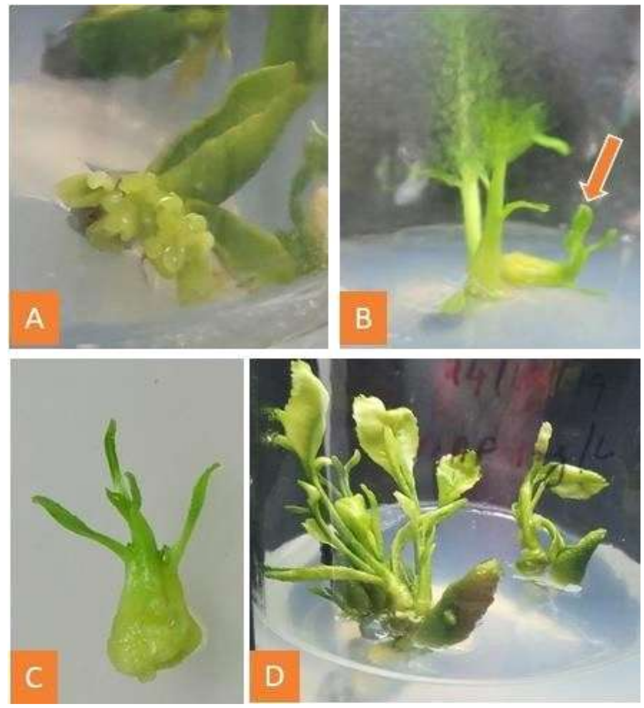

Fig. 2. Direct regeneration from *C. jambhiri* cotyledons. Direct embryogenesis on MS medium supplemented with 1 mg L^{-1} of IAA and 1 mg L^{-1} IBA in A; shoot regeneration on MS medium supplemented with 1 mg L^{-1} of IAA and 1 mg L^{-1} IBA in B; a magnified part of the regenerating shoot from the cotyledon in C; and multiple shoot regeneration on IAA and 1 mg L^{-1} IBA in D

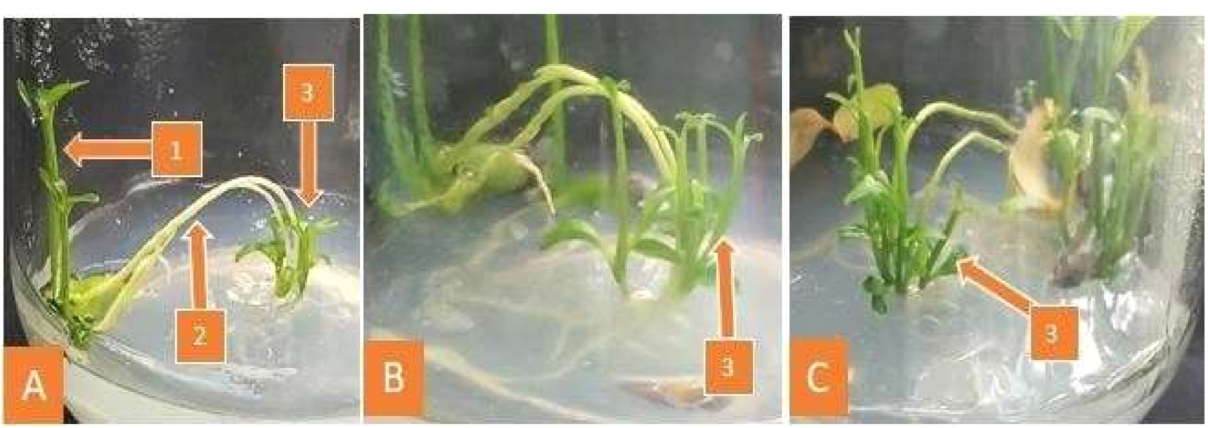

Fig. 3. Direct regrowth from *C. jambhiri* roots. Directly regenerated plantlets (A, B, and C): 1] Plumules from the germination of seeds, without touching the medium, the tap root of the germination seed expanded to a length of about 2.50 cm, and the shoots sprang directly from the root

according to a literature search conducted using Google Search. Numerous references are also available on direct shoot multiplication from nodal segments, shoot tips, cotyledonary nodes, axillary buds, and meristem culture in various citrus species (Taye et al 2018, Sharma and Roy 2020). When the MS medium was supplemented with 50 mg L^{-1} of casein hydrolysate and 1.0 mg L^{-1} of IAA combined with 1.0 mg L^{-1} of IBA, direct regeneration from cotyledons were achieved. When the MS medium was added with 50 mg L^{-1} of casein hydrolysate, a large number of plantlets regenerated from cotyledons; however, the health of the plantlets was poor, with the majority having semi-cylindrical leaves. However, some researchers have come to the conclusion that casein hydrolysate alone is more successful for plant tissue culture than the combination of the main amino acids. Casein hydrolysate reduces the glutamine deficiency when there is insufficient phosphorus for appropriate biosynthesis. As a result, it has been hypothesized that casein hydrolysates may include an unidentified growth-promoting component (George et al 2008). The majority of the plantlets produced on casein hydrolysate-added media were desiccated throughout the culture's later stages. Only a handful of the plantlets made it to the rooting media and survived. The plantlets that were grown on 1.0 mg L^{-1} of IAA plus 1.0 mg L^{-1} of IBA supplemented media, however, were healthy. After hardening, plantlets were rooted and transferred it in the soil. There are also relatively few reports on the direct regeneration of plantlets from roots. *C. aurantifolia* roots were continuously cultured for three years by Bhat et al (1992), who observed a low frequency of de novo shoot bud initiation in basal media throughout that time. Numerous studies have examined citrus species' roots-derived callus indirect regeneration (via callus induction and shoot regeneration) (Yaacob et al 2014). However, there are no current study data on direct regeneration from *C. jambhiri* roots. Our research on the direct regeneration of plantlets from roots is therefore novel, and this approach may be utilized to produce true-to-type propagules from roots.

Direct regeneration of plantlets from leaf segments is a viable method for mass-multiplications of citrus for maintaining genetic integrity. Direct organogenesis from *C. jambhiri* leaf explants is not yet observed. Explants grow buds or shoots when placed in a medium with a high cytokinin-to-auxin ratio (Schaller et al 2015). When the leaf explants of *C. limon* L. Burm cv. 'Primofiore' were cultivated on MS media supplemented with 3.5 ml L^{-1} of BAP, Kasprzyk-Pawelec et al (2015) also reported this form of direct organogenesis. In line with this, Hu et al (2017) findings revealed that cytokinin was the main cause of citrus shoot organogenesis. However, there are also instances on direct regeneration from plant species other than citrus that use leaves. An effective methodology for direct plantlet regeneration for the therapeutic plant *Aerva lanata* (L.) Juss. ex Schult. was standardized by Varutharaju et al (2014). Li et al (2013) developed an effective propagation and regeneration strategy in *Lysionotus serratus* via direct plantlet organogenesis from leaf explant. They discovered that Thidiazuron (TDZ) or 6-benzyladenine (BA) in high concentrations were efficient for direct organogenesis. A procedure for the direct regeneration of plantlets from male *Pistacia vera* L. cv. 'Atl' leaf explants was developed by Tilkat et al (2009). On a Murashige and Skoog (1962) medium with Gamborg vitamins added and various combinations and concentrations of BAP and IAA, leaves excised from axenic shoot cultures of pistachio were utilized to stimulate organogenesis. *Drosera rotundifolia* L. regenerated direct shoot as reported by Bobatk et al (1995) in either MS medium

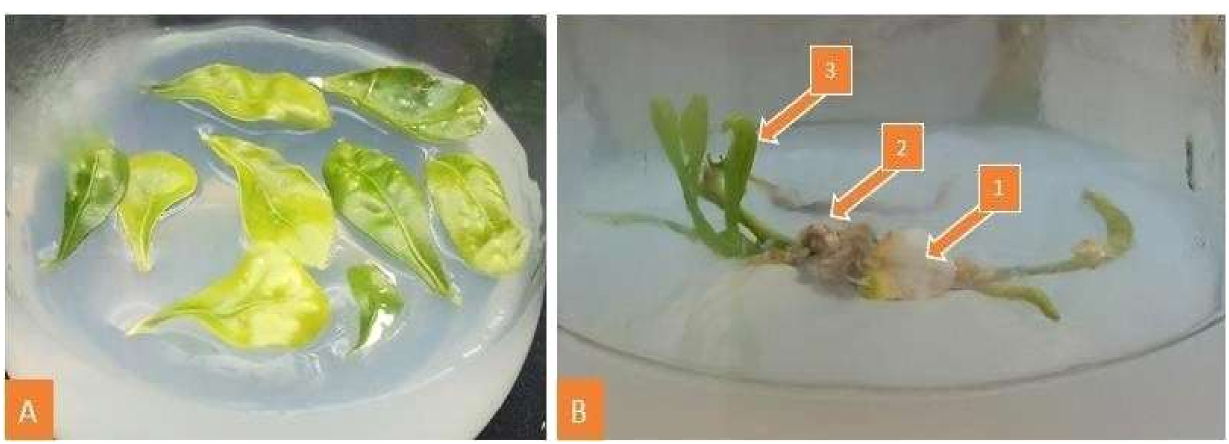

Fig. 4. Plantlets that are directly regenerated from leaves. A) *C. jambhiri* leaves that had been inoculated on MS media supplemented with 0.5 mg L^{-1} of dicamba; B) plantlets that had been regenerated from leaves: Following callus initiation, an inoculated leaf dries up, a tiny callus forms on the leaf, and a plantlet regenerates from the leaf callus on the callus induction medium

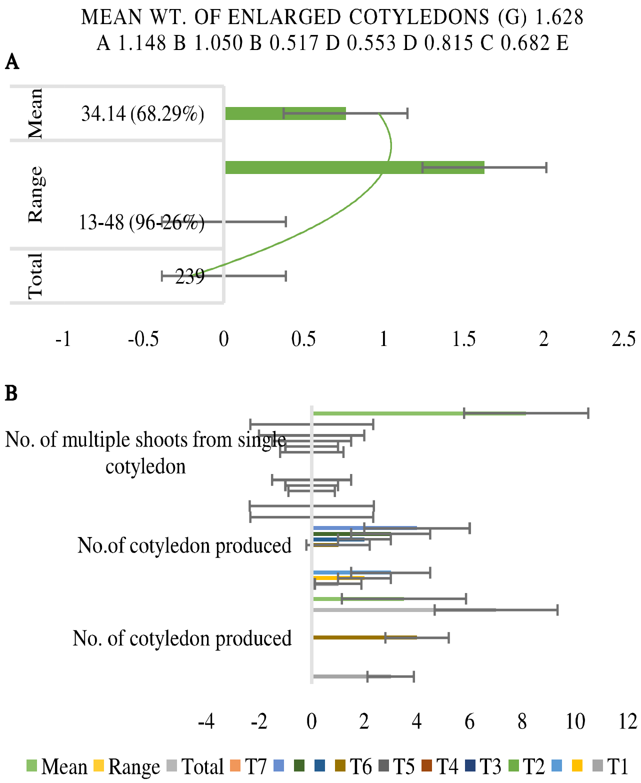

Fig. 5 (A-B). Influence of different combinations and concentrations of PGR's on number of seeds that produced enlarged cotyledons and its mean weight, number of cotyledons produced and number of multiple shoots emerged from a single cotyledon of *C. jambhiri* Lush

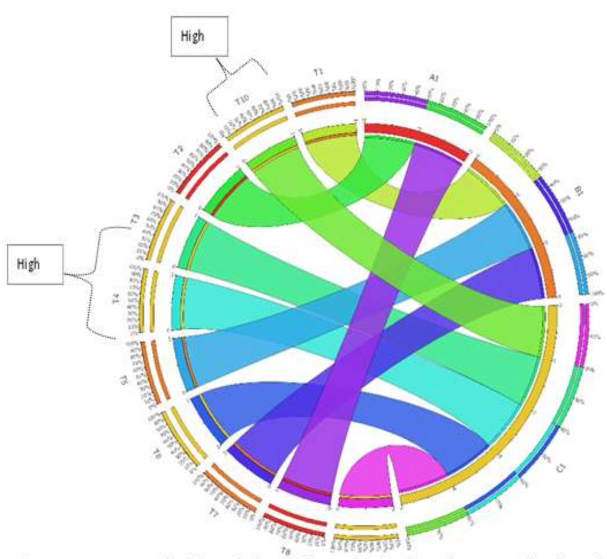

Fig. 6. Circos plot representing the percentage of callus derived from the leaf explants. Indicating that the maximum callus was obtained from the leaf segments treated with 2,4D (1.0+2.0) mg L^{-1} in conjunction with NAA (0.50) mgL^{-1} and TDZ (0.50) mg L^{-1}

supplemented with 10^{-8M} NAA or MS medium used as a basal medium. The ability of leaf tissue to regenerate was greatly improved by liquid culture media. Histological and scanning electron microscopy analyses confirmed their conclusions about direct shoot organogenesis, and it was shown that direct plant regeneration lacked intermediate callus development.

CONCLUSION

It is common practice to use *C. jambhiri* (Rough lemon) as the rootstock for planted citrus species. This report describes the direct regeneration of *C. jambhiri* plantlets from cotyledons, roots, and leaves. On a medium enriched with 50 mg L^{-1} of casein hydrolysate, 96% of the cotyledons grew larger. Few of the larger cotyledons regenerated branches directly. There might be a maximum of 32 shoots per responding cotyledon. In contrast, the plantlets' health was poor and appeared as semi-circular leaves. The majority of them died on rooting medium or dried out on maintenance medium. Healthy plantlets that had been regenerated on media were treated with IAA and IBA together with IBA established on maintenance medium and rooted on rooting medium. Additionally, leaf on MS medium supplemented with 0.50 mg L^{-1} of dicamba was successfully regenerated directly. This is the first study on the direct, extremely effective regeneration of shoot and root tissue from in vitro leaf and root growth. According to our research, plantlets from various *C. jambhiri* explants may be directly regenerated using tissue culture protocols in order to produce true-to-type plant propagules. Thus, citrus *in vitro* micropropagation is a useful technology for growing, preserving, and improving citrus plants. Citrus plants may be multiplied effectively and under control, supplying a steady stream of uniform, healthy plant material for breeding, research, and commercial orchards.

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Growth, Productivity and Profitability of Direct Seeded Rice as Influenced by Maize Crop Residue Management Practices and Fertility Levels in Rice-Maize Sequence

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Abstract: The present investigation was carried out during *kharif* seasons of 2020-21 and 2021-22 on a sandy clay loam soil at the Agricultural College Farm, Bapatla to study the growth, productivity and economics of direct seeded rice as influenced by maize crop residue management practices and fertility levels in rice-maize sequence. The experiment was laid out in split-plot design with four maize residue management techniques (M_1: Exportation of maize stover, M_2: *In-situ* burning of maize stover (farmers practice), M_3: Mulching maize stover with rotary mulcher and M_4: Incorporation of maize stover with rotovator) as main plot treatments and three fertility levels (100% RDF, 75% RDF and 50% RDF) as sub plot treatments. The incorporation of maize stover with rotovator indicated significant effect on growth, yield attributes and economics of rice compared to exportation of maize stover during both the years of experiment. Among the fertilizer levels, application of 100% RDF significantly improved the growth, yield attributes and economics of rice compared to 50% RDF treatment. Combined use of incorporation of maize stover with rotovator along with application of 100% RDF resulted significantly higher number of filled grains panicle^{-1} (169.5), grain yield (6195 kg ha^{-1}).

Keywords: Maize crop residue, Fertilizer levels, Plant height, tillers, Grain yield and direct seeded rice

One of the potential alternatives to rice-pulse systems is the rice (*Oryza sativa* L.), maize (*Zea mays* L.) system. Currently rice-maize (RM) is one of the most important cropping systems of the country due to the rising demand from the poultry sector and the tightening of the global export-import market. Overall, in India, rice and maize production is 125, 30 million metric tons from the area 45.50, 9.70 million ha with the productivity of 4.12, 3.09 metric t ha^{-1}, respectively (USDA 2021). Rice-maize systems are predominantly practiced in the southern and northeastern parts of India, with over 500,000 hectares of planted area. Andhra Pradesh has the largest rice-maize acreage in southern India and this system is rapidly expanding through resource saving techniques, mostly under zero cultivation. High-yielding Rice-Maize system extracts more nutrients, particularly N, P, or K, than rice-rice systems or rice-wheat (Yadvinder Singh 2005). Timsina et al (2010) found that in rice-maize crop systems, a very little crop residue is returned to the soil and other organic inputs are low, resulting in soil organic loss. India generates 516 mt of total crop residue annually, whereof, maize contributes 110 mt, respectively (Sahu et al 2021). Management of stover after maize harvests poses an enormous challenge to all maize farmers around the globe.

The maize stover is most often harvested in dried condition and packaged in large heaps to use as fodder in later date or in lean seasons. Now a days, the use of maize stalk as animals fodder gradually decreasing and instances of on field burning of stover increasing due to non-availability of agriculture labor for timely harvesting, increase in transportation costs, lack of sufficient time to take up next season crops. Instead of resorting to such practices, if managed to slash, shred and spread in the field evenly using machinery, this help in protecting soil and land resources from erosion. Fertilizer application is one of the most expensive costs for cereal crops growers and yet much of the N, P and K used to supplement crop needs are lost to the environment due to the low nutrient use efficiency of cereal crops. Over or under nitrogen, phosphorus and potassium fertilizer application can lead to a reduction in crop yield, in addition to creating conditions which favor nutrient losses to the environment, poor soil quality and plant nutrition. Therefore, there is a need for improved nutrient management strategies, in particular N, P and K under different scenarios like removed, burning, surface retention or incorporated residue management to properly replace nutrients, ensuring adequate plant nutrition and at least sustained grain yield. The present investigation was therefore undertaken to study the growth, productivity and profitability of direct seeded rice as influenced by maize crop residue management practices and fertility levels in rice-maize sequence.

MATERIAL AND METHODS

The experiment was conducted with four maize residue management practices M_1: Exportation of maize stover, M_2: *In-situ* burning of maize stover (farmers practice), M_3: Mulching maize stover with rotary mulcher and M_4: Incorporation of maize stover with rotovator) as main plot treatments and three fertility levels (100% RDF, 75% RDF and 50% RDF) as sub plot treatments which was replicated thrice. The experiment was carried out on sandy clay loam soils of Agricultural College Farm, Bapatla during *kharif* seasons of 2020-21 and 2021-22. The experimental soil was slightly alkaline in reaction; E.C was non-saline in nature and below the critical point, low in organic carbon, low in available nitrogen, medium in available phosphorus and high in available potassium. The average maximum and minimum temperatures were 32.0^{0}C and 24.4^{0}C during *kharif* 2020-21 and 32.0^{0}C and 23.8^{0}C during *kharif,* 2021-22, respectively. The total rainfall of 847.2 mm and 1219 mm received during *kharif* seasons of 2020-21 and 2021-22, respectively. The test variety used for sowing was BPT-5204 and crop was sown at 20 cm and 15 cm inter and intra row distance, respectively and adopted all the standard package of practices. The nutrients, namely urea, single super phosphate, and muriate of potash, were applied according to the respective treatments. Nitrogen was divided into three equal split doses, which were applied during three specific stages: sowing, active tillering, and panicle initiation. Entire quantity of phosphorus and half dose of potassium were applied at the time of sowing. Remaining dose of potassium was applied at PI stage of the crop. After harvest of maize cobs, residues of the maize crop were retained. Maize residues were added as per treatment in the four main plots. In residue removal plots, the residues were completely removed after harvest of the crop. Ninety five days were allowed for decomposition of crop residues during both the years of experimentation. The data on growth attributes, yield attributes, yield and economics were recorded as per standard procedures.

Measurement of growth parameters, yield attributes, yield and economics: For determining drymatter accumulation (DMA), samples from 50 cm row length were taken by cutting the plant from ground level and sun-dried for 2–3 hours and later oven-dried at 65^{0}C till the constant weight was achieved. The dry-weights were recorded. A quadrate of 50 cm × 50 cm^2 size was placed at two random spots in each plot and effective tillers were counted and expressed as no./m^2. Randomly five panicles from each plot were taken and from them number of filled grains/panicle and 1000-grain weight were determined. Grain and straw yield were computed by harvesting crop from the net plots leaving border area of 50 cm from each side. Harvested produce was sundried, bundled and brought to thrashing floor and threshed separately. Economics of each treatment were calculated considering the current market price of each input and output during both the years of experimentation. Gross returns were computed based on market price of rice grain and straw prevailing during study years. Net return was obtained by subtracting cost of cultivation from the gross return. However, B: C ratio was calculated dividing gross returns by cost of cultivation.

Statistical analysis: All the experimental data were statistically analyzed using OPSTAT software.

RESULTS AND DISCUSSION

Growth parameters: There was significant positive impact of crop residue incorporation as well as fertilizer levels on plant height of rice over control treatment. Plant height of rice under different maize crop residue management practices was observed between 85.4 and 112.7 cm (Table 1). Significant higher plant height of rice was with incorporation of maize stover with rotovator (M_4). Increase in plant height in residue incorporated plot may be attributable to greater nutrient availability during crop growth stages, which may have increased nitrogen absorption by the roots for the synthesis of protoplasm necessary for rapid cell division, increasing plant height. The present findings are in similarity with the earlier findings by Khatri et al (2020). The plant height of rice was significantly increased from 50% RDF to 100% RDF. Increased nitrogen levels may have resulted in higher nitrogen consumption, which facilitated the conversion of synthesized carbohydrates into amino acids and protein, resulting in a considerable change in plant height. This in turn promoted cell division and cell elongation, which facilitated the plant's ability to grow more quickly. This is in accordance with Vijayalakshmi et al (2020).

Number of tillers and drymatter production at harvest were influenced significantly by different maize crop residue management practices. The higher number of tillers and drymatter production were recorded in incorporation of maize stover with rotovator treatment (M_4) which was statistically at par with mulching of maize stover with rotary mulcher (M_3) and significantly higher than the other treatments. This might be because nutrients are more readily available and easier to absorb at different crop growth stages due to faster mineralization and release of nutrients, which may have in turn improved cell division and photosynthate synthesis at the corresponding point of growth and development. Due to the actions of beneficial microbes and the enlarged organic pool in the soil, there was improved nutrient availability for a longer period of time during crop growth. The present results are in close confirmation with the earlier reports of Chaudhary et al (2020).

There was a progressive increase in number of tillers m^{-2} and drymatter production at harvest of rice with increase in levels of fertilizers. Among the graded levels of fertilizer application, the maximum number of tillers m^{-2} and drymatter production of rice was recorded with application of 100% RDF (S_1), and found to be significantly superior to rest of the fertilizer levels. It was followed by 75% RDF (S_2) and 50% RDF (S_3). This might be due to greater reserves of photosynthates present in the stems of the plants receiving higher fertilizer levels which were translocated to the panicle and resulted in significant difference with the dry weight of panicle in plants with lower nitrogen applications (Duary and Pramanik 2019).

The senescence of leaves generally caused the mean CGR and RGR to decline with increasing crop age. At 30-60 DAS over both experiment years, various maize crop residue management techniques had a substantial impact on CGR and RGR The higher values of mean CGR and RGR were noticed with incorporation of maize stover with rotovator (M_4) followed by the treatments M_3 and M_2 which were comparable with each other. The lowest mean CGR and RGR recorded under exportation of maize stover (M_1) treatment. This could be attributed to more number of taller plants, tillers and higher drymatter production per unit area and LAI. These findings are in accordance with Kumar et al (2016) and Vijayaprabhakar et al (2020).

With respect to fertilizer levels, at 30-60 DAS, mean crop growth rate increased with increase of fertilizer level. However, there was a non–significant effect on relative growth rate at 30-60 DAS. The highest mean crop growth rate of rice was observed with application of 100% RDF (S_1), which was significantly superior to all the other levels of fertilizers where the treatment S_1 was on par with treatment S_2. The lower mean crop growth rate with application of the lowest fertilizer level @ 50% RDF (S_3). During tillering to flowering, the high LAI at higher fertilizer levels produced high CGR, which further increased DMA during the reproductive stage, resulting in high crop productivity. However, lower nitrogen concentrations result in less effective radiation usage, which in turn results in decreased biomass accumulation. The findings of present investigation are in agreement with those of Mondal et al (2013).

Yield attributes of rice: Among the various maize crop residue management practices influence significant effect on yield attributing characters of rice crop except 1000 grain weight (Table 2). A significant increase in the more of panicles m^{-2} and number of filled grains $panicle^{-1}$ respectively was found under incorporation of maize stover (M_4) which was statistically similar with mulching of maize stover with rotary mulcher (M_3). The lower number of panicles m^{-2} and number of filled grains $panicle^{-1}$ observed with exportation of maize stover (M_1) treatment which showed statistically inferiority to

Table 1. Growth parameters of direct seeded rice as influenced by maize crop residue management practices and fertilizer levels (Pooled mean of 2 years)

Treatments	Plant height (cm) at harvest	Number of tillers m^{-2} at harvest	Dry matter accumulation (kg ha^{-1}) at harvest	Leaf area index at 60 DAS	Mean crop growth rate (g day^{-1}) at 30-60 DAS	Relative growth rate (g g^{-1} day^{-1}) at 30-60 DAS
Maize crop residue management practices						
M_1	85.4	352	11205	2.42	4.15	0.040
M_2	94.5	388	12349	2.66	5.01	0.048
M_3	103.3	424	13193	2.96	5.14	0.042
M_4	112.7	460	13830	3.07	5.76	0.049
CD (p = 0.05)	7.0	30	1155	0.31	0.36	0.003
CV (%)	6.1	6.4	7.9	9.69	6.23	5.79
Fertilizer levels						
S_1	108.0	438	13663	2.96	5.68	0.046
S_2	97.8	407	12658	2.80	5.05	0.045
S_3	91.0	372	11612	2.58	4.32	0.043
CD (p = 0.05)	5.6	22	893	0.18	0.31	NS
CV (%)	6.5	6.2	8.2	7.45	7.08	6.29
Interaction						
M x S	NS	NS	NS	NS	NS	NS
S x M	NS	NS	NS	NS	NS	NS

the rest of the treatments. It might be attributed to a steady supply of sufficient nitrogen and its solubilization, which may have aided in more rapid cell division and expansion (Khatri et al 2020). Among the various fertilizer levels influence significant effect on yield attributing characters of crop except 1000 grain weight during the two years of experiment. However, number of panicles m^{-2} and number of filled grains $panicle^{-1}$ registered significantly more with application of 100% RDF (S_1) over 75% RDF (S_2). This might be due to increase in more number of tillers m^{-2} coupled with higher nutrient uptake. These findings are in corroboration with those reported by Meena et al (2015) and Reddy et al (2017). During both years of the experiment, the interaction effect between maize crop residue management practices and fertilizer levels on the number of filled grains $panicle^{-1}$ was shown to be significant (Table 3). Incorporation of maize stover with rotovator (M_4) along with application of 100% RDF (S_1) gave the higher number of filled grains $panicle^{-1}$ (169.5) than other treatment combinations during both the years respectively. This might be due to integration of crop residue

Table 2. Yield attributes, yield and harvest index of direct seeded rice as influenced by maize crop residue management practices and fertilizer levels (Pooled mean of 2 years)

Treatments	No. of panicles m^{-2}	Number of filled grains $panicle^{-1}$	Test weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)
Maize crop residue management practices						
M_1	325	122.5	14.5	4860	5873	45.02
M_2	355	132.6	14.9	5292	6398	45.18
M_3	380	139.7	15.1	5757	6879	45.59
M_4	395	156.2	15.5	5980	7034	46.02
CD (p = 0.05)	28	18.8	NS	374	472	NS
CV (%)	6.6	11.8	6.2	5.9	6.2	5.9
Fertilizer levels						
S_1	387	153.0	15.3	5923	6896	46.32
S_2	364	138.6	15.1	5603	6628	45.82
S_3	341	121.5	14.6	4891	6114	44.22
CD (p = 0.05)	17	6.4	NS	258	440	NS
CV (%)	5.5	5.4	5.2	5.4	7.8	5.8
Interaction						
M x S	NS	S	NS	S	NS	NS
S x M	NS	S	NS	S	NS	NS

Table 3. Interaction between maize crop residue management practices and fertilizer levels on number of filled grains $panicle^{-1}$ of direct seeded rice (Pooled mean of 2 years)

Treatments	Fertilizer levels			
Maize crop residue management practices	S_1	S_2	S_3	Mean
M_1	142.8	130.2	94.5	122.5
M_2	146.0	131.3	120.3	132.6
M_3	153.8	140.5	124.8	139.7
M_4	169.5	152.5	146.5	156.2
Mean	153.0	138.6	121.5	
		CD	CV	
Main plot		18.8	11.8	
Sub plot		6.4	5.4	
Interaction				
M X S		12.9		
S X M		21.5		

incorporation and chemical fertilizers increased the more number of filled grain panicle^{-1}. The present findings are also supported by Govind, (2016) in rice-rice cropping system.

Yield of rice: Grain yield and straw yield of rice were influenced significantly by different maize crop residue management practices except harvest index during both the years of experiment (Table 2). The maximum grain and straw yield of rice was with incorporation of maize stover with rotovator (M_4) over exportation of maize stover and was at par with mulching of maize stover with rotary mulcher (M_3). The superiority of incorporation of maize stover with rotovator, in terms of yield can be attributed to higher number of panicles m^{-2}, filled grains per panicle^{-1} and also improved growth parameters (LAI and drymatter production) as compared to other treatments. This may be due to the fact that crop residues are rich in C and N, and the cumulative release rates of crop residues were rapid within 90 days of incorporation, respectively (Wu et al 2011). Crop residues that are mixed with soil particles decompose faster than residues that are left on the soil surface. Through microbial degradation, incorporated maize stalks are transformed into different easily mineralizable form of soil organic matter. Plants absorb mineralized plant nutrients from soil solution both directly and indirectly. Incorporating crop residues recycles nutrients and increases soil organic matter. These results are consistent with the findings of Davari et al (2012). During both years of the experiment, significant influence of varied fertilizer levels was observed on rice grain and straw yield, except for harvest index. Application of 100% RDF gave significantly higher grain yield and straw yield of rice compared to 50% NPK and 75% NPK. Higher grain yield might be due to higher availability of nutrients as evidenced from N, P and K content in grain and straw at harvest subscribes to the view that increased availability of growth inputs involved in the formation and development of yield components. The interaction effect of maize crop residue management practices and fertilizer levels on rice grain yield was significant (Table 4). Incorporation of maize stover with rotovator (M_4) along with application of 100% RDF (S_1) gave the higher grain yield (6185 kg ha^{-1}) than other treatment. This may be due to integration of stover, along with nitrogen, phosphorus, and potassium fertilizers, into the soil resulted in a notable enhancement in rice grain yield due to the improved nutrient reserves in the soil (Khatri et al 2020). This is due to the slow release and continuous supply of balanced amounts of nutrients during the different growth stages, allowing rice to absorb sufficient photosynthetic products and thus, increases the dry matter and source capacity, resulting in higher grain and straw yield.

Economics: The results pertaining to GRs, NRs and B: C of rice with different maize crop residue management practices and fertilizer levels indicated that there was significant difference among treatments (Table 5, Fig. 1). The significantly increase in the GRs, NRs and B: C by the incorporation of maize stover with rotovator (M_4) was statistically comparable with mulching of maize stover (M_3) and both of them were significantly superior to the remaining treatments. The treatment exportation of maize stover (M_1) recorded the least gross return, net return and B: C ratio was significantly inferior compared to other treatments during two successive years of study. Among the fertilizer levels, higher GRs, NRs and B:C ratio with application of 100% RDF (S_1) was ascribed to more monetary return owing to higher yield than the other treatments.

Table 4. Interaction between maize crop residue management practices and fertilizer levels on grain yield (kg ha^{-1}) of direct seeded rice (Pooled mean of 2 years)

Treatments	Fertilizer levels			
Maize crop residue management practices	S_1	S_2	S_3	Mean
M_1	5484	5264	3831	4860
M_2	5965	5304	4607	5292
M_3	6058	5842	5373	5757
M_4	6185	6002	5752	5980
Mean	5923	5603	4891	
		CD	CV	
Main plot		374	5.9	
Sub plot		258	5.4	
Interaction				
M X S		516		
S X M		562		

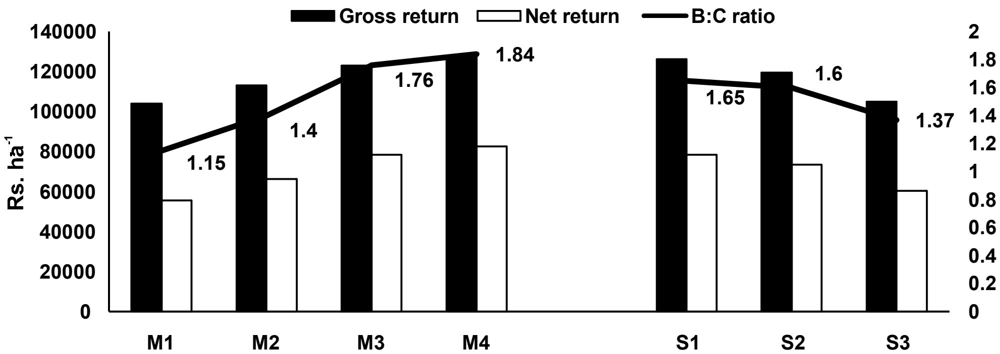

Fig. 1. Gross return (₹ ha^{-1}), net return (₹ ha^{-1}) and B: C ratio of direct seeded rice as influenced by maize crop residue management practices and fertility levels

Table 5. Gross return (₹ ha^{-1}), net return (₹ ha^{-1}) and B: C ratio of direct seeded rice as influenced by maize crop residue management practices and fertility levels (Pooled mean of 2 years)

Treatments	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B: C ratio
Maize crop residue management practices			
M_1	103977	55666	1.15
M_2	113266	66254	1.40
M_3	123061	78550	1.76
M_4	127611	82675	1.84
CD (p = 0.05)	8460	8460	0.19
CV (%)	6.3	10.4	10.6
Fertilizer levels			
S_1	126288	78475	1.65
S_2	119646	73454	1.60
S_3	105002	60430	1.37
CD (p = 0.05)	4582	4582	0.10
CV (%)	4.5	7.5	7.5
Interaction			
M x S	NS	NS	NS
S x M	NS	NS	NS

CONCLUSION

Incorporation of maize stover with rotovator along with application of 100% RDF were found to be more effective and sustainable approach to enhance the growth, yield attributes, yield and profitability of direct seeded rice in rice-maize sequence.

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Evaluation of Scented Rice Varieties under Organic Mode of Cultivation in North West Plains of India

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Abstract: Field experiment was conducted at GBPUA&T, Pantnagar during *kharif* 2020 to evaluate ten traditional scented rice varieties namely Kubri Mamhani, Kudrat-5, Chinar-20, Kesho Pohu, DRK, Kudrat-5, Pusa-1121, Type-3, Taraori and Tilak Chandan under organic mode of cultivation. Sesbania as a green manure and 2.5 t vermicompost/ha were used as top dressing to rice crops. The grain yield (42.46 q/ha) and straw yield (53.27 q/ha) were highest in variety Kudrat-5. The N, P and K contents and their uptake were also maximum in variety Kudrat-5. Under organic mode of cultivation, variety Kudrat-5 was suitable for North West plains of India.

Keywords: Green manure, Scented rice, Harvest Index, Organic, Vermicompost

The green revolution introduced new varieties of rice that had shorter stature (dwarf variety) and were responsive to high levels of inputs, such as chemical fertilizers and irrigation. These HYV were capable of producing higher yields compared to traditional rice varieties (Supriya et al 2023). The traditional varieties with good qualities were ignored because immense attraction with hybrid variations, and are now rarely in cultivation. Before the era of HYV about 30,000 traditional varieties were grown in India) including coarse, fine, scented and non-scented types (Ahuja et al 2008). Among these, traditional scented rice varieties often possess unique and diverse genetic traits and often grown for their distinct aroma (Praveen et al 2022), which can be easily affected by chemical residues. The genetic diversity was reduced as a result of a greater preference for hybrid variants over traditional kinds (Das et al 2014). The long-term sustainability and environmental impacts of the intensive practices have since led to the need of more sustainable and balanced approaches such as organic cultivation and microbial inoculation (Verma et al 2018). The use of synthetic fertilisers, pesticides, and herbicides is avoided in organic farming which ensures that the soil, crop and environment remain free from harmful chemicals. The experiment aimed to investigate the impact of organic cultivation on traditional scented rice varieties, focusing on nutrient content, uptake, and yield.

MATERIAL AND METHODS

Experimental site: Field experiment was conducted at Norman E. Borlaug Crop Research Centre of G. B. Pant University of Agriculture and Technology, Pantnagar (Uttarakhand) during *kharif* season 2020. This centre is located at 29^{0}N latitude and 79.5^{0}E latitude and 243.84 meter above mean sea level. It falls under subtropical climate at the foot hills of “Shivalik” ranges of Himalaya a narrow belt. The summer season experiences high temperatures with humid and hot conditions. The maximum temperature varies from $31.4\text{-}45.2^{0}$C. The winter season lasts from November to February and is extremely chilly. The south-west monsoon typically starts in the second or third week of June and lasts into September. The average annual rainfall is 1420 mm, with 75% of that beginning over the four-month period from June to September. There are an average of 58.1 wet days each year. Few showers may also be received in winter months due to the western disturbances. The Tarai region's soil (Mollisol) formed from calcareous coarse parent material under the dominance of vegetation from forests and under conditions of poor to moderate drainage. These soils originate from the alluvial sediments of the Indo-Gangetic plains.

Treatment details and crop management: The experiment was carried out in randomized block design with ten treatment and three replications. Gross plot size was 7.75 m × 3.75 m (29.06 m^2) and net plot 5.75m × 2.75 m (15.81 m^2). Ten traditional scented rice varieties *viz*., Kubir Mamhani, Kudrat-5, Chinar-20, Kesho Pohu, DRK, Kudrat-1, Pusa-1121, Type-3, Traori and Tilak Chandan were taken as treatment. The seedlings of 22 days old of different rice varieties were grown using wet bed method. Transplanting was done at spacing of 25cm × 12.5 cm (row to row- hill to hill) using two seedlings/hill. Seeds were treated with 5% salted water for 30 minutes prior to soaking followed by Pant Bioagent-3 (mixture of *Tricoderma* and *Pseudomonas*) @ 10g/kg seed at the time of incubation before nursery sowing. The presence of *Trichoderma* and *Pseudomonas* helped to control fungal and bacterial pathogen, also in robust growth. The nursery used the wet bed method to raise the seedlings. Large, dry seed beds of 3.5 metres by 1.5 metres were constructed. The beds were saturated with water the day before sowing, and the next day they puddled. Sprouted seeds @500g for 10m^2 plots were broadcasted on 5th June. Beds were then kept saturated with water initially up to a week and then submerged with a thin layer of water gradually to 5 cm and irrigated on alternate days in the evening. Green manuring of *Sesbania* was done, likely biomass 16 t/ha equivalent to 3.5 t/ha on dry weight basis, along with green manuring, vermicompost @ 2.5 ton/ha was applied 20 days after transplanting. The nursery beds were irrigated to soften the soil a day before the plants were plucked. Seedlings were removed one by one, and the roots were cleaned to remove any mud. Following that, rows of seedlings were spaced 25 cm apart by 12.5 cm apart and moved using nylon rope. Two seedlings were transplanted each hill. Additional agronomic practises were followed in addition to the standard set of practises for the cultivation of rice.

Plant sample analysis: Grains and straw were analysed separately for different nutrients.

Samples of rice grain and straw were taken from the harvest of the net plot and dried in the dryer. After thoroughly grinding the samples, representative samples were each individually examined for N, P, and K content.

For both grains and straw, nutrient uptake was determined individually. Grain and straw uptake were combined and expressed as kg/ha for the overall uptake. The following equation was used to compute the uptake of N, P, and K:

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content in grain /straw (\%)} \times \text{Grain/straw yield (kg/ha)}}{100}$$

Statistical analysis: Data analysis with the help of MS-excel 2019 and using OPSTAT which is programmed by HAU, Hisar, Haryana was done.

RESULTS AND DISCUSSION

Grain yield: The yield of grain of all the traditional short grain scented rice varieties differed significantly (Table 2). The rice variety Kudrat-5 (42.46 q/ha) registered significantly the highest grain yield among all the scented rice varieties and was 17.61% higher than variety Pusa-1121. It was due to highest number of effective tillers. Similar findings were observed by Singh et al (2007).

Straw yield: The straw yield varied significantly among the varieties (Table 2). Significantly highest straw yield was in Kudrat-5 (53.3 q/ha). In present study, varieties with high effective tillers produced higher straw yield even though had short stature. These results were also supported byKumari et al (2010).

Biological yield: The biological yield varied significantly where Kudrat-5 produced the significantly highest biomass (95.7 q/ha) followed by kudrat-1 (84.0 q/ha) (Table 2). Chinar-20 recorded the lowest biological yield (55.7 q/ha). The biological yield did not differ significantly among Kesho Pohu, DRK, Type 3 and Tilak Chandan. The variation total biomass may be ascribed to the capacity of a genotype to utilize the resources more efficiently and convert them into dry matter. Davari and Sharma (2010) also observed that biological yield was significantly improved by organic cultivation.

Harvest Index: The harvest index of scented rice varied significantly (Table 2) and the grain yield and straw yield were highly correlated. Chinar-20 was the variety with the highest harvest index value (48%). Varieties with good grain yield and good straw yield attained the higher harvest index. Hussain et al (2014) also noted variations in harvest index among scented rice varieties.

N, P and K contents in grains and straw: The highest N content in grains was in Pusa 1121 (1.36 %) and the lowest

Table 1. N, P, K content analysis

Particulars	Methods
Nitrogen (%)	Modified Micro-Kjeldhal's method (Jackson 1973)
Phosphorus (%)	Vanadomolybdo phosphoric acid yellow color method (Jackson 1973)
Potassium (%)	Flame photometer method (Jackson 1973)

Table 2. Yield and harvest index of different scented rice varieties

Variety	Yield (q/ha)			Harvest Index (%)
	Grain	Straw	Biological	
Kubri Mamhani	27.89	45.56	73.45	37.95
Kudrat-5	42.46	53.27	95.72	44.09
Chinar-20	26.53	29.14	55.66	47.57
Kesho Pohu	29.04	34.07	63.11	45.95
DRK	28.68	33.66	62.34	46.06
Kudrat-1	37.54	46.49	84.03	44.64
Pusa 1121	34.98	41.70	76.67	45.63
Type-3	26.82	37.56	64.38	41.77
Traori	25.17	42.94	68.10	37.00
Tilak Chandan	29.01	34.53	63.55	45.67
CD (p=0.05)	3.08	4.27	6.84	0.02

for y Kesho Pohu (1.31%) though was statistically at par (Table 3). The N content in straw did not vary significantly among Kudrat-5 Kesho Pohu, Kudrat-1 and Tilak Chandan.The P content in grains differ significantly among the varieties maximum in Kudrat-5 and Chinar-20 (0.65%) followed by, Kudrat-1 and Pusa 1121. Kudrat-1 had significantly the maximum content of P in straw (0.17%). Except varieties DRK and Pusa 1121, all other varieties were at par with each other for P content in straw. The K content in grains of scented rice ranged from 0.23% (Kudrat-1) to 0.30% (Pusa 1121). Variety Pusa 1121 had significantly higher K content in grains. The K content in grains did not vary significantly among varieties DRK, Type-3 and Traori (0.29%). The K content in straw was the maximum for variety Kudrat-1 (1.33%), which was significantly higher than rest of the varieties. The minimum K content in straw was in Kesho Pohu (1.16%) which was at par with variety DRK. The N, P and K content in grains and straw were mainly influenced by genetic traits and nutrients translocation in rice plants.Kumari et al(2013) also observed that the effect of organic nutrient management (green manuring) on nutrient content of scented rice variety Birsamati was positively correlated. Kumari et al (2010) also observed the same trend.

N, P and K uptake by grainand straw: The N, P and K uptake in grain straw and total uptake varied significantly among varieties (Table 4). The maximum and significantly higher N uptake in grains (55.77 kg/ha), straw (27.60 kg/ha) and total (83.4 kg/ha) were in Kudrat-5 than other varieties.

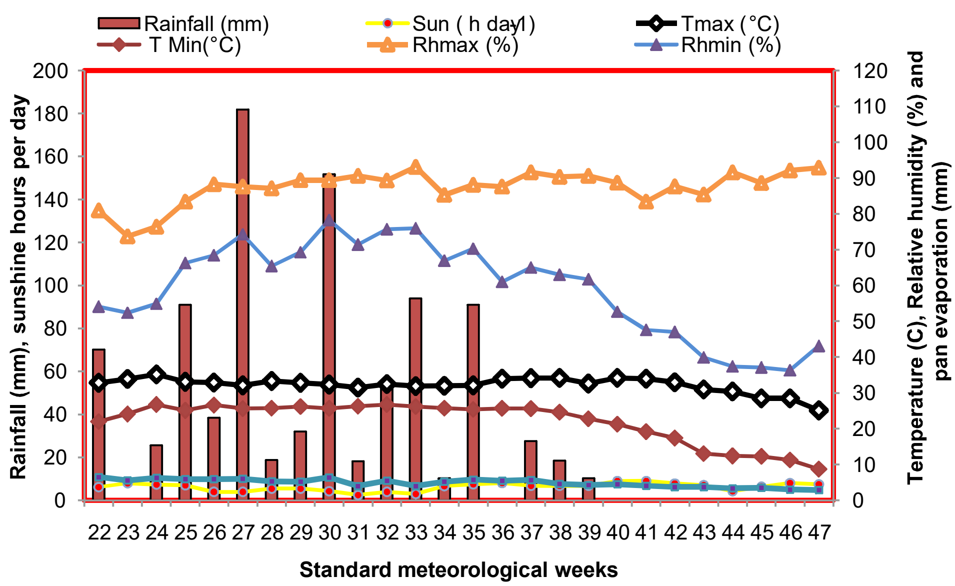

Fig. 1. Mean standard week-wise rainfall, temperature, relative humidity, evaporation and sunshine hours during cropping period (2020)

Table 3. N, P and K content in grain and straw of different rice varieties

Variety	N (%)		P (%)		K (%)	
	Grain	Straw	Grain	Straw	Grain	Straw
Kubri Mamhani	1.31	0.49	0.49	0.17	0.24	1.27
Kudrat-5	1.31	0.65	0.65	0.16	0.26	1.27
Chinar-20	1.33	0.65	0.65	0.16	0.24	1.24
Kesho Pohu	1.31	0.59	0.58	0.16	0.27	1.16
DRK	1.35	0.56	0.56	0.16	0.29	1.22
Kudrat-1	1.34	0.58	0.62	0.17	0.23	1.33
Pusa 1121	1.36	0.61	0.61	0.16	0.30	1.23
Type-3	1.36	0.50	0.50	0.16	0.29	1.28
Traori	1.34	0.50	0.50	0.16	0.29	1.25
Tilak Chandan	1.33	0.59	0.59	0.16	0.23	1.25
CD (p=0.05)	NS	0.03	0.05	0.008	0.005	0.06

Table 4. Uptake of N, P and K by different scented rice varieties

Variety	N uptake (kg/ha)			P uptake (kg/ha)			K uptake (kg/ha)		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
Kubri Mamhani	36.62	13.62	50.23	6.68	4.64	11.32	15.09	35.49	50.58
Kudrat-5	55.77	27.60	83.37	10.93	6.89	17.81	24.95	53.78	78.73
Chinar-20	35.19	17.16	52.34	6.35	4.33	10.68	14.85	32.94	47.80
Kesho Pohu	37.92	16.80	54.73	7.93	4.75	12.68	17.08	33.75	50.83
DRK	38.81	15.99	54.80	8.18	4.45	12.64	13.79	35.03	48.82
Kudrat-1	50.45	23.36	73.81	8.52	6.54	15.06	21.82	49.95	71.77
Pusa 1121	47.76	21.58	69.34	10.39	5.45	15.85	18.35	43.24	61.59
Type-3	36.38	13.40	49.78	7.70	4.35	12.05	12.02	34.34	46.36
Traori	33.74	12.66	46.39	7.28	4.06	11.34	11.96	31.60	43.46
Tilak Chandan	38.58	17.07	55.65	6.76	4.72	11.48	16.50	36.28	52.78
CD (p=0.05)	4.80	3.38	8.01	0.95	0.61	1.51	2.03	4.63	6.48

The P uptake in grains (10.93 kg/ha), in straw (6.89 kg/ha) and total P uptake (17.81 kg/ha) were also highest for variety Kudrat-5.

Variety Kudrat-5 also recorded the maximum K uptake by grains (24.95 kg/ha), straw (53.78 kg/ha). Except K uptake by straw, this variety recorded significantly higher K uptake by grain and total uptake than rest of the varieties. The contribution of contents was less and uptake was largely governed by the amount of biomass produced. Therefore, varieties which produced more biomass resulted in higher uptake of nutrients. Yadav et al (2014) also observed the similar variations in nutrient uptake among scented rice varieties. The findings were also similar with the earlier findings of Singh et al (2017).

CONCLUSION

The highest grain yield as well as nutrient content and uptake was found in scented variety Kudrat-5 which can be grown successfully under organic mode of cultivation.

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Performance of Direct Seeded Rice under Integrated Weed and Nutrient Management Practices and Residual Effect on Succeeding Rapeseed under Zero Tillage

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***Abstract*:** The field experiment was conducted with an objective to reduce our dependence on chemicals by selecting the best integrated weed and nutrient management practices in rice-rapeseed cropping system and to observed the residual effect on succeeding crop of rapeseed at College of Agriculture, Central Agricultural University, Imphal, Manipur, India during 2016-17 and 2017-18. The treatments comprised of five levels of weed management practices and three levels of nutrient management practices. The r application of pyrazosulfuron ethyl @ 30g a.i. at 7 days after sowing followed by either hand or mechanical weeding at 40 days after sowing in rice showed better yield attributes, yield and higher nutrient uptake in both rice and succeeding rapeseed crop. Among the nutrient management practices, application of 50% nitrogen from recommended dose of fertilizer with either 6 t ha^{-1} farmyard manure alone or with Azolla (dual crop) @10 t ha^{-1} and 3 t ha^{-1} farmyard manure gave higher yield and nutrient uptake in both the crops.

***Keywords*:** Direct seeded rice, Nutrient management, Rapeseed, Residual effect, Weed management

Heavy infestation of weeds is a major hindrance in successful cultivation of direct seeded rice causing drastic reduction in yield. Weed control during the critical period is essential for reducing the competition and for effective utilization of available resources for enhanced productivity. Due to their easy use and availability, herbicides are being preferred over manual weeding but there are serious concerns about the use of herbicides alone such as shifts in weed flora, development of weed resistance and impact on the environment. Integrated weed management which is the combination of many techniques (cultural, mechanical, chemical and biological) is, thus, considered a long-term approach to manage weed populations instead of controlling them using a single method.

It is observed that weeds exhaust more nutrients from the soil compared to crop plants. Chemical fertilizers release plant nutrients more rapidly into the soil as compared to organic manures as a result there is proliferation in weed growth. The effect of chemical fertilizers as well as organic manures in weed dynamics also needs to be studied since organic manures are known to release plant nutrients slowly. Providing balanced nutrition from both organic and inorganic sources may prove to be an important component of weed management. Integrated use of chemical fertilizers and organic manures has been proven to have higher effectiveness in maintaining higher productivity and stability, through correction of deficiencies of secondary and micronutrients in the course of mineralization on one hand and favorable physical and soil ecological conditions on the other (Mallikarjun and Maity 2017). Moreover, the application of Azolla significantly improves the physical properties of the soil like organic matter and chemical properties such as nitrogen status and other essential plant nutrients like Ca, Mg and Na which are released into the soil (Bhuvaneshwari and Kumar 2013) and also aids in suppression of weeds in paddy fields through the formation of a thick Azolla mat in the field.

Rapeseed-mustard is one of the important crops which can be grown successfully under zero tillage without much investment while utilizing the residual moisture and nutrients present in the soil. However, sometimes undesirable herbicide residues may affect the growth and productivity of succeeding crop. Janki et al (2015) reported that few sulfonylurea herbicide residues in soil can affect rotational crops even at low concentrations. Keeping the above points in mind, the present investigation was carried out in order to find out the performance of kharif rice under different integrated weed and nutrient management practices and their residual effect on the succeeding rapeseed crop.

MATERIAL AND METHODS

Field experiment was conducted at the Research Farm of College of Agriculture, Central Agricultural University, Imphal during 2016-17 and 2017-18. The experimental site was situated at 24°81' N latitude and 93°89' E longitude and an altitude of 790 m above the mean sea level. The soil was clayey in texture and medium in fertility having good drainage facility with 5.34 pH, high in organic carbon with 1.89 %, 280.88 kg ha^{-1} available nitrogen, 32.20 kg ha^{-1} available P_2O_5 and 270 kg ha^{-1} available K_2O, respectively. The experiment was laid out in a factorial randomized block design in three replications. The treatments were given to *kharif* rice only and comprised of five levels of weed management practices (Table 1). The varieties used were CAU-R1 and M-27 for rice and rapeseed, respectively. Rice was raised as rainfed crop in *kharif* season whereas succeeding rapeseed was grown in conserved residual soil moisture. Farmyard manure with nutrient content of 0.51% N, 0.18% P_2O_5 and 0.49% K_2O respectively was applied at the time of final puddling as per treatment. Azolla was applied as per treatment as a dual crop at 25 DAS @ 10 t ha^{-1} and incorporated at 40 DAS when a thick mat of Azolla was formed. Hand weeding and mechanical weeding with cono weeder were carried out at 40 days after sowing and herbicides were sprayed as per treatments. The recommended dose of fertilizer for rice and rapeseed were 60:40:30 and 40:30:20 kg N, P_2O_5 and K_2O ha^{-1}, respectively. Half dose of nitrogen and full dose of phosphorus and potassium were applied before sowing of rice as basal in the form of urea, single super phosphate and muriate of potash, respectively. The remaining portion of nitrogen was applied in two splits i.e. half at maximum tillering stage and another half at panicle initiation stage. For rapeseed, half dose of nitrogen and full dose of phosphorus and potassium were applied before sowing as basal and the remaining half of nitrogen was applied at flower initiation stage. Rice was sown in line at a spacing of 20 cm x 10 cm during the first week of June with a seed rate of 80 kg ha^{-1}. Rapeseed seeds were sown in lines under zero tillage with 20 cm row to row distance between the rows of stubbles left by previous rice crop and a plant to plant distance of 5 cm. Sowing was done in the last week of November with a seed rate of 12 kg ha^{-1}. The yield and yield attributes were recorded at the time of harvest of both crops. For recording panicle length, weight, number of spikelets and filled grains $panicle^{-1}$, ten panicles were randomly selected from each plot and their averages were calculated. The oil content of rapeseed seeds was estimated by adopting Soxhlet Ether Extraction Method (Sadasivam and Manickam 1996). The uptake of nitrogen, phosphorus and potassium in kg ha^{-1} was worked out by multiplying the dry matter of each crop at harvest with their corresponding percent nutrient content. The experimental data were statistically analysed by using SPSS.

RESULTS AND DISCUSSION

Yield: The pyrazosulfuron ethyl (PSE) @30 g a.i. at 7 DAS followed by either hand or mechanical weeding at 40 DAS recorded maximum effective tillers $hill^{-1}$, longest panicle, highest panicle weight, grain yield and straw yield with no significant difference except for straw yield. However, significantly highest number of spikelets and filled grains $panicle^{-1}$ in rice were in PSE@30 g a.i. at 7 DAS + 1 MW at 40 DAS. Lower weed competition in the above treatments led to the creation of an overall favorable environment for the growth and development of rice resulting in more availability of moisture, nutrients and space for rice which in turn led to improved yield. Earlier scientist also reported similar results (Parthipan et al 2013, Khwaja and Deva 2014, Parameswari and Srinivas 2014). The above treatments gave the highest and significantly at par seed, stover and oil yield in succeeding rapeseed also (Table 1). The herbicides applied in preceding rice did not produce any harmful residual effect on the yield of rapeseed and better weed control in previous crop resulted in better performance of succeeding crop (Sharma et al 2014, Bijarnia et al 2017). Earlier workers also observed that pyrazosulfuron ethyl and 2, 4-D do not persist in soil and have no adverse effect on the succeeding crop (Chakraborti et al 2017, Zahan et al 2018 and Irungbam et al 2019). The lowest yield in both the crops obtained from the weedy check plot might be due to severe competition with weeds throughout the growth period s observed by Hussain et al (2008) and Shendage et al (2017).

Among the nutrient management practices, application of 50% N from RDF + 6 t FYM gave the longest panicle length, highest number of spikelets, filled grains $panicle^{-1}$ and highest grain yield . However, grain yield was at par with 50% N from RDF + Azolla (dual crop) @10 t ha^{-1} + 3t FYM. The above two treatments also resulted in statistically higher and comparable seed and stover yield in rapeseed (Table 1). The percentage increases in grain yield in rice and seed yield in rapeseed in the above two treatments over 100% RDF were 7.73 and 4.49% and 8.84 and 8.08%, respectively. However, significantly highest oil yield was obtained in the plot which received 50% N from RDF + Azolla (dual crop) @10 t ha^{-1} + 3t FYM. The probable reason of highest yield attributes and yield might be due to higher availability of nutrients from the integration of FYM and Azolla with inorganic fertilizers and simultaneously better nutrition since early crop growth stage. Latha et al (2019) also reported beneficial effects of organic manures on yield due to better nutrition of crop. Application of FYM and Azolla in preceding rice crop had significant carryover effects on the growth and yield of succeeding rapeseed. Ghosh et al (2013), Devi et al (2015) and Lokose et al (2017) also observed significant residual effect of organic manures on the succeeding crop due to slow release of nutrients for a longer period. The interaction between different integrated weed and nutrient management practices produced significant residual effect on the oil yield of succeeding rapeseed crop (Table 4). The significantly highest oil yield was with the interaction between PSE@30 g a.i. at 7 DAS + 1 MW at 40 DAS and 50% N from RDF + Azolla (dual crop)@10 t/ha + 3t FYM. The lowest oil yield of 203.03 kg ha^{-1} was in the weedy check plot which received 50% N from RDF + 6t FYM closely followed by the interaction between weedy check and 100% RDF but there was no significant difference between them.

Nutrient uptake: The treatment PSE @ 30 g a.i. at 7 DAS followed by either hand weeding or mechanical weeding at 40 DAS recorded highest nutrient uptake in rice (Table 2). The total nitrogen, phosphorus and potassium uptake by rice ranged between 39.40 to 75.14 kg ha^{-1}, 15.65 to 30.40 kg ha^{-1} and 58.20 to 116.95 kg ha^{-1} respectively. The lowest uptake was observed in the weedy check plot due to poor dry matter production of the crops as a result of heavy weed competition. Earlier scientist also observed significant increase in nutrient uptake in integrated weed management practices over unweeded plot (Sunil et al 2011, Prashanth et al 2016, Bommayasamy and Chinnamuthu 2021). The higher uptake was mainly attributed to lower weed population

Table 1. Effect of integrated weed and nutrient management on the yield attributes of *kharif* rice and succeeding rapeseed at harvest (Pooled data)

Treatment	Number of effective tillers hill^{-1}	Panicle length (cm)	Panicle weight (g)	Number of spikelets panicle^{-1}	Number of filled grains panicle^{-1}	Rice yield (t ha^{-1})		Rapeseed yield (kg ha^{-1})		
						Grain	Straw	Seed	Stover	Oil
W_1	8.46	24.94	3.65	190.99	156.61	4.17	5.65	913.86	1908.84	319.76
W_2	9.95	25.65	4.07	215.28	167.83	4.83	6.81	988.60	2027.40	347.69
W_3	9.36	26.15	4.15	226.88	174.63	4.67	6.31	988.03	2033.65	347.39
W_4	8.86	25.66	3.85	212.27	162.45	4.44	6.02	941.02	1974.25	329.24
W_5	4.74	24.30	3.58	161.29	123.58	2.75	3.77	592.33	1271.62	209.49
CD (p=0.05)	0.69	0.51	0.28	7.10	6.10	0.26	0.44	10.79	50.38	4.01
N_1	8.56	25.61	3.91	209.59	160.71	4.32	5.83	911.53	1873.89	307.30
N_2	7.95	24.86	3.75	198.61	153.63	4.19	5.67	905.24	1871.77	324.35
N_3	8.31	25.55	3.91	195.82	156.71	4.01	5.63	837.53	1783.80	300.49
CD (p=0.05)	NS	0.40	NS	5.50	4.73	0.20	0.34	8.36	39.03	3.10

W_1: PSE @50g a.i. at 7 DAS; W_2: PSE@30g a.i. at 7 DAS + 1 HW at 40 DAS ; W_3: PSE@30 g a.i. at 7 DAS + 1 MW at 40 DAS ; W_4: PSE@30g a.i. at 7 DAS + 2, 4-D @ 0.75kg a.i. at 40 DAS; W_5: Control; N_1: 50% N from RDF + 6 t FYM; N_2: 50% N from RDF + Azolla (dual crop)@10 t/ha + 3t FYM and N_3: 100% RDF
PSE: Pyrazosulfuron ethyl, DAS: Days after sowing, HW: Hand weeding, MW: Mechanical weeding, RDF: Recommended dose of fertilizers, FYM: Farmyard manure

Table 2. Effect of integrated weed and nutrient management on NPK uptake by rice at harvest (Pooled data)

Treatment	Nitrogen uptake (kg ha^{-1})			Phosphorus uptake (kg ha^{-1})			Potassium uptake (kg ha^{-1})		
	Straw	Grain	Total	Straw	Grain	Total	Straw	Grain	Total
W_1	20.49	41.24	61.73	12.26	11.78	24.04	82.63	7.47	90.11
W_2	27.63	47.51	75.14	15.64	14.76	30.40	107.89	9.06	116.95
W_3	27.34	46.77	74.11	14.07	14.04	28.11	101.50	9.17	110.68
W_4	24.11	44.65	68.76	13.96	13.33	27.29	96.12	7.94	104.06
W_5	13.52	25.87	39.40	8.36	7.29	15.65	54.43	3.77	58.20
CD (p=0.05)	2.52	3.07	4.92	1.56	0.83	2.08	6.74	0.59	7.13
N_1	23.51	43.24	66.75	13.33	12.83	26.16	92.11	8.16	100.27
N_2	22.43	41.19	63.62	13.07	12.50	25.58	88.67	7.61	96.28
N_3	21.92	39.20	61.11	12.17	11.39	23.56	84.76	6.68	91.45
CD (p=0.05)	NS	2.38	3.81	1.21	0.64	1.61	5.22	0.46	5.52

See Table 1 for treatment details

and weed dry weight and this has helped the crops to grow well and treatment of 50% N from RDF + 6 t FYM and 50% N from RDF + Azolla (dual crop) @ 10 t ha^{-1} + 3 t FYM recorded the highest NPK uptake by both straw and grain in rice which might be due to consistent supply of nutrients and reduced rate of loss of released nutrients during the process of decomposition of FYM and Azolla and also due to improved root growth and its functional activity which helped in greater extraction of nutrients. Sahu et al (2017) also observed that integrated application of organic and inorganic forms of nutrients significantly affect the yield and nutrient uptake by rice. Similarly, in the succeeding rapeseed crop, the plots which received PSE @ 30g a.i. at 7 DAS followed by either post emergent application of 2, 4-D @ 0.75 kg a.i. ha^{-1} or a mechanical weeding at 40 DAS in the preceding *kharif* rice recorded maximum and statistically at par nitrogen uptake by stover. The highest nitrogen uptake by seed was in PSE @ 30 g a.i. at 7 DAS + 1 HW at 40 DAS with 26.65 kg ha^{-1}. Highest uptake of phosphorus and potassium by both stover and seed was also observed with PSE @ 30 g a.i. at 7 DAS followed by either hand weeding or mechanical weeding at 40 DAS. This may be attributed to low removal of nutrients by

Table 3. Effect of integrated weed and nutrient management on NPK uptake by rapeseed at harvest (Pooled data)

Treatment	Nitrogen uptake (kg ha^{-1})			Phosphorus uptake (kg ha^{-1})			Potassium uptake (kg ha^{-1})		
	Stover	Seed	Total	Stover	Seed	Total	Stover	Seed	Total
W_1	9.83	22.99	32.83	3.54	2.25	5.79	19.24	7.12	26.36
W_2	10.21	26.65	36.86	3.81	2.45	6.26	27.99	8.64	36.64
W_3	10.81	24.90	35.71	3.77	2.46	6.23	28.89	8.56	37.45
W_4	11.07	25.07	36.15	3.56	2.31	5.86	26.99	7.92	34.91
W_5	6.14	14.58	20.71	2.18	1.41	3.58	12.75	4.55	17.30
CD (p=0.05)	0.50	0.49	0.70	0.11	0.03	0.12	1.78	0.21	1.81
N_1	9.85	23.93	33.78	3.55	2.29	5.84	24.25	7.77	32.02
N_2	10.21	23.43	33.64	3.44	2.26	5.70	23.91	7.64	31.55
N_3	8.78	21.15	29.93	3.13	1.97	5.10	21.35	6.66	28.01
CD (p=0.05)	0.38	0.38	0.54	0.08	0.03	0.10	1.38	0.16	1.40

See Table 1 for treatment details

Table 4. Residual effect of interaction between integrated weed and nutrient management practices on oil yield, nitrogen and phosphorus uptake of rapeseed in rice-rapeseed cropping system (Pooled data)

Treatment	Oil yield (kg ha^{-1})	Nitrogen uptake (kg ha^{-1})			Phosphorus uptake (kg ha^{-1})		
		Stover	Seed	Total	Stover	Seed	Total
W_1N_1	315.01	10.19	23.39	33.57	3.70	2.36	6.06
W_1N_2	333.03	9.73	23.36	33.09	3.51	2.34	5.85
W_1N_3	311.24	9.58	22.23	31.82	3.42	2.06	5.48
W_2N_1	343.40	11.03	29.04	40.07	4.14	2.60	6.74
W_2N_2	358.55	10.17	27.31	37.48	3.82	2.51	6.33
W_2N_3	341.10	9.44	23.59	33.03	3.48	2.22	5.71
W_3N_1	348.29	10.89	25.78	36.67	4.02	2.60	6.63
W_3N_2	365.64	11.95	25.63	37.58	3.98	2.56	6.54
W_3N_3	328.25	9.59	23.28	32.87	3.32	2.20	5.52
W_4N_1	326.77	10.78	26.97	37.74	3.68	2.45	6.13
W_4N_2	342.15	12.78	25.39	38.17	3.63	2.40	6.03
W_4N_3	318.79	9.66	22.86	32.53	3.36	2.08	5.43
W_5N_1	203.03	6.37	14.49	20.86	2.21	1.44	3.65
W_5N_2	222.38	6.42	15.45	21.87	2.27	1.49	3.76
W_5N_3	203.07	5.62	13.79	19.41	2.05	1.29	3.34
CD (p=0.05)	6.94	0.86	0.85	1.21	0.19	0.06	0.21

See Table 1 for treatment details

weeds owing to better weed management in the preceding *kharif* crop. Integration of 50% N from RDF with either FYM alone or with Azolla recorded the highest uptake of NPK by both seed and stover in rapeseed (Table 3). Similar results were also observed earlier workers (Patel et al 2013, Susan and Kaleeswari 2015, Deewan et al 2018). Higher amount of nitrogen fixed by Azolla, production of organic acids that solubilize the native and added phosphorus and release of potassium from potassium bearing minerals by complexing agents due to the decomposition of organic manures might also have resulted in the improved uptake of nutrients by the crops. The interaction between different weed and nutrient management practices indicated significant residual effect on the uptake of nitrogen and phosphorus by rapeseed (Table 4). The highest uptake was when pyrazosulfuron ethyl was applied followed by either hand weeding or mechanical weeding or 2,4-D herbicide at 40 DAS along with 50% N from RDF + 6 t FYM or 50% N from RDF + Azolla (dual crop) @10 t/ha + 3t FYM. This may be attributed to better control of weeds combined with balanced application of plant nutrients from organic as well inorganic sources which led to better crop growth resulting in improved nutrient uptake capacity by the crops.

CONCLUSION

Application of pyrazosulfuron ethyl@30 g a.i. ha^{-1} along with either hand weeding or mechanical weeding at 40 DAS in *kharif* rice resulted in better growth, yield and nutrient uptake in both rice and the succeeding rapeseed crop. The herbicides *viz.*, pyrazosulfuron ethyl and 2, 4-D Na salt applied in preceding *kharif* rice did not produce any detrimental residual effect on the succeeding rapeseed in terms of yield. Integration of chemical fertilizers with FYM or/and Azolla also gave better yield and higher nutrient uptake in both the crops compared to sole application of inorganic fertilizers. Integrated weed and nutrient management practices adopted in *kharif* rice resulted in better productivity in both the crops and can be recommended to the farmers as a feasible and economically viable strategy to control weeds and improve the productivity of rice-rapeseed cropping system in the north east region of India.

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Yield Prediction in Maize (*Zea Mays*) using Weather Parameters under Subtropical and Intermediate Regions of North-Western Himalayas

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Abstract: For prediction of maize yield in the north western Himalayas two districts Jammu and Udhampur belonging to different agro climatic conditions i.e. subtropical and intermediate regions were selected. For running yield prediction model at F2 stage (Flowering) and F3 stage (Pre harvest) of maize crop long term weekly climatic data of Jammu and Udhampur districts from 1997 to 2021 (24 years) was collected from different departments related to Agriculture and Meteorology. For validation yield prediction model field experiments on maize crop were conducted during kharif season 2020 and 2021 at SKUAST-J main campus Chatha. Pre harvest yield prediction model for maize crop has been prepared by using this data. For prediction of maize yield at F2 and F3 stage the long-term data from 26th to 36th and 26th to 40th standard meteorological week (SMW) from 1997 to 2021 was used. Further composite weather variables were studied for developing yield forecast model. Simple and weighted weather indices have been prepared for individual weather variable and for their interaction with time. The yield forecast model were able to explain the variation in the grain yield of maize crop in subtropical Jammu region which was to the tune of 2.57 and -14.70 at F2 Stage and -3.00 and 9.70 during F3 stage where as in intermediate Udhampur district variation in F2 was 9.15 and 2.15 whereas during F3 stage -1.37 and 0.20 percent during *kharif* 2020 and *kharif* 2021.The predicted yield of maize crop for most of the stages are within acceptable error limit (+10 percent) in both the years of validation.

Keywords: Agro climatic, Maize, Forecast, Model, Prediction, Weather, Yield

Yield forecasting within the growing season would facilitate proper planning and more proficient management of grain production, handling and marketing of yield. The pre harvest yield prediction is also required for policy decisions like storage, pricing, marketing, import, export etc of grains. Weather is the main component that influence yield of crop. Crop models based on weather can provide trustworthy forecast of crop yield in advance of harvest and also forewarning of pests and diseases attack of pests and diseases attack so, that suitable plant protection measures could be taken up timely to protect the crops. Forecasting Agricultural Output using Space, Agrometeorology and Land based observations (FASAL) is an important project operational at Ministry of Agriculture cooperation and Farmer's Welfare, New Delhi through India Meteorology Department. The mandate of this project is to subject multiple crop yield forecast for various major crops under different agro climatic zones of the states at initial stage (F1), mid-season (F2) and pre-harvest (F3) stages.

Maize is the staple food and plays vital role in food security. In India, Maize is grown on 9.89-million-hectare area with production and productivity of 31.65 million tonnes and 3199 kg/ha (Anonymous 2021). In Jammu division maize is grown on 207.05-thousand-hectare area with average production of 42.40 lakh quintals and productivity of 2048 kg/ha (Anonymous 2022). In Subtropical conditions of Jammu district maize is grown in *kharif* season which contribute 6.32 percent in total area and 6.03 percent in total production of maize in Jammu division whereas intermediate region, Udhampur district contribute 15.11 percent in total area and 15.80 percent in total maize production in the Jammu division. Therefore, forecasting of maize yield is important for economic planning by policy makers in the government. For that reason the study has been undertaken to develop the model for maize yield by analysing the weather variables using weather and yield records of Jammu and Udhampur districts of Jammu region.

MATERIAL AND METHODS

Long term climate data was collected from Department of Finance revenue, Government of Jammu and Kashmir UT and weather data collected from Indian Meteorological Department of Jammu and Udhampur District from 1997-2021.Geographically Jammu is located at latitude of 32^{0}.73'N and longitude of $74^0.52'E$ with altitude of 308 meters above mean sea level where as Udhampur is located in intermediate region at latitude of $32^0.55'N$ and longitude of $75^0.09'E$ with elevation of 742 meters above mean sea level. The daily weather data was used for calculating weekly as well as monthly data in which the growth period of maize crop lies except the harvesting period were used to develop the district level yield forecast model. The standard meteorological week SMW wise weather data from 26^{th} - 36^{th} were used to develop weather-based yield prediction regression models for F_2Pre flowering stage and 26^{th} to 40^{th} for Pre harvesting stage of maize crop for above said two selected districts. The variable simple weather indices such as maximum temperature Tmax., minimum temperature Tmini. rainfall RF, relative humidity morning RH1 and relative humidity evening RH2 were used in the study. Different weather indices were generated using weekly values of weather parameters during the maize growing period and their weighted values using correlation (Table 1). To study the combined effects of weather variables on maize yield, the model used for studying effect of individual weather variables had also been extended by including interaction terms as per IASRI, New Delhi suggested by Hendricks and Scholl (1943) further modified by Agrawal et al (1980) for expressing effects of changes in weather variables on yield of maize in the crop growing period as a second degree polynomial in respective correlation coefficient between yield and weather variables . The modified statistical model given by Agrawal et al (1980) used in present study for district wise yield predictions equations for maize crop is as under:

$$Y = A_0 \sum_{i=1}^{p} \sum_{j=0}^{1} a_{ij} Z_{ij} + \sum_{i \neq i'=1}^{p} \sum_{j=o}^{1} a_{ii'j} Z_{ii'j} + cT + e$$

Where

$$Z_{ij} = \sum_{w=1}^{m} r_{iw}^{j} X_{iw} \text{and} Z_{ii'j} = \sum_{w=1}^{m} r_{ii'w}^{j} X_{iw} X_{i'w}$$

Where,

Y = Variable to forecast or seed yield of Maize

$X_{iw}/X_{ii'w}$= w is the value of i^{th} / i'^{th} weather variable under study in the w^{th} week

r_{iw}/r_{iiw}= is correlation coefficient of yield with i^{th} weather variable/product of i^{th} and i^{th} weather variables in w^{th} week , respectively, m is the week of forecast, p is the number of weather variables used and c is the random error distribution as N $(0,\sigma^2)$

In this model, two weather indices (simple - Zi0 and weighted - Zi1) accumulation of weekly weather variable, weights being correlation coefficients of weather variables in respective weeks with yield. Similarly, indices were also generated for interaction of weather variables, using weekly products of weather variables taking two at a time. Simple and weighted weather variables thus generated are presented in Table 1. Regression analysis was used for fitting equation taking year and weather as independent variable and yield as dependent variable using the SPSS software. Weather scores for each year at different phases of crop growth of maize crop in Jammu and Udhampur district obtained through these discriminant functions were used along with inputs and time trend as regressors in model development through stepwise regression. The weighting coefficients in these equations are achieved in an empirical manner using standard statistical procedures, such as multivariable regression analysis. For the validation of the above said prediction model, field experiments were conducted at SKUAST-J, Chatha, Jammu during *kharif* 2020 and 2021. The experiments were conducted in randomized block design with three replications consisting of three sowing environments and three varieties of Maize grown popularly in the region.

RESULTS AND DISCUSSION

Forecast: The weather based statistical model for forecast of maize crop at two stages (F_2 and F_3) were developed by using 24 years of data sets and validated for two years 2020 and 2021. The seed yield prediction model for maize crop for subtropical Jammu district and intermediate Udhampur districts was validated for two years 2020 and 2021. In the prediction model, coefficient of determination was significant in Jammu and Udhampur districts. The R^2 value at F_2 and F_3 (Pre harvesting) stage in Jammu district ranged between 0.55 to 0.79 whereas for Udhampur district ranged between 0.71 to 0.91.

Weather indices: The best agro meteorological indices to incorporate in the agro meteorological yield forecast model at F_2 and F_3 stage in maize crop was Tmax (Z11), T min (Z21), Tmax X Tmin (Z121), Tmin XRF (Z230),RF X RH II (Z350). In Udhampur district, the best agro meteorological indices at F_2 (pre flowering stage) and F_3 (pre harvesting stage) were Tmax (Z11), RH II(Z51), Tmax X Tmin (Z121), Tmax X RH II (Z141), RFXRH I(Z 341) and RF XRH II(Z351).Similar, results were also reported by Patel et al (2018). The validation of results of statistical model during *kharif* 2020 and results reported that the percent deviation in maize yield at F_2 stage was 2.57 percent and 9.15percent in Jammu and Udhampur district whereas at F_3 stage the percent deviation in maize yield in Jammu and Udhampur district were -3.00

Table 1. Weather derived indices used in models using composite weather variables

Weather parameters	Simple weather indices					Weighted weather indices				
	Tmax	Tmin	RF	RHI	RHII	Tmax	Tmin	RF	RHI	RHII
Tmax	Z10					Z11				
Tmin	Z120	Z20				Z121	Z21			
RF	Z130	Z230	Z30			Z131	Z231	Z31		
RHI	Z140	Z240	Z340	Z40		Z141	Z241	Z341	Z41	
RHII	Z150	Z250	Z350	Z450	Z50	Z151	Z251	Z351	Z451	Z51

Table 2. Yield prediction model at F_2 and F_3 stage of maize crop for Jammu and Udhampur districts

District	Year	Stage	Equation	R^2
Jammu	2020	F_2	Y = 8.137+0.0001*Z351+0.014*Z121	0.67
	2020	F_3	Y = -1.175+0.544*Z11+0.0001*Z230	0.79
	2021	F_2	Y= -26.63+5.07*Z21	0.55
	2021	F_3	Y = - 4.28+1.286*Z11+0.262	0.69
Udhampur	2020	F_2	Y = 25.86+0.009*Z121+0.0001*Z341	0.74
	2020	F_3	Y = -0.138+0.728*Z11	0.71
	2021	F_2	Y = -5.46+0.223*Z51+0.829*Z11+0.014*Z141	0.91
	2021	F_3	Y = 0.069 + 0.168*Z51+0.0003*Z351	0.82

Table 3. Yield prediction model at F_2 and F_3 stages of maize crop for different districts of Jammu region

Seed yield (q/ha)	Year	Jammu	Udhampur
Observed	2020	18.57	20.05
	2021	15.98	20.39
Forecasted yield at F2 stage	2020	19.06 (2.57)	22.07 (9.15)
	2021	18.25 (-14.21)	19.96 (2.11)
Forecasted yield at F3 stage	2020	18.04 (-3.00)	19.78 (-1.37)
	2021	14.43 (9.70)	20.35 (0.20)

Parenthesis are variation /error (±) in the seed yield (Percentage)

percentand-1.37 percent). In 2021 the percent deviation in maize yield in Jammu district at F_2 and F_3 stage were -14.21 percent and 9.70 percent. Similarly, for Udhampur district the percent deviations at F2 and F3 stage were 2.11 and 0.20 percent in 2021 it might be due to deviation in weather parameters during maize growing period. Similar findings were also reported by Chandrahas et al (2010). The results indicate that this model had predicted seed yield of maize crop within acceptable error/ variation limit ±10 percent in both the year of validation study for Jammu and Udhampur districts except at F_2 stage in 2021 for Jammu district where error limit is more than ±10 percent. Predicted yield was very closer to observed yield, therefore it suggested that these prediction models can be used for yield forecasting and planning purpose in the region. The results showed that agro meteorological yield model explained the yield variability due to variations in minimum and maximum temperatures together with relative humidity with respect to major maize growing districts of Jammu Province. Temperatures and rainfall are very important weather parameters influencing maize yield (Maitah et al 2021).Comparatively variable trend in maximum, minimum temperature, relative humidity and rainfall was recorded in weather parameters during F_2 and F_3 forecast of maize crop in Udhampur district during *kharif* 2020 and 2021.The maximum temperature recorded during F_2 stage from 26^{th} - 36^{th} SMW during *kharif* 2020 and 2021 was 31.1^{0}C and 31.5 ^{0}C which was well near average normal Tmax 31.0 ^{0}C recorded during 26^{th}-36^{th} SMW and the extent of variation was only 0.1^{0}C and 0.5^{0}C from the normal values . Further at F3 Stage 26^{th}-40^{th} SMW there was increase in maximum temperature to the tune of 0.6^{0}C and 0.4^{0}C from the average normal maximum temperature 30.6^{0}C recorded in maize crop during particular period. The average normal minimum temperature in maize crop during F2 stage was 21.8 ^{0}C and F3 stage was 21.0 ^{0}C. During *kharif* 2020 the extent in variation from the normal minimum temperature values at F_2 and F_3 was +1.2^{0}C and +1.3^{0}C whereas during *kharif* 2021the extent in variation from the normal values was +1.3^{0}C and +1.6^{0}C. The rainfall data showed that there was a substantial variation in rainfall during both the crop growing years. Further, in comparison to normal rainfall 1329.4 mm during the F_2 stage 26^{th} -36^{th} SMW in maize crop, the *kharif*

2020 received 3.07 percent more rainfall and *kharif* 2021 received 15.57 percent less rainfall during the respective crop growing period. At pre harvesting stage F_3 26th - 40th SMW, there was decrease in 4.89 and 13.76 percent rainfall during *kharif* 2020 and 2021 when compared with normal rainfall 1440.7 mm during that particular crop growing period. Further, in Jammu district, deviation in weather parameters viz., maximum, minimum temperature, relative humidity and rainfall was recorded at F_2 and F_3 stage from the normal values during maize growing periods. The average normal maximum temperature at F_2 stage 26-36th SMW for maize crop was 34.5^{0}C and the extent of variation in maximum temperature during *kharif* 2020 and 2021 from normal values was -0.1^{0}C and +0.5 ^{0}C. Similarly, there was increase in average minimum temperature +1.5^{0}C and +1.3 ^{0}C at F_2 stage from the normal average minimum temperature 34.5^{0}C recorded during 26 to 36th SMW in Jammu district and during F_3 stage the extent in variation in average minimum temperature was to the tune of +1.4^{0}C and +1.5 ^{0}C from the normal average minimum temperature at F_3 stage during the maize growing period in Jammu district in both the *kharif* seasons. Deviation in total rainfall was also recorded during maize growing period in Jammu district. Further, maize crop received 3.82 and 5.51 percent more rainfall in comparison to normal seasonal rainfall 756.5 mm received during 26th -36th SMW at F2 stage. There was decrease in 5.96 percent and increase in 2.32 percent rainfall in comparison to normal seasonal rainfall 835.2 mm received during (26th - 40th SMW) at F3 stage in maize crop. Variation in relative humidity was also recorded at F_2 and F_3 stage in both the districts. Yield of Maize crop is influenced by the amount of rainfall and phenological stage at which crop received rainfall. Similar results were also reported by Banotra et al 2017.

CONCLUSION

Temperatures (maximum and minimum) together with relative humidity (morning and evening) and rainfall were significant agro meteorological indices for deciding maize productivity in the Jammu and Udhampur districts. The pre harvested grain yield prediction can be reasonably accurate with R^2 (between 0.67 to 0.91). The performance of yield forecast model for forecasting yield in Jammu and Udhampur district is quite satisfactory. Therefore, it could be used for maize yield forecasting in other districts of Jammu division also.

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Response of Chickpea to Irrigation and Nitrogen Levels in Loamy Sand Soil of North Gujarat

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Abstract: A Field experiment was conducted at S.D. Agricultural University, Sardarkrushinagar, to study the response of chickpea to irrigation and nitrogen levels during *rabi* season of 2021-22 on loamy sand soil of North Gujarat. Grain and straw yield of chickpea increased significantly with at each higher level of irrigation scheduling up to 0.8 IW/CPE ratio with water application of 450 mm along with 100% RDN (20 kg/ha). Highest nitrogen content in seed and NPK uptake was recorded with 1.0 IW/CPE ratio which was at par with 0.8 IW/CPE ratio. Similarly, 125% RDN recorded at highest nitrogen content and NPK uptake which was at par with 100% RDN. Interaction effect between irrigation scheduling and nitrogen levels on seed yield and total nitrogen uptake by chickpea crop was highly significant. The highest field water use efficiency of chickpea with 0.6 IW/CPE ratio. Applied water with seed yield and field water use efficiency followed quadratic function with regression coefficient (R^2) of 0.99. Similarly, regression coefficient of applied water with NPK uptake (0.946, 0.973, 0.982) and applied nitrogen with NPK uptake (0.904, 0.974, 0.960) were highly significant and reflected close relationship between them.

Keywords: Chickpea, Irrigation, Nitrogen levels, Nutrient uptake, WUE, Yield

Pulses are wonderful gifts of nature occupy a unique place in Indian agriculture by virtue of its high protein content and its capacity to enrich the soil fertility through the mechanism of symbiotic nitrogen fixation. Currently, the higher population growth and low protein content of cereals has attracted the attention of people to pulses consumption as most effective sources of protein for vegetarian population of India. Among the different pulses, chickpea (*Cicer arietinum* L.), is second important pulse crop in the world which is commonly known as Bengal gram belongs to genus *Cicer*, family *Leguminoceae* and sub family *Papilionaceae.* It is grown on a wide range of soils from medium to heavy black during *rabi* season with optimum temperature of 24-30°C. It is a rich and cheap source of protein it helps people to improve the nutritional quality of their diet. In India, chickpea cultivated over an area of 9.99 million hectare with a production of 11.91 million tones and productivity of 1092 kg/ha (Anonymous 2021a). In Gujarat area, production and productivity of chickpea was 1.10 million hectare, 2.10 million tones and 1908 kg/ha, respectively (DES 2021). The major constraint attributing to low production of chickpea is scare and untimely water supply, poor fertility status of soil and nutrient management. Therefore, it has to be used in the most efficient manner at proper time and quantity to realize the use efficiency. During the winter season, less water is required at early stage of crop while, at later crop growth stages water requirement increases due to rapid increase in evapotranspiration demand so that among different approaches for scheduling irrigation, climatological approach based on the ratio between depth of irrigation water (IW) and cumulative pan evaporation (CPE) is found the most appropriate, scientific and practicable, as it integrates all the weather parameters. It determines the process to decide when to irrigate the crop and how much water is to be applied. Optimum scheduling of irrigation led to increase in yield and WUE in case of chickpea.

Among the major nutrients, nitrogen plays a key role for the plant growth. Nitrogen deficiency is frequently a major limiting factor for high yielding crops all over the world (Namvar et al 2013). It is the most limiting nutrient in North Gujarat soils which are loamy sand, having high infiltration and percolation rate that leads to leaching of nitrogen through irrigation water. Nitrogen plays an important role in plant metabolism by virtue of being an essential constituent of structural cell, synthesis of chlorophyll as well as amino acids, which contribute to the building unit of protein and thus growth of plant. The deficiency of nitrogen causes chlorosis, reduction in growth rate and often early senescence of older leaves, leading to yield losses (Caliskan et al 2008, Erman et al 2011). Thus, there is a need to apply nitrogenous fertilizer in the nitrogen deficient soils to overcome the deficiency of nitrogen and to harness higher yield of chickpea.

MATERIAL AND METHODS

Field experiment was carried out during winter (*rabi*) season of 2021-22 at S.D. Agricultural University, Sardarkrushinagar. The site is geographically situated at 24° 19' N Latitude and 72° 19' E Longitude with an elevation of 154.52 m above the mean sea level. The region is characterised by tropical and semi-arid with dry winter (November-February) and soil is loamy sand in texture having low in organic carbon (0.21%) and available nitrogen (168.4 kg/ha) and medium in available phosphorus (35.22 kg/ha) and available potassium (264.10 kg/ha). Chickpea variety "Gujarat Gram 5" was sown manually on 22nd November 2021 with recommended dose of fertilizer was 20:40:00 NPK kg/ha. The experiment was laid out in a split plot design with four replications, consisting of nine treatment combinations comprising three irrigation levels in main plot *viz*., 0.6, 0.8 and 1.0 IW/CPE ratio (I_3) with 50 mm depth of irrigation water at each irrigation and three nitrogen levels in sub plot *viz*., 125%), 100% and 75% RDN One common pre sowing irrigation was applied for crop establishment in all treatments thereafter; 50 mm depth of irrigation water was given through flood method as per the treatment wise. Full dose of phosphorus was applied as basal dose through SSP and nitrogen was given in two splits at half in basal and remaining half at 30 DAS as per the treatment wise. Total nitrogen content from seed and straw samples was determined by using Micro Kjeldahl's method (Jackson 1967). Phosphorus was determined by Vanadomolybdo phosphoric acid yellow colour method using HNO3 system as described by Jackson (1967). Potassium was determined by the method of Flame Photometer (Jackson 1967). The uptake of N, P and K was calculated by using following equation.

$$\text{Nutrient uptake (kg/ha)} = \frac{\left(\text{Content in seed (\%)} \times \text{Seed yield (kg/ha)}\right) + \left(\text{Content in straw (\%)} \times \text{Straw yield (kg/ha)}\right)}{100}$$

Initial and final nutrient status of soil were determined in experimental treatment plot from 0-15 cm depth as per the slandered procedure.

Multiple Linear Regression used to analyse a dependent variable against several independent/predictor variables. This kind of regression is often used due to the reality of some process is not only built by one factor instead, but several other factors are also involved in every activity. The linear regression formula's slope can also be interpreted as the linear relationship strength between the independent variable and its dependent variable.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots\ldots + \beta_i X_i$$

Y: Dependent variable, βo: Intercept, β_i: Slop for Xi, X: Independent variable SPSS software used for data analysis

RESULTS AND DISCUSSION

Seed and straw yield: Irrigation scheduled at 1.0 IW/CPE ratio recorded significantly the highest seed yield (2306 kg/ha) and straw yield (3123 kg/ha) of chickpea which was at par with 0.8 IW/CPE ratio and significantly superior over 06 IW/CPE ratio (Table 1). Increase in irrigation frequency from 0.6 to 1.0 IW/CPE ratio increase consumptive use of water, which provided congenial condition throughout the growth period of the crop. Besides adequate soil moisture in the rhizosphere of chickpea crop which results in higher photosynthesis and translocation of photosynthesis towards reproductive structures. Several researchers reported improved seed yield with irrigation scheduled at 0.8 and 1.0 IW/CPE (Pawar et al 2013, Kumbhar et al 2015, Srinivasulu et al 2016, Khot et al 2021). Application of 125% RDN recorded significantly the highest seed yield (2213 kg/ha) and straw yield (3068 kg/ha) which was at par with 100% RDN. The improvement in yield components might have resulted from favourable influence of nitrogen on growth attributes and efficient and greater partitioning of metabolites and adequate translocation of nutrients to developing reproductive structure. The results agreed with Bhadoria (2018), Dwivedi et al (2019) and Verma et al (2019).

Quality: Protein content in chickpea were significantly influenced by irrigation and nitrogen levels (Table 1). With each unit of increased in irrigation level from 0.6 to 1.0 IW/CPE. There was significant increase in protein content. Highest value of protein content (21.78%) and protein yield (503 kg/ha) was with 1.0 IW/CPE ratio which was at par with 0.8 IW/CPE ratio and significantly superior over 0.6 IW/CPE ratio. This might be due to better plant growth at optimum irrigation level, hence more dry matter production resulting dilution of nitrogen under increased moisture supply resulted more accumulation of protein in seed and higher seed yield. Mehta et al (2010) also reported similar results. The increase in levels of nitrogen levels from 75% to 125%, boosted the protein content and protein yield of chickpea up to the highest nitrogen level. The maximum values of protein content (21.40%) and protein yield (475 kg/ha) in chickpea seed were recorded under 125% RDN. However, it was at par with 100% RDN and significantly superior 75% RDN. This increase in protein content may be attributed to increased concentration of nitrogen in seed and higher seed yield of chickpea due to application of nitrogen fertilizers. Similar results were reported by Bonde and Gawande (2017) and Singh and Singh (2017). The applied water in chickpea was found to be significantly and positively correlated to protein content in seed and protein yield of chickpea. The higher level of irrigation from 0.6 to 1.0 IW/CPE ratio, increased growth of plant at optimum moisture levels and enhanced nutrient content and uptake seed which ultimately affected on protein yield. Similarly the increase in nitrogen levels from 75 to 125%, showed curvilinear increase in protein content in seed and protein yield due to better uptake of nitrogen in seed and higher seed yield. The relationship between applied water and nitrogen levels with protein content and protein yield was curvilinear (polynomial of first order) (Fig. 1 and 2). This relationship could be expressed as follows:

$y = -3E - 0.05x^2 + 0.0409x - 9.2675$ ($R^2 = 0.99$) ………….. Eq. 1

$y = -0.0037x^2 + 4.22x - 683.63$ ($R^2 = 0.99$) ………………… Eq. 2

Nutrient Content and Uptake

Nutrient content: The irrigation scheduling exhibited significant difference on nitrogen content in seed and straw of chickpea (Table 2). This was nonsignificant in the phosphorus and potassium content. Significantly higher nitrogen content in seed (3.49%) and straw (1.51%) were with irrigation scheduled at 1.0 IW/CPE ratio being at par with 0.8 IW/CPE ratio. This might be due to irrigation at higher levels created better environment for availability of moisture eventually increases the nitrogen uptake, increasing the amount of protein and therefore, the amount of protoplasm (Yasari and Patwardhan 2006). This increase in term, results in greater cell size and leaf area, vigorous root growth, higher uptake and thus in greater photosynthetic activity. The present findings are in line with Emamzada (2015) and Bhadoria (2018). The significantly higher nitrogen content in seed (3.42%) and straw (1.50%) were recorded under 125% RDN which remained statistically at par with 100% RDN. Phosphorus and potassium content in seed and straw did not differ significantly. Nitrogen content in seed and straw of a chickpea was relatively higher with increase in level of nitrogen. Since the concentration of nitrogen and dry matter production increased with nitrogen application, the uptake of nutrient also increased. It is because of the ability of nitrogen to more towards reproductive organs. Similar findings were reported by Kumar et al (2014) and Verma et al (2020).

Nutrient Uptake: Nutrients (N, P and K) uptake by chickpea

Table 1: Effect of irrigation scheduling and nitrogen levels on yield and nutrients content of chickpea

Treatment	Seed yield (kg/ha)	Straw yield (kg/ha)	Protein content (%)	Protein yield (kg/ha)	FWUE (kg/ha/mm)
Irrigation scheduling: (I)					
I_1: 0.6 IW/CPE ratio	1715	2660	19.54	334	4.90
I_2: 0.8 IW/CPE ratio	2173	2953	20.99	455	4.83
I_3: 1.0 IW/CPE ratio	2306	3123	21.78	504	4.19
CD (p=0.05)	357.6	265.9	1.58	47.90	-
Nitrogen levels: (N)					
N_1: 125% RDN	2213	3068	21.40	475	4.92
N_2: 100% RDN	2142	2927	21.20	454	4.76
N_3: 75% RDN	1839	2742	19.70	364	4.09
CD (p=0.05)	160.4	248.9	1.40	34.80	-

Table 2. Effect of irrigation scheduling and nitrogen levels on nutrients content and uptake and available soil status after harvest of chickpea

Treatment	N content (%)		P content (%)		K content (%)		N uptake (kg/ha)	P uptake (kg/ha)	K uptake (kg/ha)	Nutrient status in soil after harvest (kg/ha)		
	Seed	Straw	Seed	Straw	Seed	Straw						
Irrigation scheduling: (I)												
I_1: 0.6 IW/CPE ratio	3.13	1.35	0.56	0.30	0.77	1.23	89.59	17.58	45.92	154.0	33.46	231.1
I_2: 0.8 IW/CPE ratio	3.36	1.47	0.58	0.31	0.80	1.26	116.4	21.76	54.59	151.2	32.64	222.3
I_3: 1.0 IW/CPE ratio	3.49	1.51	0.61	0.33	0.83	1.29	127.6	24.37	59.43	146.6	28.82	211.3
CD (p=0.05)	0.25	0.06	NS	NS	NS	NS	8.12	3.05	3.36	NS	NS	NS
Nitrogen levels: (N)												
N_1: 125% RDN	3.42	1.50	0.60	0.32	0.81	1.28	121.7	23.10	57.20	155.0	30.94	214.7
N_2: 100% RDN	3.39	1.48	0.59	0.31	0.80	1.26	115.9	21.71	54.02	151.6	31.58	221.5
N_3: 75% RDN	3.15	1.36	0.56	0.31	0.78	1.24	95.22	18.80	48.35	145.2	32.39	228.4
CD (p=0.05)	0.22	0.09	NS	NS	NS	NS	5.75	1.24	3.69	7.86	NS	NS

crop under varying irrigation schedules on were significant (Table 2). Significantly higher N, P and K uptake by crop (127.6, 24.37 and 59.43 kg/ha, respectively) were with irrigation scheduled at 1.0 IW/CPE ratio being at par with 0.8 IW/CPE ratio. This might be due to better availability of moisture and availability of nutrients throughout the growth stages, leading to better uptake of nutrients. Since most of the nutrients taken up by chickpea is in water soluble form, better availability of moisture could have increased root growth and thus increased absorption of nutrients, it might have increased mobilization of nutrients and thereby increased its availability to the plants and might have increased the availability of plant root to absorb nutrients by affecting the metabolic activity of the plant. Sodavadiya (2017) and Bhadoria (2018) also reported similar trend. Total nutrients uptake by chickpea were influenced significantly due to different nitrogen levels. Significantly higher N, P and K uptake by crop (121.7, 23.10 and 57.20 kg/ha, respectively) were recorded under 125% RDN being at par with 100% RDN. This might be due to higher nitrogen application produced significantly higher seed yield and higher nutrient content than lower nitrogen doses that finally leads to higher nutrient uptake by chickpea. This indicates that uptake of nutrients is directly proportional to the seed and straw yield of chickpea crop. These results are in accordance with findings of Kumar (2014) and Pancholi (2020). The applied water in chickpea indicated significantly positively correlation to nutrient uptake (Fig. 3). The regression coefficient of applied water on NPK uptake was 0.946, 0.973 and 0.982, respectively. Similarly applied nitrogen levels had significant and positive association between with nutrient uptake and coefficient of determination was 0.904, 0.974, 0.960, respectively (Fig. 4).

Nutrient status in soil after harvest: The different irrigation scheduling did not show any significant difference in available nutrients in soil after harvest of crop. The significantly highest N status in soil after harvest (155.0 kg/ha) was obtained when the crop was fertilized with 125% RDN which was at par with 100% RDN. The available phosphorus and potassium status in soil after harvest of crop were not influenced significantly due to the nitrogen levels. The increase in available nitrogen status in soil might be

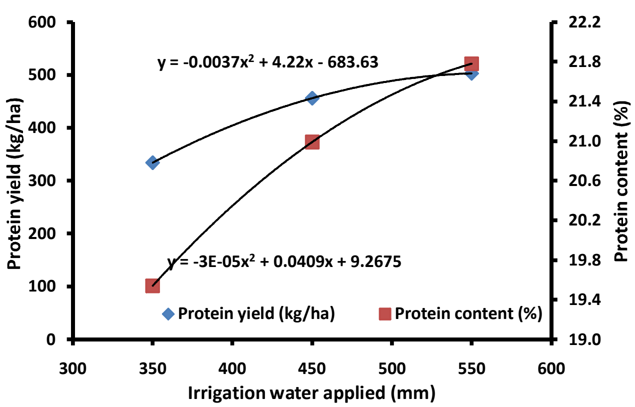

Fig. 1. Relationship of irrigation water applied to protein content and protein yield

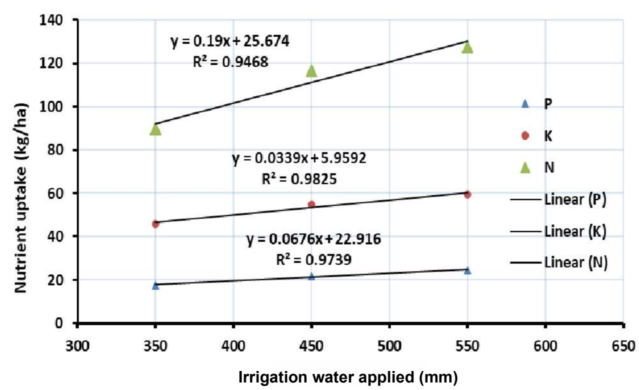

Fig. 3. Relationship of irrigation applied water with NPK nutrient uptake

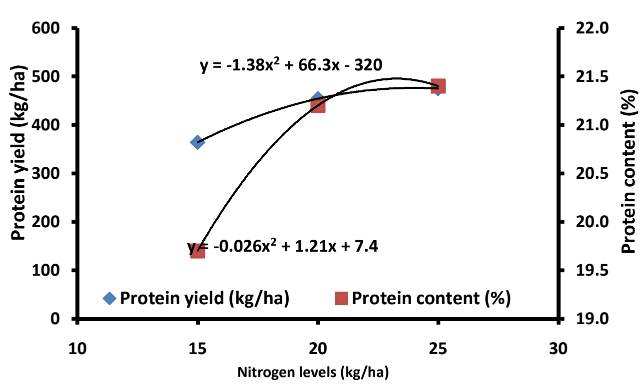

Fig. 2. Relationship of nitrogen levels to protein content and protein yield

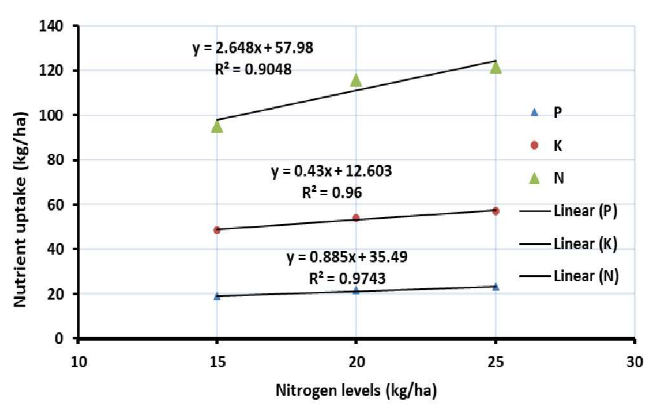

Fig. 4. Relationship of applied nitrogen levels with NPK nutrient uptake

Table 3. Seed yield and total nitrogen uptake of chickpea as influenced by interaction between irrigation scheduling and nitrogen levels

Irrigation scheduling	Seed yield (kg/ha)			Total nitrogen uptake (kg/ha)		
	N_1: 125% RDN	N_2: 100% RDN	N_3: 75% RDN	N_1: 125% RDN	N_2: 100% RDN	N_3: 75% RDN
I_1: 0.6 IW/CPE ratio	1734	1711	1702	94.17	91.71	82.00
I_2: 0.8 IW/CPE ratio	2384	2280	1854	129.4	120.7	98.59
I_3: 1.0 IW/CPE ratio	2521	2436	1961	142.8	135.0	105.8
CD (p=0.05)		277.8			9.95	

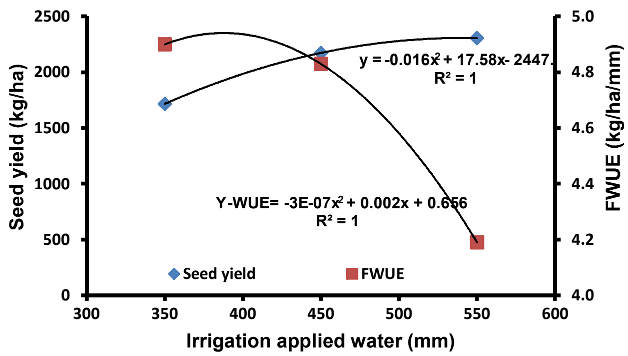

Fig. 5. Relationship of irrigation water applied to seed yield and water use efficiency

attributed to the increased application of nitrogen in soil and plants cannot utilize the excessive nitrogen content from soil solution. Pancholi (2020) reported higher available soil N after harvest of chickpea under higher nitrogen dose.

Interaction effect between irrigation scheduling and nitrogen levels: The irrigation scheduled at 1.0 IW/CPE ratio along with application of 125% RDN recorded significantly higher seed yield (2521 kg/ha) and total nitrogen uptake (142.8 kg/ha) by chickpea which was at par with irrigation scheduled at 1.00IW/CPE along with 100% RDN, 0.8 IW/CPE and along with 125% RDN and 0.8 IW/CPE with 100% RDN which were significantly superior over rest of treatments (Table 3). The results agree with the Gadade et al (2021). The crop fertilized with nitrogen along with adequate amount of irrigation can increased in nitrogen uptake by plant. Nitrogen accumulation during vegetative growth period, which was conducive to transfer to seed at maturity stage improved dry matter accumulation at harvest and ultimately seed yield.

Yield water use efficiency (Y-WUE): Y-WUE was significantly affected by irrigation water applied during experimental period. Each higher level of irrigation from 0.6 to 1.0 IW/CPE ratio decreased water use efficiency of chickpea. Numerically, highest water use efficiency (4.90 kg/ha/mm) was recorded at 0.6 IW/CPE ratio. The relationship between Y-WUE was curvilinear (polynomial of second order) (Fig. 5). This relationship could be expressed as follows:

$$Y - WUE = -3E - 07\,x^2 + 0.002\,x + 0.656\ (R^2 = 0.99)$$

Y-WUE increased with increasing water shortage in the root zone, indicating that yield losses was proportionally smaller than the amount of water used by crops. The different effects of water deficit on Y-WUE observed in various studies can be attributed to the level of water stress experienced by the crop. Chickpea crop develop deep root system which potentially increases the water availability for the plants and attenuates negative effects of water deficit. This may bring up the crop more resistant to water stress and a greater Y-WUE. In the shallow soils, as in experiment, the development of the rooting system was very limited and resulted in severe water stress with a very negative impact on the yield and Y-WUE. The application of each higher level of nitrogen improved Y-WUE, as well as yield, in agreement with results reported by Gadade et al (2021).

CONCLUSIONS

The remunerative higher yield of chickpea can be achieved by irrigation scheduled at 0.8 IW/CPE ratio along with application of 100% recommended dose of nitrogen (20 kg/ha) in sandy loam soil of North Gujarat. Each unit increase in irrigation and nitrogen level from lower to higher levels, there was significantly increased nutrient content, nutrient uptake, protein content in seed and protein yield. Relationship between irrigation water applied and nitrogen levels with seed yield, FWUE, nutrient content and uptake, protein content in seed and protein yield was highly significant and coefficient of determination >90% indicate strong relationship between them.

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Influence of Crop Diversification in Potato-Based Cropping Sequence on Growth, Productivity and Economics of Potato in Red and Lateritic Soil of West Bengal

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Abstract: Field experiment was conducted at Agricultural farm of the Institute during 2020-21 and 2021-22 to study growth, yield attributes, yield and economics of potato as influenced by potato-based cropping sequences. The experiment, consisted of seven treatments (viz. Potato-sesame; Potato-green gram; Potato-baby corn; Potato-okra; Potato-groundnut; Potato-blackgram and Potato–vegetable cowpea. Potato in potato-groundnut sequence exhibited highest growth, yield attributes (number of tubers hill^{-1} and fresh weight of tubers hill^{-1}) with tuber and haulm yield of 23.95 and 1.30 t ha^{-1}, respectively. Highest gross return, net return and return per rupee investment in potato was also achieved from potato-groundnut sequence (₹ 264 × 10^{3} ha^{-1}, ₹ 174 × 10^{3} ha^{-1} and 2.91, respectively). These were at par with potato in potato-vegetable cowpea, potato-blackgram and potato–green gram sequences and significantly higher than potato in potato-sesame, potato-baby corn and potato-okra cropping sequences. Inclusion of legume crops in potato-based cropping sequences enhanced tuber and haulm yield of potato resulting in higher return from the sequence.

Keywords: Cropping sequence, Economics, Growth, Potato and yield

The rice-wheat cropping system (RWCS) has been practiced by farmers in Asia and this cropping system is one of the world's largest agricultural production systems, covering an area of 26 million hectares spread over Indo-Gangetic Plains (IGP) in South Asia and China (Singh et al 2019) and is the most important cropping system of India adopted on about 10.5 M ha (Sarkar 2015) and has played a significant role in food security of the country. However, in recent years sustainability of RWCS is adversely affected as yields of both rice and wheat are either stagnant or decreasing due to deterioration of soil health; resurgence of diseases, insects, and weeds; environmental pollution/degradation; decrement in factor productivity or input-use efficiency; increase in cultivation costs and reduction in profit margins (Gautam and Sharma 2004, Gangwar and Prasad 2005, Reddy and Suresh 2009, Chauhan et al 2013). Traditionally, prior to the Green Revolution, agriculture was more diversified and sustainable (Paroda 2019). Scientific advancements and options for improved varieties and new crops led to a shift towards a few crops having potential to yield more and provide a higher income. Such an approach eventually narrowed down dependence to just a few crops like wheat, rice, maize, sugarcane, *etc*. In Green Revolution era (1967-68 to 1977-78), the major focus was on cereals (mainly rice and wheat). Over the years since then, fortunately, food basket has started to diversify again, although more progress still needs to happen.

Crop diversification largely depends on technological innovations aimed at sustainable intensification and increased productivity while reducing the cost of inputs so as to raise the income of farmers. The dynamic aspect of diversification includes the accommodation of new crops or cropping systems that are best suited to prevailing eco-regional conditions while ensuring higher production and income. By growing a variety of crops, farmers lower their risk and can gain access to national and international markets. Agricultural intensification has helped us achieve food security in the past, but now we need to reorient existing cropping systems to be more sustainable and to continue addressing our household food, nutrition, and environmental security. Legume-inclusive production systems can play important roles by delivering multiple services at production-system level, due to the capacity to fix atmospheric nitrogen making them potentially highly suitable for inclusion in low-input cropping systems, and at cropping system levels, as diversification of crops in agroecosystems based on few major species, breaking the cycles of pests and diseases. In India, over the years, the new cropping systems have become predominant in view of their higher productivity as well as income for farmers. Examples are rice-wheat cropping system in the north, groundnut in Gujarat, sugarcane in the north, chickpea in southern states, arhar in the north-western states, soybean in Madhya Pradesh and adjoining states, and winter maize in Bihar. Unfortunately, most of these systems require diversification for greater sustainability and conservation of natural resources. There is need to bring reforms in the existing cropping systems that are more scientifically based and more suited to varying agro-climatic conditions. Diversification of cropping systems is necessary to get higher yield and return, to maintain soil health, preserve environment and meet daily requirement of human and animals (Saha et al 2020). Thus, not only the number of crops but the type of crops included in the cropping sequence are also important and dependence on cereal crops need to be shifted to other food crops like potato, vegetables, root crops, pulse and oil seeds (Samui et al 2004). Hence, an attempt was made to identify suitable cropping sequence for red and lateritic soil of West Bengal with a view to utilize resources judiciously for optimal production levels at reduced costs and with minimum impact on the environment.

MATERIAL AND METHODS

The field experiment was conducted during *rabi* and summer seasons of 2020-21 and 2021-22 at Agricultural farm (23° 39' N latitude, 87° 42' E longitude at an elevation of 58.9 m above mean sea level), Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal. The soil of the experimental site was sandy loam in texture, acidic in nature (pH 5.12), low in organic carbon (0.42%), available nitrogen (140.31 kg N ha^{-1}) and phosphorus (20.14 kg P_2O_5 ha^{-1}) and medium in available potassium (192.67 kg K_2O ha^{-1}) content. The experiment, comprising of seven cropping systems was laid out in randomized block design with three replication (Table 1). The recommended dose of fertilizers (200:150:150 kg of N: P_2O_5:K_2O kg ha^{-1}) was applied in potato where half quantity of total nitrogen, entire P_2O_5 and K_2O was applied as basal. Top dressing of the remaining nitrogen was done at the time of earthing up at 30 DAP (days after planting). Potato (variety Kufri jyoti) was planted on flat beds with a spacing of 50 cm × 25 cm on November 30, during both the years of 2020-21 and 2021-22, and harvested on March 02, during both years, Summer crops viz, sesame (var. Roma), green gram (var. Samrat), baby corn (hybrid hm-4), okra (Hybrid F-1), groundnut (TAG-24), blackgram (Kalindi) and vegetable cowpea (Pusa sukomal) were sown on March 09 and harvested during last week of June and first week of July during 2021 and 2022, respectively. The summer crops were raised as per recommended package of practices for each crop. The biometric observations for different growth parameters and yield attributes of potato were recorded at regular interval. The dry matter accumulation of plant samples was recorded by drying the plant samples in hot air oven at 65° C for 48 hours, till constant weights were obtained. The crop growth rate was calculated as increase in dry matter per unit of land area per unit of time and expressed as (g m^{-2} day^{-1}) .

$$CGR = (W_2 - W_1)/ (t_2 - t_1)$$

Where W_2 and W_1 are the final and initial dry weights at times t_2 and t_1, respectively.

Weight of fresh tubers was taken from randomly selected plants in each plot and the tuber bulking rate (TBR) between 30 to 45, 45 to 60 and 60 to 75 DAP was estimated and expressed as (g m^{-2} day^{-1}) .

$$TBR = (W_2 - W_1)/ (t_2 - t_1)$$

Where W_2 and W_1 are the final and initial fresh weights of tubers per unit area at times t_2 and t_1, respectively.

The tuber growth rate (TGR) was calculated by taking dry weights of potato tubers at 30 to 45, 45 to 60 and 60 to 75 DAP and expressed as (g m^{-2} day^{-1}) .:

$$TGR = (TW_2 - TW_1)/ (t_2 - t_1)$$

Where TW_2 and TW_1 are the final and initial dry weights of tubers per unit area at times t_2 and t_1, respectively.

Table 1. Growth attributes of potato as influenced by crop diversification in potato-based cropping sequences (Pool data for 2 years)

Treatment	Plant height (cm) at harvest	LAI at 60 DAP	Dry matter accumulation (g m^{-2}) at harvest	CGR (g m^{-2} day^{-1}) at 60-75 DAP	TBR (g m^{-2} day^{-1}) at 60-75 DAP	TGR (g m^{-2} day^{-1}) at 60-75 DAP
T_1 - Potato–sesame	83.0	4.57	592.3	10.66	83.53	12.09
T_2 - Potato–green gram	87.4	4.86	652.0	12.08	85.26	13.61
T_3 - Potato–baby corn	82.8	4.56	543.8	9.33	81.71	12.06
T_4 - Potato–okra	82.7	4.48	533.4	9.62	79.07	11.38
T_5 - Potato–groundnut	89.7	5.07	686.8	12.68	88.42	14.93
T_6 - Potato–blackgram	87.4	4.94	665.3	12.24	86.33	13.79
T_7 - Potato–vegetable cowpea	88.0	4.94	654.6	11.78	87.42	15.39
CD (p=0.05)	NS	NS	NS	NS	NS	0.96

RESULTS AND DISCUSSION

Growth attributes of potato: The growth attributes of potato *viz*. plant height, leaf area index, dry matter accumulation, CGR, TBR and TGR at different growth stages were significantly influenced by crop diversification in various potato-based cropping sequences on pooled data basis (Table 1). The highest plant height (89.7 cm at harvest), LAI (5.07 at 60 DAP), dry matter accumulation (686.8 g m^{-2}) and CGR (12.68 g m^{-2} day^{-1} at 60-75 DAP) of potato was observed in potato-groundnut sequence which was at par with potato in potato-vegetable cowpea, potato-blackgram and potato-green gram sequences, but significantly higher when compared to other sequences, *viz*. potato-sesame, potato-baby corn and potato-okra. Higher growth attributes in potato-legume sequences over potato-non legume ones might be attributed to the fact that N fixation occurred in legumes which might have led to higher carryover effect on soil fertility parameters resulted in higher availability and uptake of nutrients by potato crop.

Highest TGR (15.39 g m^{-2} day^{-1}) of potato was observed at 60-75 DAP in potato-vegetable cowpea sequence which was statistically at par with potato-groundnut, potato-blackgram and potato-green gram sequences but significantly higher than potato-non legume cropping sequences during all the growth stages which might be due to higher accumulation of photosynthates into the tubers thus increasing the fresh weight and dry weight of tubers. However, TBR was not influenced significantly by various potato-based cropping sequences The higher growth attributes of potato in potato-legume sequences might be attributed to the 'nitrogen effect' of the associated legume crop through N provision from BNF (Peoples et al 2009). Angus et al (2015) also reported similar results in wheat when it was grown in wheat-legume sequences. Similar results in terms of higher growth attributes in rice was reported by Saha et al (2020).

Yield components and yield of potato: The significant response was found from crop diversification in potato-based cropping sequences on yield components (Table 2) of potato (i.e., number of tubers $hill^{-1}$ and fresh weight of tubers $hill^{-1}$). at harvest. Among different potato-based cropping sequences, highest number of tubers per hill and fresh weight of tubers per hill was in potato-groundnut sequence (6.88 and 312.1 g, respectively) because of the nitrogen effect of the legume crop which resulted in higher number of tubers in potato crop. The significant response was recorded in tuber yield of potato due to inclusion of various crops in potato-based cropping sequences whereas the haulm yield showed no significant response. Tuber yield of potato was significantly higher in potato-groundnut sequence (23.95 t ha^{-1}) due to higher growth parameters and yield components which finally led to higher tuber yield. This was followed by potato-vegetable cowpea (23.67 t ha^{-1}), potato-blackgram (23.64 t ha^{-1}) and potato-green gram (23.51 t ha^{-1}). However, these treatments were at par with each other (Table 2). In terms of tuber yield of potato, potato-sesame, potato-baby corn and potato-okra sequences, were significantly lower when compared to potato-legume-based sequences. Inclusion of legume crops in the sequences might have enhanced the yield components of potato resulting in higher yield when compared with non-legume crops in the sequence. The crop yield after legumes is often enhanced due to combined and interrelated effects of nitrogen provision and non-nitrogen effects (suppressed pest and disease infestation, improved soil properties (Robson et al 2002, Peoples et al 2009 , Ditzler et al 2021) and phosphorus mobilization (Shen et al 2011). Similar results of higher yield associated with the inclusion of legume crops have been reported by Angus et al (2015) and Mukherjee (2016).

Table 2. Yield components, yield and economics of potato as influenced by crop diversification in potato-based cropping sequences (Pool data for 2 years)

Treatment	Number of tubers $hill^{-1}$	Fresh weight (g) of tubers/hill at harvest	Tuber yield (t ha^{-1})	Haulm yield (t ha^{-1})	Gross return (× 10^3 ₹ ha^{-1})	Net return (× 10^3 ₹ ha^{-1})	Return per rupee investment (₹)
T_1	6.17	281.5	22.43	1.20	247	157	2.72
T_2	6.55	291.0	23.51	1.25	259	169	2.85
T_3	6.17	280.4	22.40	1.19	247	156	2.72
T_4	6.16	277.6	22.40	1.19	247	156	2.72
T_5	6.88	297.5	23.95	1.30	264	174	2.91
T_6	6.65	292.8	23.64	1.27	260	170	2.87
T_7	6.65	295.4	23.67	1.29	261	171	2.88
CD (p=0.05)	NS	6.50	0.75	NS	7.74	7.74	0.09

NS - Non-Significant, See Table 1 for treatment details

Economics: The gross return, net return and return per rupee invested in potato were significantly influenced by various potato-based cropping sequences (Table 3). The highest gross return (₹ 264 × 10^3 ha^{-1}), net return (₹ 174 × 10^3 ha^{-1}) and return per rupee investment (₹ 2.91) in potato was under potato-groundnut sequence which was statistically at par with potato-vegetable cowpea, potato-blackgram and potato-green gram sequences. However, these were significantly higher than potato in potato-sesame, potato-baby corn and potato-okra sequences. This could be primarily due to higher yield of potato which was associated with nitrogen effect of legumes under these sequences. Saha et al (2020) also reported similar results in rice when inclusion of legume crops in rice-based cropping systems exerted positive influence in increasing the yield of rice resulting in higher gross return, net return and return per rupee investment. Diversification with high-value crops encouraged the export of farm produce, bringing more profits as mentioned by Singh et al (2019).

CONCLUSION

Potato in potato-groundnut cropping sequence produced higher tuber yield, gross return, net return and return per rupee investment which was statistically at par with potato in potato-vegetable cowpea, potato-blackgram and potato-green gram sequences. Potato-legume-based cropping sequences exhibited significantly higher tuber yield and economic returns over potato-sesame, potato-baby corn and potato-okra sequences.

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Impact of Floor Management using Banana Biomat Mulch and Leguminous Cover crop on Available Nitrogen in Soil, Growth, Yield and Quality of Banana cv. Martaman

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***Abstract*:** The present investigation was carried out at ICAR-AICRP on Fruits, Mohanpur, Bidhan Chandra Krishi Vishwavidyalaya, Mondouri, Nadia, West Bengal with six treatments. Banana Biomat Mulch (BBM) @ 30 kg fresh/m^{-2} + Leguminous Cover Crops (LCC) @ 3g seeds/ m^{-2} + 0% recommended dose of fertilizer or 25, 50%, 75% and 100 % RDF practices (no BBM & LCC with 100% RDF i.e., 5kg FYM, N-200g + P_2O_5-50g + K_2O-250g/plant/year. Treatments were imposed thrice a year on orchard floor of banana cv. Martaman. Observations were recorded on plant height, girth, leaf number per plant, status of nitrogen content, qualitative and quantitative parameters such as bunch weight, finger weight, finger length, finger diameter, number of fingers per bunch, hands per bunch, total sugar, acidity, sugar: acid ratio and productivity. The application of BBM+LCC with 75 or 100% of RDF significantly increased plant height, girth and number of leaves per plant two months after third treatment. The increase in average available nitrogen content in soil, bunch weight, number of hands per bunch, finger per bunch, finger weight, finger length, finger diameter, total sugar, acidity, sugar: acid ratio and productivity was higher as compared with conventional practice and BBM + LCC and RDF @ 0-50%.

Keywords: Banana, Mulching, Soil, Nitrogen, Yield and quality

Banana (*Musa paradisiaca*) is diploid, triploid and tetraploid (n=11) and belongs to the family Musaceae. It is one of the most important, common and favorite fruit, originated from South East Asia (Indo Malayan). Banana is 4th important food crop in terms of gross value. It is a very popular fruit due to its high nutritive value with low price. It is very predominant and popular among people that it is liked by both poor and rich. It can be consumed as ripe as well as cooked. In banana, fruit size and quality are of great importance through consumer acceptance varies from place to place (Bauri et al 2014). India has a production of 31504 metric tonnes from the area of 878 thousand hectares. The productivity of banana in India is 37 metric tonnes per hectare (Anonymous 2019).

In commercial banana cultivation, out of the total biomass produced by a banana plant (cv. Martaman), only 15-20 % constitute the fruits and marketed immediately but rest biomass (80-85%) including pseudo stem, leaf, rhizome etc. is a neglected waste and not used properly. The unutilized biomass was estimated to be about 150 tonnes/ha (Debnath et al 2010). Utilization of banana crop waste is a cheap source of nutrients and increases organic matter, stimulate soil microbial life enhances water holding capacity and increases crop yields (Phirke and Kothari 2005). Mulching is a process of covering the soil and make more favorable conditions for plant growth and development. It is an important cultural method of reducing the amount of work involved in gardening and helps to produce healthy plants with good productivity (Sathiyamurthy et al 2017). It is a practice which helps in proper growth and development of the plants by providing better soil moisture conservation and better nutrient availability (Kher et al 2010). Application of organic mulching such as dry grass in banana significantly increased plant height, stem girth, number of leaves, length and girth of fruit, fruit weight and bunch weight (Wankhade et al 2023). Organic mulching helps to regulate soil temperature, water use efficiency, plant growth, quality and yield (Amare and Desta 2021). Organic mulching and leguminous cover crops have a beneficial effect on vegetative growth, nutrient content, quality and quantity of banana (Subba et al 2023). Plant height as well as other vegetative growth can be significantly increased due to sufficient soil moisture near root zone and minimum evaporation loss due to organic mulching (Marichamy et al 2016). Organic mulches derived from plants such as straw, hay, husk, saw dust and leaves improve soil physical properties, supply organic matter, improve nitrogen balance resulting in increasing yield and productivity (Sarolia and

Bhardwaj 2013). Cover crops have long been used to reduce soil erosion and water runoff, and improve water infiltration, soil moisture conservation, and also helps in improving soil tilth, organic carbon and nitrogen (Sainju and Singh 1997). Based on the above background, the present studies were conducted.

MATERIAL AND METHODS

The investigation was carried out at Bidhan Chandra Krishi Vishwavidyalaya, Mondouri, Nadia, West Bengal, during the year 2018-2020. Healthy and uniform sword suckers of banana cv. Martaman (500-750 g) were collected and planted at 2 m x 2 m spacing as per the layout of experimental design in randomized block design with 4 replications and 10 plants per replication (Table 1). The recommended dose of fertilizer (RDF) used in the experiment of banana was 5kg FYM, N-200g + P_2O_5-50g + K_2O-250g/plant/year. Application rate was between 0 and 100% of RDF based on treatments. The treatments consisted of application of banana biomat mulch (BBM), leguminous cover crop (LCC) and different level of fertilizer doses. The overnight soaked seed of leguminous cover crop (LCC) was sown @ 3g m^{-2} in the ground area of plants as per the treatment, about 36-48 hours after irrigation. Black gram var. Kalindi was sown during winter and spring months and moong bean var. Samrat was sown during summer and rainy months. The pseudo stem of banana was collected from the harvested banana field. Strips were prepared by cutting the leaf sheath of pseudo stem into 1.4-1.5 m in length and 10-15 cm in wide. The banana biomat mulch (BBM) was prepared by weaving the strips cross-wise and were spread on the ground area of each plant @ 30 kg fresh m^{-2}. Pre-soaked moong bean seeds along with vermicompost was sown at 25-30 cm spacing in between the two banana strips of BBM. The grown up LCC was incorporated in soil during 50 to 60 days after sowing.

Table 1. Treatment details

Treatments	Combination
T_1	BBM @ 30 kg fresh m^{-2} + LCC @ 3g seeds m^{-2} + 0% RDF
T_2	BBM @ 30 kg fresh m^{-2} + LCC @ 3g seeds m^{-2} + 25% RDF
T_3	BBM @ 30 kg fresh m^{-2} + LCC @ 3g seeds m^{-2} + 50% RDF
T_4	BBM @ 30 kg fresh m^{-2} + LCC @ 3g seeds m^{-2} + 75% RDF
T_5	BBM @ 30 kg fresh m^{-2} + LCC @ 3g seeds m^{-2} + 100% RDF
T_6	Control – No BBM & LCC with 100% RDF

*BBM-banana biomat mulch, LCC-leguminous cover crops, RDF-recommended dose of fertilizer i.e., 5kg FYM, N-200g + P_2O_5-50g + K_2O-250g/plant/year

Application of treatments was repeated three times: First application at the time of planting (10-25 August, 2018), second application at 3 months after 1st application (10-25 November, 2018, at plant age of 3 months) and third application at 6 months after 1st application (10-25 February, 2019, at plant age of 6 months). Observations were recorded on plant height, plant girth, number of leaves per plant, nitrogen content, bunch weight, number of hands per bunch, total sugar, acidity, sugar: acid ratio, productivity, number of finger per bunch, finger length, finger weight and finger width. The data was analysed in Statistical Package for the Social Sciences software.

RESULTS AND DISCUSSION

Plant height, girth and leaf number two month after 1st treatment: All treatments with banana biomat mulch (BBM) and leguminous cover crop (LCC) with varying dose of fertilizer on banana cv. Martaman caused non-significant variations in plant height, plant girth and number of leaves per plant (Table 2). The minimum plant height (58.75 cm) was in T_1 i.e., mulching with BBM & LCC + 0% RDF and maximum) (79.23 cm) plant height was recorded under in mulching with BBM & LCC + 100% RDF. The minimum plant girth (20.99 cm) was in T1 and maximum (25.00 cm) was under T_3 treatment i.e., mulching with BBM & LCC + 50% RDF. The minimum number of leaves per plant (4.00) were in T_1 & T_6 treatment and maximum (5.75) in T_5 treatment i.e., mulching with BBM & LCC + 100% RDF.

Plant height, girth and leaf number two month after 2nd treatment: The significant increase in plant height, girth and number of leaves per plant was recorded during the period of 2nd treatments on banana cv. Martaman (Table 2). The minimum plant height (83.42 cm) was in mulching with T_1 treatment (BBM & LCC + 0% RDF) and maximum (107.49 cm) plant height was recorded under T_5 i.e., mulching with BBM & LCC + 100% RDF. The minimum (32.93 cm) plant girth was in T_1 and maximum (52.33 cm) was under T_5. The minimum (9.00) number of leaves per plant (9.00) were in T_6 treatment and maximum (12.00) leaf number per plant (12.00) was recorded under T_5 Francois et al (2020) and Kumar et al (2020) also reported that organic mulching can significantly increase plant height, girth and number of leaves in banana. Subba et al (2023) also reported the beneficial effect of using organic mulching to increase the vegetative growth of banana. Similar effect of organic mulching on plant growth, plant girth and leaf number per plant were reported earlier in guava by Patra et al (2004).

Plant height, girth and leaf number two month after 3rd treatment: All treatments with banana biomat mulching (BBM) and leguminous cover crop (LCC) with varying dose of fertilizer on banana cv. Martaman caused significant variations in plant height, plant girth and number of leaves per plant (Table 2). The minimum plant height (149.32 cm) was in recorded under T_1 treatment i.e., mulching with BBM & LCC + 0% RDF and maximum (180.03 cm) was under T_5 treatment i.e., mulching with BBM & LCC + 100% RDF. The minimum plant girth (45.63 cm) was in T1 maximum plant girth (63.80 cm) was under T5. The minimum leaf number per plant (11.25) was T_1 and T_6 and maximum number of leaves per plant (14.00) was recorded under T_5 Wankhede et al (2013) and Francois et al (2020) also reported that organic mulching can significantly increase plant height, girth and number of leaves in banana. This observation was in agreement with the observation of Subba et al (2023) where vegetative growth increased by using organic mulching with leguminous cover crops. Similar finding of using organic mulching on plant growth, plant girth and leaf number per plant were reported earlier in guava by Maji and Das (2008) and Bhattacharjee et al (2020).

Available nitrogen (Kg ha^{-1}): All treatments with banana biomat mulch (BBM) and Leguminous cover crop (LCC) with varying dose of fertilizer on banana cv. Martaman caused significant variations in available nitrogen content in soil except the initial month of experiment (Aug,18) (Table 3). The minimum (164.88 Kg ha^{-1}) available nitrogen was in T_1 and maximum (171.66 Kg ha^{-1}) in T_5. However, the effect of T_2 and T_6 were statistically at par. Kher et al (2010) and Subba et al (2023) also reported the same trend. Sarolia and Bhardwaj (2013) observed organic mulching and cover crops can increase the organic matter and nitrogen content in soil. Frame (2005) and Peoples et al (2009) reported similar effect of legume crops grown as cover crops and those incorporated in orchard soil between 50-60 days after sowing and hence, it was considered to add 30-40 kg nitrogen per hectare.

Yield and quality of banana: Mulching with different treatments showed significant increase in bunch weight, number of hands per bunch, total sugar, acidity, sugar: acid ratio and productivity (Table 3). The maximum bunch weight (19.43 kg) was in T_5 and minimum bunch weight (14.01 kg) was obtained from T_1. The maximum number of hands per bunch (8.54) was in T_5 and minimum (7.08) was in T_6 treatment. The maximum total sugar (12.82%) was in T_5 and minimum (8.55%) in T6. The maximum acidity (0.29%) was recorded under T_4 treatment and minimum (0.26%) in T_1 and T_6. The sugar: acid ratio was recorded highest (47.48) in T_5

Table 2. Effect of banana biomat mulch and leguminous cover crop on vegetative growth of banana plant (2 month after treatment)

Treatments	1st treatment			2nd treatment			3rd treatment		
	Plant height (cm)	Girth (cm)	Leaf no. per plant	Plant height (cm)	Girth (cm)	Leaf no. per plant	Plant height (cm)	Girth (cm)	Leaf no. per plant
T_1	58.75	20.99	4.00	83.42	32.93	9.25	149.32	45.63	11.25
T_2	66.88	20.38	5.25	89.65	40.70	9.75	158.21	53.84	12.00
T_3	72.75	25.00	4.25	94.90	45.66	10.50	166.71	56.22	12.75
T_4	76.75	24.38	4.50	98.82	48.18	11.25	175.05	60.00	13.25
T_5	79.23	24.13	5.75	107.49	52.33	12.00	180.03	63.80	14.00
T_6	62.86	21.88	4.00	87.70	36.04	9.00	155.18	48.24	11.25
CD (p=0.05)		NS		5.23	4.68	1.79	1.53	6.49	0.99

During October, 2018 (2 months after 1st treatment in August, 2018), January, 2019 (2 months after 2nd treatment in November, 2018) and during April, 2019 (2 months after 3rd treatment in February, 2019)

Table 3. Effect of banana biomat mulch and leguminous cover crop on available nitrogen content (kg ha^{-1}) of soil in banana orchard

Treatment	Initial (August, 18)	November, 2018	February, 2019	May, 2019	Average
T_1	159.23	165.75	166.47	168.09	164.88
T_2	159.82	167.61	169.31	170.18	166.73
T_3	159.48	170.4	171.41	172.03	168.33
T_4	159.08	172.57	173.74	174.31	169.92
T_5	159.37	174.16	176.02	177.09	171.66
T_6	159.33	166.61	168.52	169.91	166.01
CD (p=0.05)		5.92	5.28	1.841	-

Table 4. Effect of banana biomat mulch and leguminous cover crop on fruit yield and quality of banana cultivation

Treatments	Bunch wt. (Kg $plant^{-1}$)	No. of hands/ bunch	Total sugar (%)	Acidity (%)	Sugar acid ratio	Productivity (t ha^{-1})
T_1	14.01	8.17	10.17	0.26	39.1	35.02
T_2	17.56	8.24	10.79	0.28	38.53	38.28
T_3	18.18	8.26	11.36	0.28	40.57	38.96
T_4	18.9	8.39	11.92	0.29	41.1	39.1
T_5	19.43	8.54	12.82	0.27	47.48	40.58
T_6	16.93	7.08	8.55	0.26	32.88	37.5
CD (p=0.05)	0.861	0.075	0.09	0.04	2.66	0.13

Table 5. Effect of banana biomat mulch and leguminous cover crop on finger characters of banana cv. Martaman

Treatments	No. of finger/bunch	Finger wt. (g)	Finger length (cm)	Finger diameter (cm)
T_1	117.50	115.79	10.95	3.95
T_2	123.50	122.58	11.25	4.14
T_3	127.69	125.40	11.17	4.12
T_4	130.91	127.70	11.35	4.18
T_5	133.48	131.99	11.45	4.27
T_6	120.62	105.56	10.14	3.36
CD (p=0.05)	4.060	2.932	0.416	0.062

lowest (32.88) in T_6 (32.88). The variations in productivity ranging from 35.02 to 40.58 t ha^{-1}. The minimum productivity (35.02 t ha^{-1}) was in T_1 and maximum (40.58 t ha^{-1}) was recorded under T_5. Similar results were in tune with the finding of Wankhede et al (2013), Francois et al (2020), Kumar et al (2020) and Subba et al (2023). The results are in accordance with Das et al (2010) and Rajput et al (2014) in guava, and Ghosh and Tarai (2007) in ber. The minimum number of fingers (117.50) was recorded under T_1 and maximum (133.48) in T5. The maximum finger weight and length was in T_5 (131.99 g, 11.45 cm) The highest finger diameter (4.27 cm) was in T_5 and lowest (3.36 cm) in T_6 treatment. However, T_2 and T_3 were statistically at par. Kumar et al (2020) and Francois et al (2020) also observed same trend.

CONCLUSION

Based on current study recommended for the banana growers in the Gangetic Alluvium region of West Bengal to apply banana biomat mulch (webbed leaf-sheath of banana @ 30 kg fresh m^{-2}), leguminous cover crops (@ 3g m^{-2}; black gram cv. Kalindi in winter, mung bean cv. Samrat in summer) thrice a year in banana (at planting time and at 3 & 6 months after planting) and 75% of recommended dose of fertilizer (in 3 splits at 3, 6 & 9 months after planting), followed by incorporation of leguminous cover crops into the soil at 50-60 days after sowing for beneficial effects on vegetative growth, available nitrogen content in soil, better fruit quality, higher fruit yield and productivity of banana cv. Martaman (AAB).

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Comparison of Coloured Sticky Traps against Bean Flower Thrips *Megalurothrips distalis* (Karny) (Thysanoptera: Thripidae) in Summer Mung Bean

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Abstract: Mung bean grown in summer season in Punjab is an additional short duration crop with many benefits. During the hot summer season, the crop is highly prone to attack by bean flower thrips, *Megalurothrips distalis* (Karny) that cause flower shedding resulting in considerable yield losses. Field experiments were conducted in 2018 and 2019 to determine the efficacy of different coloured sticky traps against the pest. Blue coloured sticky traps (both commercial and handmade) were best in trapping bean flower thrips, which was followed by commercial yellow and handmade yellow traps that captured significantly higher thrips than clear, handmade purple and pink traps. Plots with blue traps recorded significantly lesser thrips incidence in flowers and higher grain yields. The study indicated that blue coloured sticky traps were best in attracting bean flower thrips of mung bean.

Keywords: Bean flower thrips, *Megalurothrips distalis*, Mung bean, Coloured sticky traps

Mung bean *Vigna radiata* (L.) Wilczek is an important warm season pulse crop after chickpea and pigeon pea in the Indian sub-continent. It has great importance in the vegetarian diet, due to its high protein content, besides having good amount of vitamins, minerals and bioactive compounds (Zhou et al 2019). In India, it is grown in *kharif* (rainy), spring and summer season in North and *rabi* (winter) season in the South. Under Punjab conditions, cultivating mung bean during summer season is widely accepted as an additional short duration crop for extra income, improvement in soil fertility, efficient land utilization and crop diversification (Dodwadia and Sharma 2012, Kumar et al 2022). Mung bean production is threatened by several biotic and abiotic factors, of which insect pests are of much importance (Nair et al 2019). The crop is attacked by several insect pests such as whitefly, jassids, thrips, stem fly, blister beetle, pod sucking bug, spotted pod borer and tobacco caterpillars causing considerable losses, especially on the main (rainy) season crop. Thrips target legumes especially Vigna group resulting in the considerable loss of crop yield (Hadiya 2017). Bean flower thrips, *Megalurothrips distalis* (Karny) is a major sucking insect pest of mung bean sown in summer season in Punjab that causes extensive flower shedding (Singh et al 2020). Farmers often resort to blanket sprays of un-recommended insecticides and mixtures as soon as flowering starts. To minimize excessive use of insecticide and to safeguard beneficial insects, this practice needs to be avoided. Various management options need to be reconsidered and used collectively for effective, economical and eco-friendly management of the pest. Monitoring of pest population and use of new safer insecticides should be preferred. Possibility of neem-based insecticides and horticultural mineral oils has recently been explored and may be incorporated as an integrated pest management strategy for managing this pest (Singh et al 2020). Management of pests cannot be done without the knowledge of precise pest population densities. Farmers can rely on tapping of flowers/ buds and counting the thrips or use of coloured sticky traps to monitor thrips incidence. Sticky colour cards or traps have been used for monitoring and mass trapping of insects, as compared to time consuming sampling of plants, for an early detection of the pest in horticultural crop ecosystems and some other crops (Muvea et al 2014, Tang et al 2015). Different species of thrips are attracted to different colours. Moreover, the use of coloured sticky traps is risky because some colours like yellow in pea crop may capture more of non-target predatory insects along with target insect pests (Pobozniak et al 2020). Hence, the selection of trap colour for a pest should be based on the proper knowledge. The trap colour for managing the pest should also ensure a high correlation between the size of their population in the crop and the number captured in the trap (Rőth et al 2016). The present study compared the effectiveness of different coloured traps for monitoring bean flower thrips *M. distalis* in summer mung bean aiming to identify the optimal trap colour for monitoring and management of the thrips in mung bean.

MATERIAL AND METHODS

For the comparison of different coloured sticky traps against *M. distalis* in summer mung bean, field trials were conducted at Punjab Agricultural University, Ludhiana (30°90'N, 75°85'E with an elevation of 247 m above mean sea level) during 2018 and 2019. Mung bean short duration variety (TMB 37) was sown in the first week of April in randomized complete block design (RCBD) with eight treatments and three replicates, in the plots of 35m^2 (26 rows of 6 m row length at 22.5 cm spacing) as per recommended agronomic practices (Anonymous 2018). Mean monthly temperatures for the months of April to June ranged from 25.6 to 32.9 °C during the 2018 and 24.7 to 34.6 °C during 2019. Bean flower thrips, *M. distalis* were abundant during this hot and dry period. Trials were conducted under unsprayed conditions and no other insect pest or disease incidence was observed.

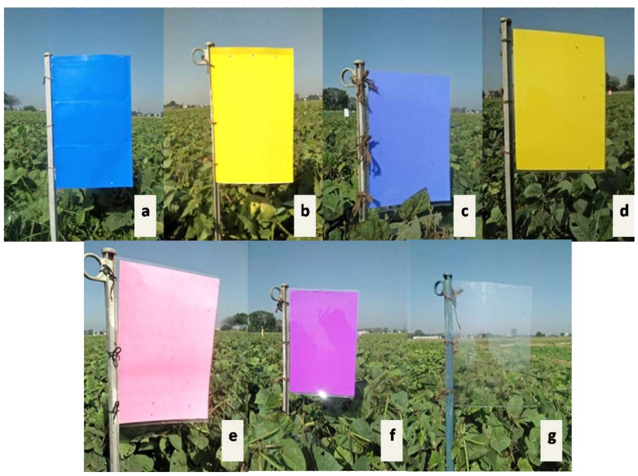

Fig. 1 Coloured sticky traps: (a) Commercial blue (b) Commercial yellow (c) Handmade blue (d) Handmade yellow (e) Handmade Pink (f) Handmade purple (g) Clear (transparent)

There were eight treatments that included blue, yellow, pink, purple, transparent (clear) and one control (without trap) (Fig. 1). The commercial blue and yellow sticky traps were purchased from Pest Control India, Chandigarh. Blue, yellow, pink, purple and clear traps were handmade. They were prepared manually using coloured paper sheets of 33 cm x 22 cm (total area 726 cm^2) and laminated. The handmade coloured traps were smeared uniformly on both the surfaces with castor oil to make them sticky. The traps (both commercial and handmade) were installed in the crop plots at the time of flower initiation stage, one trap per replication. They were mounted vertically using sticks and were positioned such that the lower edges were 5-10 cm above the plant tops. After installation of the traps, observations were recorded for the number of thrips caught per trap for four successive weeks. Count of thrips per trap was recorded using hand held 10X magnifying lens and the traps were replaced every week till the end of the season. In addition to the counts on traps, thrips population was recorded simultaneously from the crop. It was done twice a week for four weeks and expressed as thrips per 10 flowers. Pre-count data of thrips from flowers was recorded for each treatment before installation of the traps.

Statistical analysis: The data by were analysed by Duncans Multiple Range Test (DMRT) (significance level was p= 0.05).

RESULTS AND DISCUSSION

During 20th standard meteorological week (SMW) of 2018 (second week of May), significantly higher number of bean flower thrips were caught on commercial blue (66.67 thrips per trap per week) followed by handmade blue trap and were statistically on par with each other (Table 1). Furthermore, commercial yellow, handmade yellow, handmade purple, clear and handmade pink coloured sticky traps were statistically on par with each other. During 21th SMW, 129.67 thrips were

Table 1. Weekly trap catches of bean flower thrips on different coloured sticky traps in mung bean during 2018 and 2019

Trap	Number of thrips trapped per trap per week									
	2018	2019	2018	2019	2018	2019	2018	2019	Mean (2018)	Mean (2019)
SMW	20th Week		21th Week		22th Week		23th Week			
Crop days	41-47		48-54		55-61		62-68			
Commercial blue	66.67^{a}	36.67^{c}	85.33^{b}	69.33^{a}	150.33^{a}	151.33^{a}	332.00^{a}	216.00^{b}	158.58^{a}	118.33^{b}
Commercial yellow	42.33^{b}	48.66^{b}	64.00^{c}	37.33^{c}	85.00^{c}	74.67^{b}	174.66^{c}	131.33^{c}	91.41^{c}	73.00^{c}
Blue	62.67^{a}	111.33^{a}	129.67^{a}	66.00^{b}	118.33^{b}	155.00^{a}	198.00^{b}	232.00^{a}	127.17^{b}	141.08^{a}
Yellow	39.33^{b}	34.00^{c}	52.00^{d}	28.67^{d}	68.33^{d}	65.00^{c}	132.00^{d}	107.33^{d}	72.92^{d}	58.75^{d}
Pink	33.33^{b}	20.00^{e}	36.67^{ef}	18.67^{e}	31.66^{e}	30.33^{e}	58.67^{f}	48.00^{f}	40.08^{f}	29.25^{f}
Purple	36.67^{b}	24.00^{f}	40.00^{e}	19.00^{e}	33.00^{e}	49.00^{d}	48.00^{f}	70.66^{e}	39.42^{f}	40.75^{e}
Clear	35.00^{b}	28.43^{d}	33.00^{f}	19.67^{e}	74.67^{cd}	49.00^{d}	88.00^{e}	77.33^{e}	57.67^{e}	43.61^{e}

In column treatment means having same letter(s) are not significantly different by DMRT at 5% level of significance. SMW= Standard Meteorological Week caught on handmade blue trap and were significantly higher than commercial blue and commercial yellow traps. The lowest numbers of thrips were caught on clear followed by pink- and purple-coloured sticky traps. During 22^{th} and 23^{th} SMW of 2018, significantly higher population of thrips was recorded on commercial blue (150.33 and 332.00) followed by handmade blue trap. The mean number of thrips pooled over four weeks of 2018 on commercial blue were 158.58 per trap per week which was highest followed by handmade blue, commercial yellow and handmade yellow traps. Least number of thrips was recorded on purple and pink traps, these were significantly lesser than all other treatments. In 2019, handmade blue traps recorded significantly higher thrips in the 20^{th}, $22^{nd}$and 23^{rd} SMW. However, during 21^{st}week, commercial blue coloured trap recorded significantly higher thrips catch followed by handmade blue trap. The mean number of thrips caught per trap per week pooled over four weeks of 2019 was maximum on handmade blue (141.08 thrips) which was statistically higher than all other treatments and was followed by commercial blue, commercial yellow and handmade yellow-coloured traps (Table 1).

The mean number of thrips per 10 flowers ranged from 5.50-14.57 and 5.33-11.16 thrips with different coloured sticky traps during 2018 and 2019, respectively (Table 2). During 2018, the mean number of thrips were lowest in plots with handmade blue (5.50 thrips) and commercial yellow traps (5.80 thrips) followed by plots with commercial blue and handmade yellow traps. Maximum thrips incidence was found in control plots without traps (14.57 thrips per 10 flowers followed by plots with pink and clear trap. The highest mean of thrips caught per trap per day in 2018 were recorded on commercial blue (35.33) followed by handmade blue trap which was on par with it. However, during 2019, the numbers of thrips per 10 flowers were least in plots with commercial blue and handmade blue traps (5.33) and were significantly lesser than the plots with yellow-coloured traps. Control plots and plots with handmade purple trap recorded higher thrips count of 11.16 and 9.33 thrips per 10 flowers, respectively. The maximum mean number of thrips caught per trap per day was 40.67 on handmade blue trap followed by commercial blue trap (34.00 thrips per trap) which was on par with it, followed by commercial yellow and handmade yellow traps that were the next best treatments. An inverse relation was observed between thrips caught in traps and thrips in flowers of mung bean crop. Overall, plots with blue coloured sticky traps had significantly lower incidence of thrips in flowers during both the years.

The highest mean yield of mung bean crop was recorded from the plot with handmade blue trap (1179 kg ha^{-1}in 2018 and 1244 kg ha^{-1}in 2019) and was significantly better than all other treatments and was followed by commercial blue traps in both the years (Table 2). Lowest yields were recorded in the plots where no trap was installed. The per cent increase in yield over control during two years of study was maximum in handmade blue (57.62, 63.68) followed by commercial blue commercial yellow and handmade yellow. Lowest per cent yield increase over control (up to 2.76%) was recorded with use of pink traps.

Pooled data of two years indicated significantly higher number of thrips caught on commercial blue (138.45) followed by handmade blue trap which was on par with it (Table 3). Commercial yellow and handmade yellow sticky traps were the next best treatments. The lowest number of thrips were caught on handmade pink (34.67) followed by handmade purple and handmade clear trap Significantly higher mean yield was recorded from plots with handmade

Table 2. Bean flower thrips in traps, in flowers and yield of mung bean during 2018 and 2019

Trap	2018					2019				
	Pre-count	Mean number of thrips per day		Yield (Kg ha^{-1})	Per cent increase in yield over control	Pre-count	Mean number of thrips per day		Yield (Kg ha^{-1})	Per cent increase in yield over control
		Per 10 flowers	Per trap				Per 10 flowers	Per trap		
Commercial blue	15.33	6.00^{c}	35.33^{a}	1046^{b}	39.83	14.00	5.33^{a}	34.00^{a}	1122^{b}	47.63
Commercial yellow	15.33	5.80^{b}	20.22^{b}	958^{c}	28.07	14.67	7.00^{b}	21.08^{b}	1054^{c}	38.68
Blue	15.00	5.50^{a}	31.66^{a}	1179^{a}	57.62	13.67	5.33^{a}	40.67^{a}	1244^{a}	63.68
Yellow	14.66	6.00^{c}	16.00^{c}	938^{c}	25.40	14.00	7.42^{bc}	16.21^{c}	980^{d}	28.95
Pink	14.66	9.60^{f}	6.00^{d}	742^{e}	-0.80	14.33	8.50^{cd}	8.13^{e}	781^{g}	2.76
Purple	15.00	7.90^{d}	8.33^{d}	813^{d}	8.68	14.00	9.33^{d}	11.71^{d}	810^{f}	6.57
Clear	14.00	9.20^{e}	11.17^{c}	874^{d}	16.84	13.67	7.58^{bc}	12.25^{d}	950^{e}	25.00
No trap (Control)	15.00	14.57^{g}	0.00^{e}	748^{e}	-	13.33	11.16^{e}	0.00^{f}	760^{h}	

In column treatment means having same letter(s) are not significantly different by DMRT at 5% level of significance

Table 3. Trap catches of bean flower thrips and yield in mung bean (Pooled data of 2018 and 2019)

Trap	Number of thrips trapped per week				Mean number of thrips trapped per week	Pooled yield (Kg ha^{-1})
SMW	20th Week	21th Week	22th Week	23th Week		
Crop days	41-47	48-54	55-61	62-68		
Commercial blue	51.7^{b}	77.33^{b}	150.83^{a}	274.00^{a}	138.45^{a}	1084^{b}
Commercial yellow	45.50^{c}	50.67^{c}	79.83^{c}	152.83^{c}	82.20^{b}	1006^{c}
Blue	87.00^{a}	97.83^{a}	136.67^{b}	215.00^{b}	134.13^{a}	1211^{a}
Yellow	36.66^{d}	40.33^{d}	66.67^{d}	119.67^{d}	65.83^{c}	959^{d}
Pink	26.67^{f}	27.67^{ef}	31.00^{g}	53.33^{f}	34.67^{f}	761^{g}
Purple	30.33^{ef}	29.50^{e}	41.00^{f}	59.50^{f}	40.08^{e}	812^{f}
Clear	31.83^{e}	26.33^{f}	61.83^{e}	82.67^{e}	50.67^{d}	912^{e}

In column treatment means having same letter(s) are not significantly different by DMRT at 5% level of significance

blue trap (1211 kg ha^{-1}) that was followed by commercial blue and commercial yellow traps.

In the present study, bean flower thrips *Megalurothrips distalis* has shown preference towards blue coloured sticky traps over all other coloured traps. Tang et al (2016) and Yan et al (2017) also reported preference of *M. usitatus* (Bagrall) for blue and light blue coloured traps in cowpea over other colours including purple and yellow. Similarly, *M. sjostedti* Trybom on French bean has been reported to be more attracted towards blue trap (Muvea et al 2014). Blue coloured sticky traps were most effective for *S. dorsalis* in open field rose crop (Sridhar and Naik 2015) and on chilli crop as compared to white, yellow, green and pink coloured traps (Hossain et al 2020). Similarly blue traps were useful than yellow for *F. occidentalis* in fruit trees and green house rose (Broughton and Harrison 2012, Khavand et al 2019) and for *F. bispinosa* in olive grove (Allan and Gillett-Kaufman 2018). However, higher efficacy of yellow sticky traps was found for attracting *Thrips tabaci* L. on onion under open field conditions (Mukhtar et al 2022) and *S. aurantii* on avocado (Bara and Laing 2020).

CONCLUSION

The blue sticky traps (both commercial and handmade) were significantly better in attracting bean flower thrips than all other coloured sticky traps in mung bean crop. These traps can be used along with other components of Integrated Pest Management program where detection and monitoring of thrips population is an integral part to decide upon commencement of insecticide application. They are also likely to lessen the population of the pest in the crop. Blue coloured sticky traps have potential against flower thrips in mung bean crop.

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Impact of Intercropping Soybean on Natural Enemy Guilds in Cotton and Suitability of Trapping Methods for Various Insects

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Abstract: Field studies were carried out in cotton in the experimental fields of College Farm, Rajendranagar, Hyderabad during *kharif* 2019-20 to determine the impact of soybean as an intercrop and study its role in mitigating pests and enhancing the diversity of natural enemies. The study also estimated the efficiency of various sampling methods for insects of various orders. Insect pests of 18 families of 6 orders from intercropped cotton and 13 families of 5 orders from sole cotton were collected while predators of 22 families and 9 orders from intercropped cotton and of 22 families and 8 orders were collected from sole cotton. Diversity indices revealed a strong and robust natural enemy assemblage in the intercropped and sole cropped cotton ecosystems. However, intercropped cotton recorded lesser pest density (9.68/m^2), higher predator (1.06/m^2) and parasitoid density (0.31/m^2) than sole cotton (11.21, 0.75 and 0.14/m^2, respectively).Yellow sticky traps were most effective for sampling major pests namely leaf hoppers, whiteflies and thrips at 66.02, 87.89 and 85.32 per cent of their total numbers, respectively. Coccinellids and hymenopterans could be effectively sampled from sticky traps (85.95 and 75.50-93.42 per cent, respectively).

Keywords: Cotton, Intercrop, Soybean, Parasitoids, Predators

Cotton occupy about 2.4 per cent of the world's arable land. It supports the global textile mills market and the global apparel manufacturing market that produce garments for wide use valued at USD 748 billion and 786 billion, respectively, in 2016 (Lu 2018). Yield loss due to sucking pests in *Bt* cotton was 35.61 per cent in 2016-17 (Makwana et al 2018) and 33.02 per cent in *Bt* seed cotton in 2016 (Tukaram et al 2017). Globally, cotton 10 per cent of insecticide in 2019 according to International Cotton Advisory Committee. Cotton forms 6.5 per cent of the gross cropped area in India while consuming 50% of the total pesticides (Department of Agriculture, Cooperation & Farmers' Welfare, Annual Report 2020-21, Nayak and Solanki 2021).

An over reliance on synthetic insecticides and its associated environmental impact have resulted in the evolution of resistance in insects, secondary pest outbreaks, and resurgences (Razaq et al 2019). The introduction of *Bt* cotton has helped minimise pesticidal sprays to some extent, however, an integrated approach is required to gain control of the devastating pests attacking the crop. Out of the many pest management practices feasible at the farmers' level, increasing plant diversity in the field can achieve increased population of various natural enemies, which subsequently enhance natural pest control. For many pest species, natural enemies are the primary regulating force in the dynamics of their populations (Pedigo and Rice 2009). Deterrence of colonisation is probably one of the most promising means of controlling insect pests through intra-field diversity, because only a little additional diversity in the crop field may have a profound effect on colonization by insects (Cromartrie Jr 1993).

In cotton, intercropping can provide resources such as food and shelter and enhance the abundance and effectiveness of natural enemies (Mensah 1999). Growing short duration intercrops like soybean in cotton helps to safeguard the economy of the farmer through extra yields of intercrop and protects from adverse climatic risk and improves soil fertility through biological nitrogen fixation. Much work has been done on agronomic and soil aspects of cotton-soybean intercropping methods but little is known about the composition and nature of predatory and parasitic guilds and the impact they create on pest abundance and diversity.

Sampling is an essential and fundamental component of any experimental based research in entomology, whether conducted in laboratory, greenhouse or field. When selecting an appropriate sampling method, one should closely consider the design of the respective sampling tools and their costs, as well as the ecological traits and habitat conditions of the target taxa (Gullan and Cranston 2010). Various sampling methods have been used to sample and monitor cotton insect pests. Sticky traps have been widely used to sample harmful and beneficial insects. Preference of insects towards specific colour is a much-known phenomenon. Most often yellow coloured sticky traps are used to trap aphids and whiteflies (Devi and Roy 2017). Sweep net (SN) is considered to be a simple and cost-effective method to collect parasitic Hymenoptera from vegetation (Narendran 2001, Yi et al 2012). Five methods were evaluated and their suitability in sampling various groups of insects in the cotton ecosystem.

MATERIAL AND METHODS

The experiment was laid out in a plot of 1200 m^2 in College Farm, Rajendranagar during *kharif* 2019-20. The plot was divided into two modules *viz*., module M-I and module M-II of 600 m^2 each. Module M-I was raised as sole cotton while in Module M-II cotton was intercropped with soybean in 1:2 ratio. Spacing adopted was 90 X 60 cm for cotton and 30 X 10 cm for soybean. Bt cotton variety Jadoo was sown in the second week of July and soybean variety, JS 335 was sown ten days after germination of cotton to allow it to establish. Observations on insect fauna were recorded 10 days after germination to the second harvest of crop i.e. from the last week of August to the second week of December using yellow pan traps (YPT), pitfall traps (PFT), yellow sticky traps (ST), sweep nets (SN) and visual observations (VC). Five yellow pan traps and four pitfall traps were placed in each module and water mixed with little soap and salt was poured into them. One sticky trap was placed in each module. Twenty-four hours after placing traps in the field, insects trapped were collected, separated into respected families under each order and their abundance was worked out. A sweep net was used to collect insects in the modules once every fortnight by moving in a diagonal path across each module. At each point, five sweeps were taken up and a total of five points were considered. Twenty randomly selected plants were examined in visual counts. After compiling data on insect abundance, it was analyzed using OPSTAT software (Sheoran et al 1998). Diversity indices were calibrated to study the diversity parameters of pests, natural enemies, and neutral insects in the modules using the following formulae:

a) Species diversity (H) was calculated using formula Shannon-Weaver index (1949).

$$\text{Species diversity (H)} = \sum_{i=1}^{s} (pi)(\ln pi)$$

where pi = Proportion of ith species in the total sample

pi = fi/n

n = Total number of specimens in the sample

fi = Number of specimens of the ith species

s = Total number of species

ln = Natural logarithm (loge)

b) Margelef diversity index (Margalef 1958): This was calculated using the formula

$$= (S-1)/Ln(N)$$

Where,

S = Total number of species

N = Total number of individuals in the sample

Ln = Natural logarithm

c) Pielou's Evenness Index (E) (Pielou, 1966) was calculated using the formula.

$$E = H' / Ln\ S$$

where,

H' = Shannon – Wiener diversity index

S = Total number of species in the sample

Ln = Natural logarithm

d) Simpson's Index of Diversity (D) (Simpson 1949)

$$D = \Sigma\ ((n_i-1) / N * (N-1))$$

where: n_i- Number of individuals in the *i*-th species;

N -Total number of individuals in the community

e) Total predator density was calculated using the formula

$$\frac{\text{Total no. of predators collected}}{\text{Total area (sq.m.) sampled}}$$

RESULTS AND DISCUSSION

Insect pests: Insect pests of 18 families belonging to six orders from intercropped cotton and 13 families belonging to five orders from sole cotton were collected. A total of 5,843 insects were collected from intercropped cotton and 6,732 individuals from sole cotton. Abundance of major pest families of cotton was significantly greater in sole cotton crop than intercropped cotton. Abundance values of *Amrasca biguttula, A. devastans* (Cicadellidae), *Aphis gossypii* Glover (Aphididae), *Bemisia tabaci* Gennadius (Aleyrodidae) and *Thrips tabaci* Lindeman (Thripidae) were 784, 935, 781 and 2709, respectively in intercropped cotton and 925, 1112, 1154 and 3437, respectively in sole cotton (Table 1). Studies on pest density revealed that soybean had considerable negative impact on pest density and hence qualifies for a very effective candidate crop to be considered as an intercrop in cotton ecosystem. Total pest density was 9.68 per sq.m. and 11.21 per sq.m. in intercropped cotton and sole cotton, respectively highlighting the role of soybean as an intercrop in suppressing pest populations by boosting natural enemy population.

Predators: Arthropod predators of 22 families and 9 orders from intercropped cotton and those of 22 families and 8 orders were collected from sole cotton during the period. A total of 636 predator individuals were collected in intercropped cotton and 454 individuals from sole cotton plots. Family Coccinellidae of Coleoptera was represented by eight genera *Cheilomenes sexmaculata* (Fabricius), *Coccinella transversalis* Fabricius, *Propyleadis secta*(Mulsant), *Harmonia octomaculata* (Fabricius), *Hippodamia variegata* (Goeze), *Brumoidessuturalis* (Fabricius), *Scymnus nubilus* Mulsat and *Illeiscincta* (Fabricius). *H. octomaculata*, *H. variegata* and *C. transversalis* were recorded during the first one month, while remaining species till harvest. *C. sexmaculata* was most abundant species. Intercropped cotton recorded higher population (132 beetles) of Coccinellids than sole cotton (82 beetles). Carabidae and Staphylinidae (*Paederus fuscipes* Curtis) were the other two families and their total population was 22 and 53, respectively in intercropped module and 21 and 28, respectively in sole cotton (Table 1). Predatory hemiptera was another major order represented by four families *viz*, Anthocoridae [(*Orius tantillus* (*Motschulsky*)], Lygaeidae (*Geocoris* sp.), Nabidae (*Nabis* sp. commonly called as damsel bugs) and Reduviidae (*Rhynocoris* sp). Their population was 13, 16, 4 and 3, respectively in intercropped module while it was 6, 11, 4 and 2, respectively in sole cotton. Order Diptera included predatory insects from two families *viz*., *Ischiodan scutellaris* (Fabricius) and *Paragus* sp. from Syrphidae and long-legged flies from Dolichopodidae. Population of Syrphidae and Dolichopodidae was 13 and 56, respectively in intercropped module, while it was 6 and 40, respectively in sole cotton. Predators of other families were observed in very low numbers and were of less importance. Order Araneae was represented by nine families of spiders, among which Lycosidae and Araneidae were the most abundant. Their total population was 85 and 78, respectively in intercropped module while it was 73 and 46, respectively in sole cotton.

Table 1. Abundance of insect families in intercropped and sole cotton modules

Insect family	Population in module		p value
	Intercropped	Sole	
Cicadellidae	784	925	0.014*
Aphididae	935	1112	0.029*
Aleyrodidae	781	1154	0.001*
Thripidae	2709	3437	0.017*
Coccinellidae	132	82	0.283
Staphylinidae	53	28	0.251
Araneidae	78	46	0.073
Platygasteridae	52	21	0.015*
Diapriidae	32	18	0.025*
Eupelmidae	23	7	0.021*
Braconidae	21	11	0.033*

*Significant at 5% level

Shannon-Wiener index (H') was 2.47 and 2.46, respectively in intercropped and sole cotton, while Margelef's index of diversity was 3.25 and 3.43 in intercropped cotton and sole cotton modules, respectively indicating a very stable predator community. Pielou's evenness index (E) was 0.79 in both modules implying uniform numbers of the various families which is indicative of higher biodiversity ensuring good natural control in the field. Simpson's Diversity index (D) was 0.11 and 0.12 in intercropped cotton and sole cotton, respectively which again revealed a very strong and balanced predator community in both the modules. In general, predator community at Rajendranagar was reliable and long lasting, safe guarding the crop against pests and maintaining their levels much below the ETL for most part of the crop season. However, though diversity indices did not differ much between the intercropped and sole cotton, predator density was 1.4 times higher in intercropped module compared to sole cotton module (1.06 and 0.75 no./sq.m., respectively) underlining the role of intercropping on predator population enhancement (Table 2).

Parasitoids: Parasitoids of 14 families and 2 orders were collected from each module. A total of 185 individuals were collected in intercropped cotton and 90 individuals from sole cotton. Hymenoptera and Diptera were the two orders observed. The five most abundant families were of Platygastridae, Diapriidae, Mymaridae (*Mymar sp*., *Anagrus sp*.and *Gonatocerus sp.*), Braconidae and Eupelmidae with total population of 52, 32, 25, 21 and 23, respectively in intercropped module which was far higher than that in sole cotton module *i.e*, 21, 18, 15, 11 and 7, respectively. Platygastridae and Mymaridae were effective egg parasitoids of Hemipterans, Mymarids specially parasitize eggs of leaf hoppers. Other families of Hymenoptera were recorded in very low numbers in both the modules (Table 1).

Studies on diversity indices of parasitoids revealed that Shannon-Wiener index (H') was 2.04 and 2.13, respectively in intercropped and sole cotton; Margelef's diversity index was 2.29 and 2.67 in intercropped cotton and sole cotton, respectively implying very stable population of parasitoids. Higher values of diversity index and Margelef's diversity index in both modules indicated a balanced population which rendered natural control so successfully in the field that for most of the crop growth period the pests were found to be below ETL. Pielou's evenness index (E) was 0.80 and 0.83 for intercropped cotton and sole cotton, respectively showing almost uniform numbers of parasitoids of each family. Simpson's Diversity Index (D) was 0.15 and 0.13 in both modules, respectively revealing the rich diversity of parasitoids. Higher diversity indices implied lesser competition between the genera for various resources since parasitoids of different families vary in terms of food preferences and this helps to keep up chances of enhanced natural control. Though diversity indices did not differ between the modules, total parasitoid density in intercropped module was more than twice that in sole cropped one underlining yet again how intercropping favoured build-up of natural enemies (0.31 and 0.14/sq.m. respectively) (Table 2).

Neutral insects: Neutral insects of 14 families belonging to 7 orders were collected from each module during the study. A total of 495 neutral insect individuals were collected in intercropped cotton while 358 were collected from sole cotton. Flower beetles of Nitidulidae (Coleoptera) (200) and Entomobryidae (Collembola) (178) were the most abundant insects in both the modules. Population of other families *i.e*. Muscidae, Phoridae, Caliphoridae, Forficulidae, Apidae, Tipulidae, Stratiomyidae, Baetidae, Tephritidae, Scarabaeidae and Sarcophagidae was very low (Table 6). Total numbers were higher in intercropped module compared to sole cotton. *Apis dorsata Fabricius* and *Apis florae Fabricius* (Apidae; Hymenoptera) were found foraging actively throughout the flowering period. Forficulidae (Dermaptera) and Epispadias (Zygentoma) were scavenger insects collected in the study. Baetidae of Ephemeroptera (Mayflies) can be categorized as occasional visitors to the field. Each trophic level of the food pyramid plays an important role in the maintenance of the ecological balance. Maintenance of vegetation adjacent to or in crop fields provides alternative food, refuge and sometimes oviposition substrate for predators and parasitoids thereby increasing natural enemy abundance and colonization of neighbouring crops. Neutral insects are the key factors for flow of energy in a food web and hence their numbers were also documented in the present study.

The diversity indices of neutral insects in predators and parasitoids, the modules did not differ with each other with respect to diversity indices. Shannon-Wiener index (H') and Margelef's diversity index were 1.56 and 1.68 and 2.09 and 2.18 in intercropped cotton and sole cotton, respectively indicating a stable population in the modules. Pielou's evenness index (E) was 0.59 and 0.63 in intercropped cotton and sole cotton, respectively indicating that they contained almost unvarying numbers of insects in the families (Table 2). However, density of neutral insects was quite different between the modules (0.82 and 0.64 in intercropped cotton and sole cotton, respectively) exhibiting positive effects of intercropping on the population of neutral insects.

Suitability of trapping methods to insects of various families: Analysis of results on insect catches in various methods of trapping revealed the suitability of sampling methods. Insects of 8 families belonging to 4 orders were recorded in the study.

Insect pests: Among various sampling methods for pests of various families, sticky traps collected significantly greatest number of pests *viz*., leaf hoppers (66.02% of total catch), thrips (65.94%), whiteflies (87.89%) and Mirids (85.32%), while visual counts were good enough to sample aphids (41.53%) and Pyrrhocorids (55.75 %) and yellow pan traps collected fairly good number of leafhoppers (19.74%), whiteflies (17.01%), lesser numbers of Mirids (3.66%) and Pyrrhocorids (1.76%). Sweep nets were useful in sampling Pyrrhocorids (42.47%), while pitfall traps trapped all of the Acridids (100%) (Table 3).

Predators: Three predator families of Coleoptera were among which Coccinellids were more abundant and significantly in higher numbers (85.95%) were collected mostly from sticky traps than other methods. Visual counts, sweep nets and yellow pan traps were less effective since they collected 7.53, 3.68 and 2.84 per cent of Coccinellids, respectively. Carabids being mostly groundwellers, were collected only in Pit fall traps (100%). Yellow pan traps were more effective to trap rove beetles (Staphylinidae) (61.43%) than other methods. Sweep nets and pit fall traps recorded very few numbers of the beetles (22.86 and 11.43% respectively). All the Dolichopodids were trapped in yellow pan traps. Nabid bugs were observed in significantly higher numbers in sticky traps (91.21%), folllowed by Sweep nets (6.51%) and Visual counts (2.28%) (Table 4).

Table 2. Diversity indices and density of predators and parasitoids in intercropped and sole cotton

Diversity indices	Predators		Parasitoids		Neutral insects	
	IC	SC	IC	SC	IC	SC
Shannon Wiener (H')	2.47	2.46	2.04	2.13	1.56	1.68
Margelef's diversity index	3.25	3.43	2.29	2.67	2.09	2.18
Pielou's evenness (E)	0.79	0.79	0.80	0.83	0.59	0.63
Simpson diversity (D)	0.11	0.12	0.15	0.13	0.30	0.26
Total density (no./sq.m)	1.06	0.75	0.31	0.14	0.82	0.64

IC = Intercropped cotton, SC = Sole cotton

Spiders belonging to four families were observed during the study. All Lycosid and Theridiid spiders which live close to the ground were trapped in pit fall traps. Sweep nets and visual counts were significantly effective to record Araneid spiders (45.45%) than yellow pan traps (9.09%). Thomisid spiders which usually stay near the flowers and wait for the prey were best sampled in Visual counts (100%).

Parasitoids: Sticky traps displayed significant attraction for almost all of the Hymenopteran families namely Platygastridae, Diapriidae, Mymaridae, Braconidae and Eupelmidae (75.50, 80.28, 93.42, 85.07 and 85.80% respectively of total population). Yellow pan traps were second most effective trapping 24.50 per cent of Platygastrids, 19.72 per cent of Diapriids, 6.58 per cent of Eupelmids, 14.93 per cent of Mymarids and 14.14 per cent of Braconids, while Cynipid wasps were collected only in yellow pan traps (Table 5).

Neutral insects: Those insects which form a part of the ecosystem but were neither pests nor natural enemies were considered as neutral insects. Ten families of neutral insects belonging to five orders were recorded in various sampling methods. Springtails of family Entomobryidae live in debris on the ground and hence were collected in significantly higher numbers from pit fall traps (72.41% of total population) followed by yellow pan traps (27.59%). Yellow pan traps can capture the entire population of four Dipteran families *viz*, Sarcophagidae, Calliphoridae, Muscidae and Phoridae, while insects of Tipulidae, another Dipteran family was observed only in sticky traps. Earwigs of Forficulidae were trapped only in pit fall traps (100%) as they move close to the ground. Flower beetles in the family Nitidulidae were trapped in significantly higher numbers in sticky traps (64.31%), while17.36 and 12.86 per cent were sampled using sweep nets and yellow pan traps. Scarabaeids were trapped only in pit fall traps (Table 5).

The present study threw light on abundance and diversity of predator, parasitoid and neutral insect assemblages in cotton ecosystem and compared them in the presence and absence of an intercrop (soybean). Though diversity of natural enemies and neutral insects was more or less similar

Table 3. Insect pest abundance in different collection methods

Pest family	Trap catch (% of total catch)				
	Visual	Yellow pan trap	Sticky trap	Sweep net	Pitfall trap
Cicadellidae	14.23[c]	19.74[b]	66.02[a]	0.00[d]	0.00[d]
Aphididae	41.53[a]	23.93[c]	34.53[b]	0.00[d]	0.00[d]
Aleyrodidae	3.54[c]	8.56[b]	87.89[a]	0.00[d]	0.00[d]
Miridae	9.17[b]	3.66[c]	85.32[a]	1.83[d]	0.00[e]
Pyrrhocoridae	55.75[a]	1.76[c]	0.00[d]	42.47[b]	0.00[d]
Thripidae	22.12[b]	11.92[c]	65.94[a]	0.00[d]	0.00[d]
Gelechiidae	66.43[a]	13.98[b]	19.58[b]	0.00[c]	0.00[c]
Acrididae	0.00[b]	0.00[b]	0.00[b]	0.00[b]	100[a]

Values in a row with the same alphabet are not statistically different

Table 4. Predator abundance in different collection methods

Family	Trap catch (% of total catch)				
	Visual	Yellow pan trap	Sticky trap	Sweep net	Pitfall trap
Coccinellidae	7.53[b]	2.84[d]	85.95[a]	3.68[c]	0.00[e]
Carabidae	0.00[b]	0.00[b]	0.00[b]	0.00[b]	100.00[a]
Staphylinidae	4.29[d]	61.43[a]	0.00[e]	22.86[b]	11.43[c]
Dolichopodidae	0.00[b]	100.00[a]	0.00[b]	0.00[b]	0.00[b]
Nabidae	2.28[b]	0.00[c]	91.21[a]	6.51[b]	0.00[c]
Lycosidae	0.00[b]	0.00[b]	0.00[b]	0.00[b]	100.00[a]
Araneidae	45.45[a]	9.09[b]	0.00[c]	45.45[a]	0.00[c]
Thomisidae	100.00[a]	0.00[b]	0.00[b]	0.00[b]	0.00[b]
Theridiidae	0.00[b]	0.00[b]	0.00[b]	0.00[b]	100.00[a]

Values in a row with the same alphabet are not statistically different

Table 5. Parasitoids and neutral insect abundance in different collection methods

Family	Trap catch (% of total catch)				
	Visual	Yellow pan trap	Sticky trap	Sweep net	Pitfall trap
Parasitoids					
Platygastridae	0.00[c]	24.50[b]	75.50[a]	0.00[c]	0.00[c]
Diapriidae	0.00[c]	19.72[b]	80.28[a]	0.00[c]	0.00[c]
Eupelmidae	0.00[c]	6.58[b]	93.42[a]	0.00[c]	0.00[c]
Mymaridae	0.00[c]	14.93[b]	85.07[a]	0.00[c]	0.00[c]
Braconidae	0.00[c]	14.14[b]	85.80[a]	0.00[c]	0.00[c]
Cynipidae	0.00[c]	100.00[a]	0.00[b]	0.00[c]	0.00[c]
Neutral Insects					
Entomobryidae	0.00[c]	27.59[b]	0.00[c]	0.00[c]	72.41[a]
Sarcophagidae	0.00[b]	100.00[a]	0.00[b]	0.00[b]	0.00[b]
Calliphoridae	0.00[b]	100.00[a]	0.00[b]	0.00[b]	0.00[b]
Muscidae	0.00[b]	100.00[a]	0.00[b]	0.00[b]	0.00[b]
Phoridae	0.00[b]	100.00[a]	0.00[b]	0.00[b]	0.00[b]
Tipulidae	0.00[b]	0.00[b]	100.00[a]	0.00[b]	0.00[b]
Apidae	0.00[b]	100.00[a]	0.00[b]	0.00[b]	0.00[b]
Forficulidae	0.00[b]	0.00[b]	0.00[b]	0.00[b]	100.00[a]
Scarabaeidae	0.00[b]	0.00[b]	0.00[b]	0.00[b]	100.00[a]
Nitidulidae	5.47[d]	12.86[c]	64.31[a]	17.36[b]	0.00[e]

Values in a row with the same alphabet are not statistically different

between the modules, their increased abundance in the intercropped module ensured continues flow of energy from one trophic level to another leading to a complex interwoven food web. Such web rarely allowed pest levels to rise above the ETL due to enhanced natural control. An intercrop, if correctly assembled in time and space, can lead to agroecosystems capable of maintaining their own soil fertility, regulating natural protection against pests and sustaining productivity (Thrupp 2002, Scherr and McNeely 2008). Intercropping of compatible plants promotes biodiversity by providing a habitat for a variety of insects and soil organisms that would not be present in a single crop environment. The most common advantage of intercropping is the production of greater yield from the same field making more efficient use of the available growth resources using a mixture of crops of different nutrient requirements based on the complementary utilization of growth resources by the component crops (Lithourgidis et al 2011). Moreover, intercropping cotton with soybean improves soil fertility through biological nitrogen fixation, increases soil conservation through greater ground cover than sole cropping. Intercropping provides insurance against crop failure or against unstable market prices for cotton, especially in areas subject to extreme weather conditions such as frost, drought, and floods (Lithourgidis et al 2011). Rao (2011) also recorded significantly lowest infestation of whitefly in cotton + soybean (1.07 whiteflies/leaf), compared to other intercropped treatments and lowest population of thrips was in cotton + soybean, but aphids was lowest in cotton + green gram. Godhani (2006) quantified low population of aphids in cotton intercropped with maize, sesamum, soybean than pure cotton plots, respectively. Kadam et al (2014) observed that, cotton + soybean was superior treatment recording highest count of chrysopids followed by, cotton + green gram), cotton + sesamum (leaves) and least in sole cotton.

Khuhro et al (2020) found that yellow sticky traps collected overall highest number of whiteflies followed by green colour sticky traps, pink colour sticky traps and light green colour sticky traps. Sweep net and yellow pan traps were suitable for quantitative estimation of parasitoids whereas malaise trap was more suitable for qualitative estimates (Shweta and Rajmohana 2018). Mellet et al (2006) observed that ground dwellers comprised 21 families, 49 genera and 54 species, of which Lycosidae represented 62.5 per cent followed by Theridiidae comprising 20.0 per cent and Linyphiidae (9.1 per cent).

CONCLUSIONS

The higher diversity of natural enemies in the intercropped plot kept the pest under check from time to time and the need for pest management practices was low, leading to lesser input costs and a safer environment. The intercropping cotton with soybean is suitable for many areas of the state, where both cotton and soybean are grown but mostly as sole crops. Intercropping offers greater financial stability than sole cropping, which makes the system particularly suitable for labour-intensive small farms to reap good harvests and keep their ecosystems safe for generations to come. Findings on suitable trap types for various insects benefits biodiversity studies. Yellow sticky traps could attract majority of herbivorous hemipterans, predaceous coccinellids, parasitoids of hymenoptera, crane flies and flower beetles and can be preferably be used for sampling and studying them. Pitfall traps are highly useful to trap both adults and immature stages of epigeal insects and spiders.

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Prevalence of Different Post Harvest Rots of Papaya in Subtropical Zone of Himachal Pradesh

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Abstract: Papaya "The Common Man's Fruit" is grown throughout the tropics and sub tropics and is relished for its good taste and medicinal properties. Papaya fruits are highly susceptible to various post harvest rots. During the present investigation, different post harvest rots of papaya were found to be prevalent throughout the year at five fruit markets surveyed in district Hamirpur, Himachal Pradesh during May, 2019 to April, 2020. The pathogens associated were identified as *Colletotrichum fructicola*, *C. truncatum*, *Rhizopus stolonifer*, *Aspergillus flavus*, *Fusarium pallidoroseum* and *Alternaria* sp. to cause various post harvest rots in the region. Among these rots, Fusarium rot caused by *F. pallidoroseum* was the most prevalent followed by anthracnose caused by *C. fructicola*. During pathogenicity experiments, an incubation period of 3 days each was recorded in case of *C. fructicola, C. truncatum* and *F. pallidoroseum* while, that of 1, 2 and 4 days was recorded in case of *R. stolonifer, A. flavus* and *Alternaria* sp., respectively indicating the confirmed association of these pathogens with the rots. Symptoms of each rot varied initially, but ultimately lead to rotting of the fruit.

keywords: Post harvest rots, Papaya, Symptoms, *Rhizopus stolonifer*, *Aspergillus flavus*, *Fusarium pallidoroseum*, *Alternaria* sp, *Colletotrichum fructicola*

Papaya (*Carica papaya* L.) is a native of tropical America and is grown throughout the tropics and subtropics for its melon like fruit and ranks third in importance among fruits. Papaya contains sugars and nutrients at high level and low pH values make them susceptible to fungal decay (Singh and Sharma 2007). Due to high moisture and nutrient content, papaya is highly susceptible to microbial spoilage caused by fungi, bacteria, yeast and moulds. During the post-harvest period fungal and bacterial diseases cause heavy loss (Yahaya and Mardiyya 2019). Various workers have reported the incidence of different post harvest rots *viz*., anthracnose, fusarium rot, stem end rot, rhizopus rot, aspergillus rot and penicillium rot to be prevalent in papaya (Hamim et al 2014, Velenzuela et al 2015, Saini et al 2017, Helal et al 2018) but, the incidence of anthracnose was highest followed by Fusarium rot. The major portion of papaya production i.e. 40-60 per cent losses of the total production at various papaya growing regions are reported due to perishable nature despite a large production with the highest productivity among all the fruits grown in India (Prasad and Paul, 2021). Anthracnose alone has been reported to cause huge losses in production which may approximate to 90 per cent (Velenzuela et al 2015). Many important postharvest fungi have been reported to be associated with papaya out of which, *Colletotrichum gloeosporioides*, causing anthracnose is the most common and widespread pathogen of papaya around the world (da Silva and Michereff 2013, Patel 2013, Chowdhury et al 2014, Velenzuela et al 2015, Yohannes et al 2015, Saini et al 2017). Anthracnose of papaya caused by *C. truncatum* was reported by Ramapersad (2011), Torezz – Calzada et al (2018) and dos Santos Vieria et al (2019). Other species of *Colletotrichum* are associated with post harvest rots in papaya include *C. fructicola* (Marquez-Zequera et al 2018) and *C. dematium* (Helal et al 2018). At local level, fungi such as *Fusarium* spp, *Alternaria solani*, *Rhizopus stolonifer*, *Penicillium digitatum* , *Guignardia* spp., *Cercospora papayae Botryodiplodia theobromae, Phomopsis caricae-papayae*, *Mycosphaerella* spp. and *Phytophthora palmivora* are other important postharvest fungi associated with papaya (Chowdhury et al 2014, Akinro et al 2015, Kadam et al 2019, Sharma, 2015 , Helal et al 2018). Keeping in view the importance of the different post harvest rots in papaya, present investigations were conducted with the objectives to conduct survey and surveillance of local fruit markets in sub-tropical zone of Himachal Pradesh to record the incidence and abundance of post-harvest rots of papaya.

MATERIAL AND METHODS

The present investigations were conducted during 2018-2020 in the Plant Pathology Laboratory, Department of Plant Pathology, College of Horticulture and Forestry, Neri, Hamirpur.

Survey and surveillance: The routine survey and surveillance was conducted from May, 2019 to April, 2020 in the local fruit markets *viz*., Hamirpur, Nadaun, Sujanpur, Sulagwan and Barsar of district Hamirpur (Himachal Pradesh) to record the incidence (%) of different post harvest rots of papaya. From each market, 15 diseased fruits were collected and brought to laboratory for identification of a particular rot and pathogen associated with it. The associated pathogen was preliminarily identified on the basis of microscopic characters and symptoms produced by it. Disease abundance of each rot was then calculated. Disease incidence (%) and disease abundance (%) were calculated.

Isolation and maintenance of the associated pathogen (s): Associated pathogens were isolated from diseased fruits of papaya by single spore isolation method (Tuite 1969). Pure cultures of fungal pathogens thus obtained were further purified and maintained by using hyphal tip method on PDA slants under aseptic condition and stored in refrigerator at 4-5ºC for further studies.

Identification of associated pathogen(s): The pathogen(s) were preliminarily identified on basis of cultural and morphological characteristics. Three of the cultures were further got identified from ITCC, New Delhi and two of the cultures were identified from National Centre of Fungal Taxonomy. However, one pathogen associated with the rot exhibiting very low abundance was identified on the bases of its microscopic characters up to genus level only.

Pathogenicity of associated pathogen(s): For the pathogenicity experiments, healthy mature fruits of papaya were selected from the papaya plants or procured from the local market, washed thoroughly with tap water, swabbed with sodium hypochlorite (1 part sodium hypochlorite and 3 parts distilled water) for 30 seconds and washed with sterile distilled water to remove the traces of sodium hypochlorite. The inoculated fruits were placed in plastic trays and covered with transparent polythene sheet internally sprayed with sterilized distilled water so as to maintain the appropriate humidity. These trays were then incubated at room temperature and data were recorded in terms of incubation period (days).

RESULTS AND DISCUSSION

Survey and surveillance: Post harvest rots were prevalent in all the areas surveyed throughout the year (Table 1). The mean incidence of post-harvest rots was be minimum (15.77%) in May, 2019 which increased drastically in June, 2019 (100%) and remained at the same level from the June, 2019 to December, 2019, at all the locations surveyed. In January, 2020, the mean incidence of the disease (77.03%) started declining and reduced to 34.00 per cent by April, 2020. On an average, mean disease incidence (81.11%) was maximum at fruit market Hamirpur followed by Nadaun (79.46%) and Barsar (77.17%) while, minimum mean disease incidence (73.91%) was at Sujanpur followed by Sulagwan (76.00%) (Fig. 4. 2). All five fungal species *viz., Colletotrichum fructicola, C. truncatum*, *Rhizopus stolonifer, Aspergillus flavus* and *Fusarium pallidoroseum* were predominantly associated with the post harvest rots in papaya (Table 2). However, in addition to these, *Alternaria* sp. was associated to a limited extent during three months of the year, only (Fig. 1). Three of the cultures were got identified from ITCC, New Delhi as *R. stolonifer, A. flavus, F.*

Table 1. Frequency of post-harvest rots of papaya at different locations in Himachal Pradesh

Month	Disease incidence (%) at location					
	Hamirpur	Nadaun	Sujanpur	Sulagwan	Barsar	Average
May, 2019	15.38	18.18	11.11	23.08	11.11	15.77
June, 2019	100	100	100	100	100	100
July, 2019	100	100	100	100	100	100
August, 2019	100	100	100	100	100	100
September, 2019	100	100	100	100	100	100
October, 2019	100	100	100	100	100	100
November, 2019	100	100	100	100	100	100
December, 2019	100	100	100	100	100	100
January, 2020	85.71	75.00	80.00	66.67	77.78	77.03
February, 2020	66.67	44.44	62.50	50.00	60.00	56.72
March, 2020	55.55	71.42	62.50	50.00	57.14	59.32
April, 2020	50.00	44.44	33.33	22.22	20.00	34.00
Average	81.11	79.46	79.12	76.00	77.17	78.57

pallidoroseum under ITCC No. 11309.20, 11310.20 and 11308.20, respectively and two cultures were got identified from National Centre of Fungal Taxonomy as *C. fructicola and C. truncatum* under Id No. 9013.20 and 9014.20, respectively. However, *Alternaria* sp. was identified on the basis of mycelium and spore structures etc. within the laboratory itself. *C. fructicola* was responsible for causing post harvest rot throughout the year from May, 2019 to April, 2020 except in June, 2019 while, *C. truncatum* was associated with post harvest rots in of September to December, 2019 only. *R. stolonifer* was present and caused post harvest rot from June to August, 2019, while, *A. flavus* was from May to November, 2019 which disappeared in December, 2019 and reappeared in April, 2020. *F. pallidoroseum* was associated in post-harvest rots throughout the year except in June, 2019. However, *Alternaria* sp. present from July to September, 2019 only.

The maximum mean abundance (59.17) was in F. *pallidoroseum* followed by *C. fructicola* (39.48) while, minimum mean abundance (1.61) was in *Alternaria* sp followed by *R*. *stolonifer* (19.64) (Table 3). *C*. *fructicola* was present throughout the year except in June, 2019. Irrespective of the locations, maximum mean abundance (86.11%) of the pathogen was in July, 2019 followed by August (78.70%) reducing up to 14.87 per cent in April, 2020 while, minimum mean abundance (11.00%) was in May, 2019. *C. truncatum* was present from September to December, 2019. Maximum mean abundance (83.31%) of the pathogen was in September, 2019 followed by October, 2019 (74.78%) reducing to 74.17 per cent in November, 2019 while minimum mean abundance (66.10%) was in December, 2019. *R. stolonifer* was recorded to cause post harvest rot from June to August, 2019. Irrespective of the location of survey, maximum mean abundance (85.50%) of the pathogen was in June, 2019 followed by 77.79 per cent in July, 2019 and reducing to 72.43 per cent in August, 2019. Rot caused by *A. flavus* was prevalent from May to November, 2019 and again in April, 2020. The maximum abundance of *A. flavus* was observed in July averaging 100 per cent at all the locations surveyed followed by June, 2019 (54.10%) while, minimum mean abundance (10.50%) was recorded in May, *F. pallidoroseum* was prevalent throughout the year except June, 2019. The mean maximum abundance (86.44%) of the pathogen was recorded in March, 2020 followed by February (84.85%) and January, 2020 (83.47%) while, minimum (17.20%) was in July, 2019. Rot caused by *Alternaria* sp. was prevalent from July, 2019 to September, 2019. The maximum average abundance (12.06%) of the pathogen was in August, 2019 while, the minimum (2.50%) was in September, 2019. Fusarium rot caused by *F. pallidoroseum* was the predominant rot at all the five locations surveyed, as its mean abundance was highest at each location (Fig. 2). Anthracnose caused by *C. fructicola* was next highest in terms of mean abundance at each location surveyed. However, *Alternaria* rot was least abundant at all the locations surveyed. Rest of the rots exhibited intermediate range of abundance at various locations surveyed in district Hamirpur.

Symptomatology: The symptoms of *C*. *fructicola* causing anthracnose were recorded as dark brown to black coloured sunken water soaked spots in which orange coloured acervuli were visible in the form of concentric rings (Fig. 3). However, *C*. *truncatum* produced dark brown to black sunken lesions with black coloured acervuli in concentric rings. In Rhizopus rot, a soft rot was observed which developed white to grayish black fluffy mycelium bearing sporangia. *A. flavus*

Table 2. Association of different pathogens with post harvest rots of papaya during the year 2019-20

Month	Pathogens associated
May, 2019	*Colletotrichum fructicola, Aspergillus flavus* and *Fusarium pallidoroseum*
June, 2019	*Rhizopus stolonifer* and *A. flavus*
July, 2019	*C. fructicola, A. flavus, R. stolonifer, F. pallidoroseum* and *Alternaria* sp.
August, 2019	*C. fructicola, A. flavus , R. stolonifer , F. pallidoroseum* and *Alternaria* sp.
September, 2019	*C. fructicola, C. truncatum, A. flavus* and *F. pallidoroseum* and *Alternaria* sp.
October, 2019	*C. fructicola, C. truncatum, A. flavus, and F. pallidoroseum*
November, 2019	*C. fructicola, C. truncatum, A. flavus* and *F. pallidoroseum*
December, 2019	*C. fructicola, C. truncatum* and *F. pallidoroseum*
January, 2020	*C. fructicola* and *F. pallidoroseum*
February, 2020	*C. fructicola* and *F. pallidoroseum*
March, 2020	*C. fructicola* and *F. pallidoroseum*
April, 2020	*C. fructicola, A. flavus* and *F. pallidoroseum*

produced soft rot bearing white mycelium with suppressed growth and green coloured conidial mass. In case of Fusarium rot, symptoms developed as sunken watery spots with white to yellowish or pinkish mycelial growth which later became soft with time. Symptoms of *Alternaria* sp. were recorded as brown semicircular to circular spots covered with dark brown mycelium (Fig. 3).

Pathogenicity: Pathogenicity tests were conducted by inoculating the pure culture bits of these pathogens on young uninfected/healthy papaya fruits and incubation period was recorded in each case (Table 4). The incubation period of 3 days each was in *C. fructicola, C. truncatum* and *F. pallidoroseum* while, 1, 2 and 4 days was recorded in *R. stolonifer*, *A. flavus* and *Alternaria* sp., respectively. Symptoms developed after artificial inoculation of pathogens on papaya fruit produced symptoms similar to natural symptoms on the fruits thus confirming their pathogenicity (Fig. 4). During present studies, various post harvest rots were found to be prevalent throughout the year being maximum from June to December. Rahman et al (2008) also reported an incidence of post-harvest rots in papaya to be as high as 90-98 per cent in Malaysia. Pooja et al (2012) reported the presence of *Alternaria alternata*, *Aspergillus flavus*, *A. niger*, *C. gloeosporioides, F. moniliforme*, *F.*

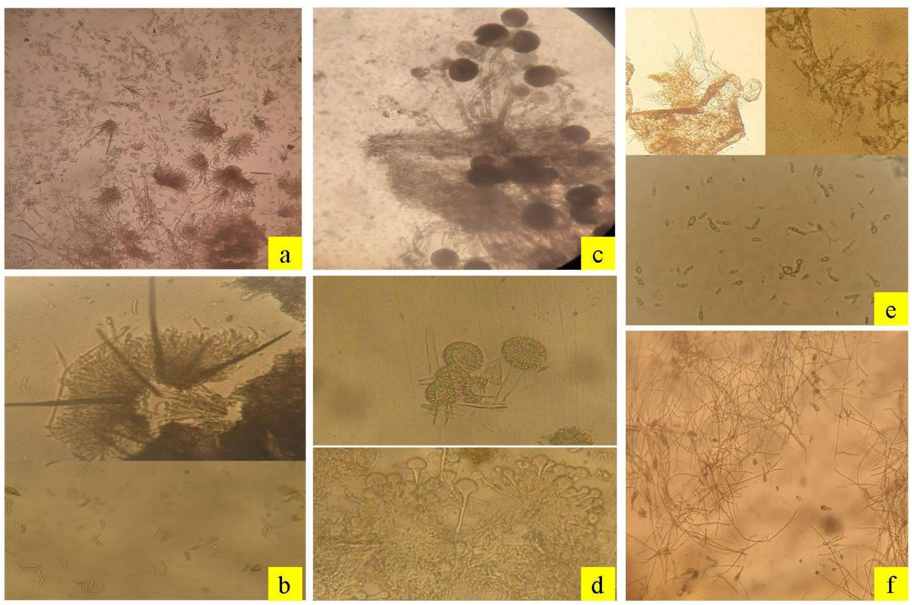

Fig. 1. Microscopic observation of a) *Colletotrichum fructicola* , b) *C. truncatum*, c) *Rhizopus stolonifer*, d) *Aspergillus flavus*, e) *Fusarium pallidoroseum* and *Alternaria* sp.

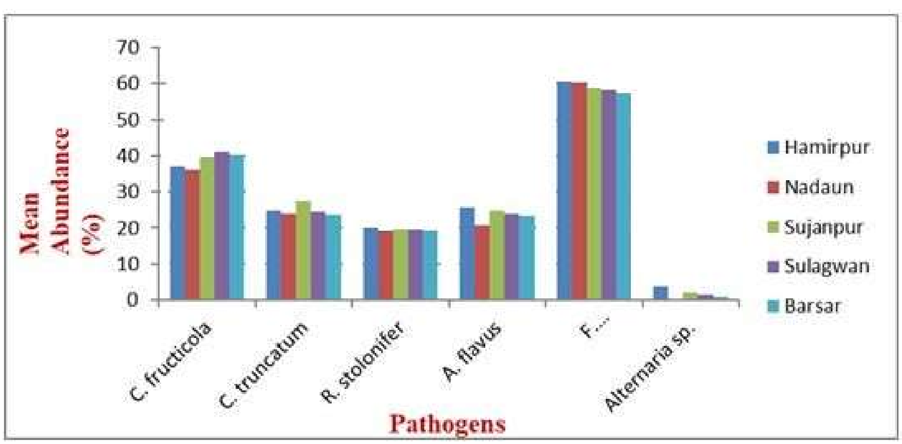

Fig. 2. Mean abundance of different post harvest rot of papaya at various locations of district Hamirpur during 2019-20

oxysporum and *R. stolonifer* in infected papaya fruits and highest total incidence and abundance of *A. flavus* in rainy season (July-Oct) and *F. moniliforme* during winter (November-February). The association of *C. truncatum* with the post harvest rot of papaya is confirmed by the findings of earlier researcher (Aktaruzzaman et al 2018, Torrez – Calzada et al 2018, dos Santos Vieria et al (2019) However, *C. fructicola* was associated with post harvest rots of papaya (Phoulivong et al 2012, Marquez-Zequera et al 2018) . Association of *Colletotrichum* spp. with the papaya fruit rots was recorded to be throughout the year except in June 2019. Patel (2013) also reported maximum prevalence of fruit rot in papaya was due to *Colletotrichum* sp.

The variation in abundance of different pathogens during various months of the year can be attributed to the fact that favorable conditions for the growth and development of pathogens vary according to the climatic conditions especially, temperature and relative humidity. These findings are also supported to certain extent by the findings of Pooja et al (2012) where *A. flavus* to be prevalent in the rainy season (July to October) and *Fusarium* sp. was abundant in winter months (November-February). Hamim et al (2014) reported the abundance of fusarium rot and anthracnose of papaya during November, 2012 to May, 2013 in Bangladesh. The symptoms of various post harvest rots recorded during present studies were similar to the symptoms of various rots observed in papaya by many workers earlier (Moraes et al 2013, Sharma and Kulshrestha 2015, Aktaruzzaman et al 2018).

The incubation of 1 to 4 days was recorded in different pathogenicity experiments. Vivekananth (2006) also reported an incubation period of three to four days in papaya fruits inoculated with *Colletotrichum* sp. Than et al (2008) inoculated chilli fruits artificially with *C capsici* as well as *C gloeosporioides* and reported that lesions appeared in 3 days after inoculation with wound/drop inoculation method. Popat (2013) also reported that symptoms appeared in 2-4 days in

Table 3. Average abundance of various post harvest rot of papaya in different months during 2019-20

Month	Disease abundance (%) at locations					
	C. fructicola	*C. truncatum*	*R. stolonifer*	*A. flavus*	*F. pallidoroseum*	*Alternaria* sp.
May, 2019	11.00	0.00	0.00	10.50	76.50	0.00
June, 2019	0.00	0.00	85.50	54.10	0.00	0.00
July, 2019	86.11	0.00	77.79	100.00	17.20	4.72
August, 2019	78.70	0.00	72.43	40.74	40.33	12.06
September, 2019	70.79	83.31	0.00	23.05	50.89	2.50
October, 2019	57.26	74.78	0.00	22.33	53.47	0.00
November, 2019	56.36	74.17	0.00	19.11	66.33	0.00
December, 2019	51.01	66.10	0.00	0.00	70.62	0.00
January, 2020	16.72	0.00	0.00	0.00	83.47	0.00
February, 2020	15.88	0.00	0.00	0.00	84.85	0.00
March, 2020	15.09	0.00	0.00	0.00	86.44	0.00
April, 2020	14.87	0.00	0.00	13.67	79.97	0.00
Average	39.48	24.86	19.64	23.63	59.17	1.61

Table 4. Symptoms and incubation period of various post harvest rots of papaya prevalent in district Hamirpur (HP)

Rot	Symptoms	Incubation period (days)
Anthracnose (*Colletotrichum fructicola)*	Dark brown to black sunken water soaked spots with orange coloured acervuli in the form of concentric rings.	3
Anthracnose (*Colletotrichum truncatum)*	Dark brown to black sunken lesions with black coloured acervuli in concentric rings.	3
Rhizopus rot	Soft, water soaked lesions with white to grayish black fluffy mycelium bearing sporangia	1
Aspergillus rot	Water soaked lesions with green coloured conidial mass.	2
Fusarium rot	Sunken, watery spots with white to yellowish and pinkish wavy mycelium later turning into soft rot.	3
Alternaria rot	Brown, semicircular to circular spots with dark mycelium.	4

Fig. 3. Symptoms of *a) C. fructicola, b) C. truncatum, c) R. stolonifer, d) A. flavus, e) F. pallidoroseum and f) Alternara* sp.

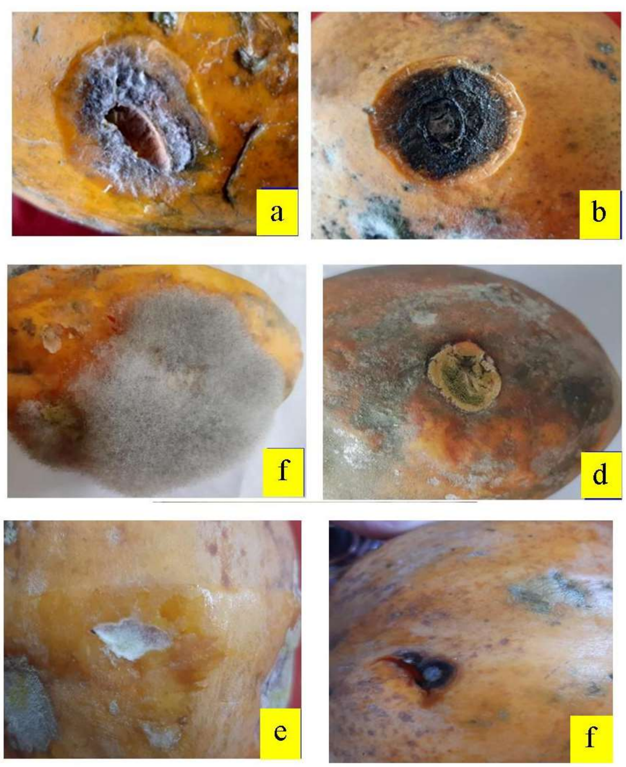

Fig. 4. Pathogenicity test of a) *C. fructicola, b) C. truncatum, c) R. stolonifer, d) A. flavus, e) F. pallidoroseum and f) Alternara* sp.

papaya fruits inoculated with *R. stolonifer* while, in 4-6 days when inoculated with *Alternaria* sp. Bautista-Banos et al (2008) also reported that *R. stolonifer* produced infection symptoms after 24 to 48 h in tomato in the presence of adequate temperature. Gore et al (2016) further strengthened findings and reported that symptoms of *Fusarium* sp. and *Alternaria* sp. appear in 2 to 4 days after inoculation on papaya fruits. The incubation period recorded in papaya fruits inoculated with *A. flavus* was in conformity with Louis et al (2013) who recorded an incubation period of 2 days in different plants inoculated with *Aspergillus* sp.

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Sustainable Management of Wet Bubble Disease (*Mycogone Perniciosa*) in Button Mushroom (*Agaricus Bisporus*) using Botanicals Agents under Temperate Conditions

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Abstract: *Agaricus bisporus* (Lange) Imbach is the most widely cultivated mushroom globally. Wet bubble disease, mainly caused by *Mycogone perniciosa*, is a major threat to *A. bisporus* production worldwide. In the current study, it was expected to select safe plant extracts that can successfully control wet bubble disease on mushroom due to the biological similarity of *M. perniciosa.* Seven antifungal potentials of some plant extracts namely, *Azadirachta indica, Azadirachta indica* (seed kernel*), Ocimum sanctum, Lanatana camara, Allium sativum, Azadirachta indica +lanatana camara* and *Aloe vera* were evaluated for their efficacy against pathogen *M. pernicosa*, under *in vitro* conditions. The test botanicals were highly effective at 3 per cent concentrations. The ethanol extract of *Azadirachta indica* and *Azadirachta indica + lanatana camara* behaved in a similar way. *M. perniciosa*, *Azadirachta indica* and *Azadirachta indica + lanatana camara* showed highly inhibitory against the pathogen with over all mean mycelium inhibition of 59.35 and 57.37 per cent respectively. The least inhibition of *M. perniciosa* was exhibited by *Allium sativum.* Under *in vivo* conditions, use of *Azadirachta indica* and *Azadirachta indica + lanatana camara* in different concentration resulted in a maximum yield of button mushroom of 401.11g and 360.26g/kg compost.

Keywords: *Agaricus bisporus,* Compost, Disease control, *Mycogone perniciosa*

Agaricus bisporus (Lange) Imbach, also known as the white button mushroom, is the most widely cultivated mushroom worldwide. Given its nutritional value, medicinal value (antitumor activity and hypoglycemic and hypo cholesterol limbic effects) and environmentally friendly status, the white button mushroom constitutes an increasing proportion of the diet (Grube et al 2001, Jeong et al 2010, Du et al 2017). Wet bubble disease of *A. bisporus* is a soil-borne disease mainly caused by *Mycogone perniciosa* (Magnus) Delacroix is reported worldwide wherever *A. bisporus* is grown (Sharma and Singh 2003, Ghazzawi and Beig 2011). *M. perniciosa* can infect the fruiting bodies of *A. bisporus* at various growth stages, causing the massive deformed tissues (Sclerodermoid mushrooms) before the mushroom tissue has differentiated into stalks and caps. *M. perniciosa* can produce two types of spores, phialoconidia and chlamydospores (Gea et al 2010). Both types of conidia can initiate disease, although their roles in dissemination and survival are still unclear (Glamoclija et al 2008). Casing soil is considered the main source of wet bubble disease as *M. perniciosa* releases phialoconidia or chlamydospores into the soil. Since most commercial cultivars of *A. bisporus* are highly susceptible to wet bubble disease control of wet bubble disease mainly involves fungicide disinfection of casing soil, cultural practices, and sanitation. The immediate application of salt to the infected areas is reportedly to be effective against *M. perniciosa* (Pieterse 2005). Chemical control is an effective method for the management of many fungal plant diseases (Shi et al 2020). Considering the serious nature and limited information available on the disease detail investigations on isolation, identification, and proving the pathogenicity of the Wet bubble disease and *In-vitro* and *in- vivo* management strategies.

MATERIAL AND METHODS

Isolation and Identification of wet bubble disease The study was conducted during 2019-20 to 2020-2021 at Division of Plant Pathology, SKUAST Jammu, Wet bubble disease (*M. perniciosa*) was isolated from infected casing and infected sporophores, displaying typical symptoms, by routine pathological techniques of Holliday (1980). The isolated *M. perniciosa* was tested for its aggressiveness towards the button mushroom under *in vivo* conditions. In the first experiment, conidial suspension (1x 104/mL SDW) of isolated *M. perniciosa*, inoculated in sterilized casing mixture at the time of casing. In the second experiment, isolated *M. perniciosa* was inoculated on healthy pinheads and fruit-bodies via conidial suspension (1 ×104/mL SDW) and the mycelial discs from the active culture plate to observe bubble symptom development (Fig. 1). After inoculation, the bags were kept in an isolated room at a temperature of 21 ± 1^{0}C with relative humidity of 87 per cent. Poly bags without pathogen inoculation, maintained under similar conditions, served as a control and were kept apart to avoid contamination. Both the experiments of pathogenicity tests were closely monitored for symptom development. The morphological cultural characteristics, *viz.,* mycelial, colour and growth; shape, size, color and septation of hyphae and conidiophores, conidia and phialides of the isolated *M. perniciosa* on host *A. bisporus* and in artificial culture were examined. The isolated micro-organism was identified on the basis of its morphological and cultural characteristics of comparing it with the standard descriptions of *M. perniciosa* given by Hus and Han (1981) and Singh and Sharma (2002). To further support the identification, *M. perniciosa* was also reconfirmed from CSIR- Indian Institute of Integrative Medicinal Jammu and the culture deposited under accession No. 1060.

In-*vitro* evaluation: Ethanol extract of six botanicals (Table 1) were evaluated in the laboratory for their efficacy against mycelial growth of *M. pernisiona* through poison food technique (Nene and Thapliyer 1993). Each the ethanol extract of the botanicals was prepared by the method of Deshpande et al (2004). The plants/plant parts were washed with tap water and rinsed with sterile distilled water followed by shade drying. Leaves of neem, lantana, tulsi, and garlic cloves were also dried till brittle. The shade dried plant/plant parts were ground with the help of electric grinder to obtain fine powder of each botanical. The dried powder was then stored in plastic containers for further use. The dried powder of the plant parts (20g) was mixed with 200 ml solvent (70% ethanol) in 250 ml conical flask. The flasks were tightly plugged with sterile cotton plugs wrapped with aluminum foil

Table 1. Botanicals against the wet bubble disease of button mushroom (*A. bisporus*)

Treatment	Common name	Botanical name	Part used
Trt$_1$	Neem	*Azadirachta indica*	Leaves
Trt2	Neem cake	*Azadirachta indica*	Seeds
Trt$_3$	Garlic	*Allium sativum*	Bulbs
Trt$_4$	Tulsi	*Ocimum sanctum*	Leaves
Trt5	Lantana	*Lantana camara*	Leaves
Trt$_6$	Neem +lantana	*Azadirachta indica +Lantana camara*	Leaves
Trt$_7$	Control	-	-

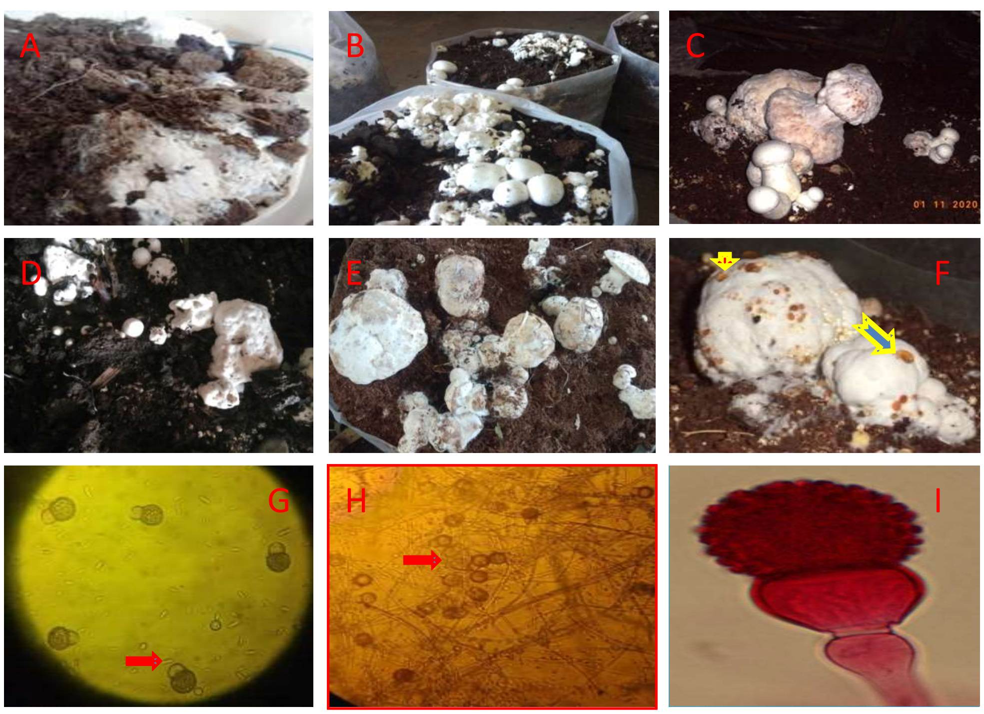

Fig. 1. Wet bubble symptoms and microscopic photograph of *M. perniciosa*.A) Early stage of disease turns into a shapeless mass. B) Later stage of amber exudation of fluffy mycelium. C) Sporophores mushroom became malformed with stipes, deformed caps .D) Infected pin head showing amorphic shapes. E) Cauliflower like distortion of infected fruit bodies. F) Little droplets of liquid amber in color appear on the surface of fruit bodies. G) Read arrow indicates single conidia. H) Single and Bio-cellular chamydospore. F) Terminal chamydospore

and kept on a rotator shaker for 36 hours and kept undisturbed for 6 hours to allow suspended plant material to settle down. The extract was decanted, filtered and centrifuged at 500 rpm for 15 minutes. The supernatant was collected and the solvent was evaporated at 40-50°C to make final volume 1/4th of the original volume. The test concentrations of 1, 2, and 3% were achieved by adding appropriate amounts of sterile, distilled water to the standard solution (100%). Two ml from each extract was dispensed in petriplates (90mm) and then 20 ml of molten PDA was poured gently containing extract solution. After solidification, inoculations were done with 5 mm disc of mycelial cut from 6 days old cultures of M.*pernisiona* isolated pathogens separately. The media without the plant extract served as control. The plates were incubated at 27±1°C till the complete growth was observed in control plates. Percent inhibition in growth was calculated in relation to growth in control.

$$\text{Growth inhibition} = \frac{\text{Radial growth in control} - \text{Radial growth in treatment}}{\text{Radial growth in control}} \times 100$$

***In vivo* evaluation of botanicals:** In this study, effects of the botanicals which showed maximum inhibitory to *M. perniciosa* were evaluated against the wet bubble disease in cultivation trials during the month of September-March of 2019-20 and 2020-21 in Mushroom Cropping Room, Division of Plant Pathology, SKUAST-Jammu. Mushroom compost was prepared according to the method of Mantel et al (1972) followed by the Long Method, using different constituents (wheat straw, 500 kg; rice bran, 50 kg; chicken manure, 200kg; mustard oil cake ,25 kg, gypsum, 15 kg and Urea 4 kg). After that added the different supplement *viz*. Neem, neem cake, Tulsi, Lantana and Garlicin crushed into a fine powder with the help of the grinder. The wet substrate and supplements were mixed thoroughly of the compost at 1, 2 and 3% (w/w) and the polythene bags of 22.5 cm × 30 cm size were filled with 1 kg of prepared compost. Spawn of *A. bisporus* was added at 10-12g/kg of compost. The untreated bags (devoid of botanicals) were kept as control. All the treatments including control were replicated five times. The bags were then incubated inside the Mushroom Cropping Room in dark for 10-15 days and the temperature was maintained at (22-24°C) till complete colonization of the compost with fungal mycelium was observed (El-Kattan and El-Hadded, 1998). After complete colonization on compost with mycelium of *A. bisporus*, the bags were inoculated with 3ml spore suspension of *M. perniciosa* separately with a spore load of 1×10^3 spores ml^{-1} in the middle of the bag with the help of syringe. The untreated bags (devoid of botanicals) with the same inoculums load were kept as control. Once the bags attained full spawn growth, casing layer (1.5 inches) was applied and the temperature was reduced to 15-18°C and humidity (80-85%). Observations on days for complete spawn run, days for pin head initiation, per cent increase in yield over control and disease incidence were recorded.

RESULTS AND DISCUSSION

Effect of ethanol extract of botanicals against of *M. perniciosa in vitro:* The botanicals at each level of concentration significantly varied in inhibitory effects (Table 2, Fig. 2). *Azadirachta indica* exhibited maximum inhibition of 67.65% followed by *Azadirachta indica* + *Lantana camara* at 3% concentration 64.60%).

Days for complete colonization/Spawn-run: There was significant difference between the effects of plant extracts on time taken for complete colonization by mycelium of *A. bisporus*. The average number of the days required for spawn run in *A. bisporus* was significantly less in Trt1 followed by Trt6 at 3 per cent concentration. The next best treatments were Trt1 and Trt6 at 2 % and 1 % concentration. The average number of the days for spawn-run was significantly more in control, devoid of plant extracts. The time taken for pin head formation by *A. bisporus* showed no significant difference between the effect of botanicals and concentrations. All the botanicals slightly reduced the days for pin formation as compared to control (8.70 days)

Effect of botanicals on yield and disease incidence: The yield of mushrooms was maximum in Trt1 (401.11/ kg compost) followed by Trt6 (360.26g/ kg compost). The lowest yield was in Trt3 (337.84g/kg compost) and to check untreated control (323.38/ kg compost). The different concentrations of botanicals showed significant reduction in disease incidence caused by *M. perniciosa*. The botanical Trt1 was most effective (29.28%), followed by Trt6, Trt5 and Trt4 . The highest disease incidence (71.23%) was in control. Significant disease control of mushrooms in different treatments was observed when compared with inoculated-unsprayed control. Trt1 sprayed bags recorded maximum reduction in disease incidence and statistically superior over other botanical treatments followed by Trt6 and Trt4. Wet bubble is widely distributed in mushroom growing countries of the world and generally appears in substrate rich in carbohydrates and deficient in nitrogen (Sharma 1999). The use of biological management tools such as botanicals agents is necessary for the successful and effective management of wet bubble disease. The botanicals agents were tested both *in vitro* as well as *in vivo* against *M. perniciosa* to choose the most effective for disease management. Botanical extracts not only inhibit mycelial growth of the pathogen but also significantly influence the yield and disease control of button mushroom. *In vitro* evaluation of botanicals *Azadirachta indica* showed the highest mycelial growth inhibition of 59.35% . Furthermore, under *in vivo* evaluation, the application of Trt1 resulted in disease control of 58.88%. The study is also in line with the work of Shaiesta et al (2011) and Kumar et al (2017). Antifungal properties of neem against moulds of mushroom have been reported by Grewal (1988). Sharma and Jandaik (1994) also observed that *Azadirachta indica, Eucalypyus, Tegetus erectus* and garlic extract inhibited the growth of various weed fungi of *A. bisporus*. Haq et al (2010) reported that bioactive components of *Azadirachta indica, Eucalyptus camaldulensis*, *Cymbopogon marginatus,* and citrus lemon are capable of enhancing the potential yield of mushrooms and slow down the progression of pathogenic microbes in oyster mushroom cultivation. Singh et al (2015) and Szumigaj et al (2012) also advocated the integrated use of botanicals where *A. indica* was the most effective botanical and showed maximum inhibition against *M. perniciosa* without inhibiting the mushroom mycelium. The findings indicate the potential usefulness of *Azadirachta indica* and *Azadirachta indica* + *lantana camara, Lantana camara, Ocimum sanctum* and

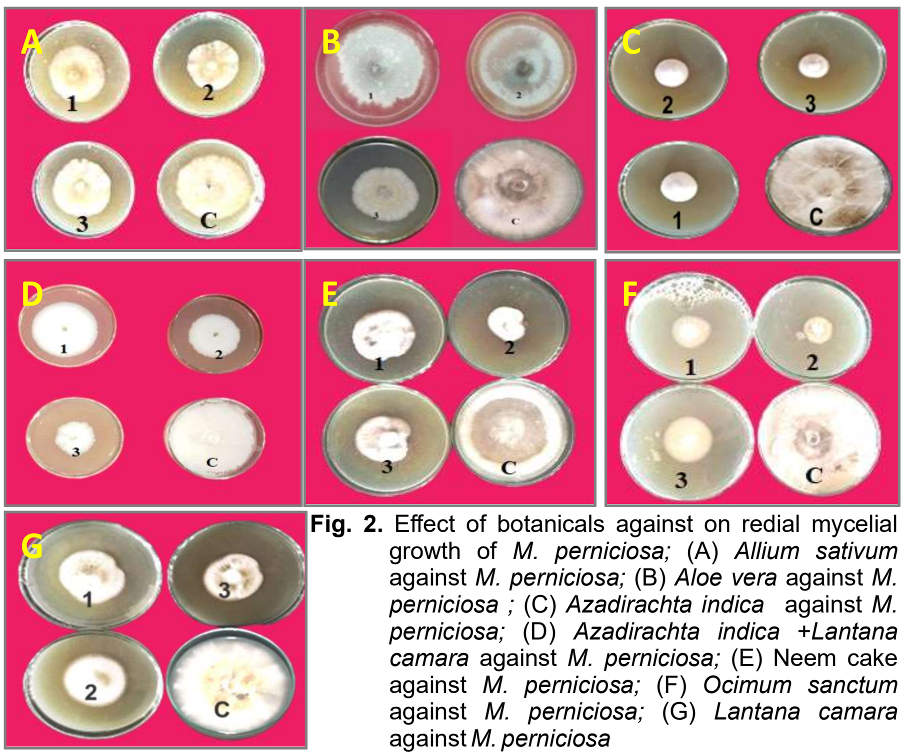

Fig. 2. Effect of botanicals against on redial mycelial growth of *M. perniciosa;* (A) *Allium sativum* against *M. perniciosa;* (B) *Aloe vera* against *M. perniciosa ;* (C) *Azadirachta indica* against *M. perniciosa;* (D) *Azadirachta indica +Lantana camara* against *M. perniciosa;* (E) Neem cake against *M. perniciosa;* (F) *Ocimum sanctum* against *M. perniciosa;* (G) *Lantana camara* against *M. perniciosa*

Table 2. *In vitro* evaluation of ethanol extract of botanicals against *Mycogone perniciosa* of button mushroom

Treatments	Mycelical growth different at concentrations (%)			Mycelical growth inhibition at different concentrations (%)			Mean
	1	2	3	1	2	3	
Azadirachta indica	46.44	34.19	29.11	48.40	62.01	67.65	59.35
Aloe vera	52.42	50.87	47.19	41.75	43.47	47.56	44.26
Azadirachta indica +Lantana camara	47.03	36.68	31.86	47.74	59.78	64.60	57.37
Lantana camara	51.62	37.67	32.00	42.64	58.14	64.44	55.07
Ocimum sanctum	51.32	40.18	32.00	42.97	55.35	64.40	54.24
Allium sativum	61.91	56.18	51.28	31.21	37.57	43.02	37.27
Neem cake	62.26	55.25	49.20	30.82	38.61	45.33	38.25
Control	90.00	90.00	90.00	-	-	-	

Source	Botanical (B)	Concentrations (C)	Botanical × Concentration
CD (p=0.05)	0.90	0.98	2.66

Table 3. Impact of selected botanicals on time taken for complete mycelium run, pin head inhibition, yield and disease incidence of button mushroom under in *vivo*

Treatment	Concentration (%)	Complete colonization (days)		Pin head initiation /first picking (days) (Pooled)	Yield (g)/kg (Pooled)	Disease incidence (%) (Pooled)	Disease control (%) (Pooled)
		2019-20	2020-21				
Trt1	1	17.10	17.32	6.55	374.22	34.77	51.92
	2	16.02	16.67	6.30	392.23	30.81	56.77
	3	15.12	15.10	6.00	436.88	22.26	68.05
	Mean	16.08	16.36	6.28	401.11	29.28	58.88
Trt2	1	19.28	19.39	7.85	340.74	57.42	19.38
	2	19.03	19.07	7.60	343.01	55.23	22.46
	3	18.78	18.78	7.45	350.99	48.60	31.75
	Mean	19.03	19.08	7.63	344.91	53.75	24.53
Trt3	1	19.02	18.89	8.05	331.17	56.05	21.28
	2	18.78	18.44	7.85	337.28	51.44	27.77
	3	18.00	17.89	7.65	345.07	47.37	33.51
	Mean	18.60	18.41	7.85	337.84	51.62	27.51
Trt4	1	18.67	18.29	7.35	335.71	49.27	30.80
	2	18.19	18.01	7.05	356.39	46.04	35.34
	3	17.32	17.19	6.85	365.94	41.73	41.37
	Mean	18.06	17.83	7.08	352.68	45.68	35.83
Trt5	1	17.55	17.89	7.10	350.59	44.65	37.27
	2	16.23	16.78	6.85	358.21	40.60	42.97
	3	15.54	15.87	6.45	367.88	31.99	55.05
	Mean	16.44	16.85	6.80	358.89	39.08	45.09
Trt6	1	17.34	17.47	6.95	351.44	43.33	39.12
	2	16.11	16.20	6.55	359.74	37.94	46.71
	3	15.34	15.47	5.80	369.61	29.59	58.42
	Mean	16.26	16.38	6.43	360.26	36.95	48.08
Trt7	(Untreated inoculated)	20.45	20.11	8.70	323.38	71.23	

Allium sativum as amendments or sprays in soil or compost casing to reduce wet bubble disease to low levels.

CONCLUSIONS

The ethanol extracts of *Azadirachta indica* and *Azadirachta indica* + *Lantana camara* showed significant mycelial inhibition of *M. perniciosa* at a concentration of 3% was most effective in inhibiting the wet bubble disease while having the least effect on host mycelium and a positive effect on mushroom yield. Therefore, the present study reveals that a treatment of botanicals agents on compost and soil casing may cause substantial increases in yield by subduing wet bubble disease.

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Production, Export and Price Behavior of Fenugreek in India

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***Abstract*:** The area under fenugreek cultivation has shown an undulating trend in India in the last two decades. There are various price and non-price factors that play a role in determining the area under a crop. This study analyzed the area, production, productivity and export of fenugreek in India from 1980-81 to 2020-21, using exponential growth function and instability analysis. Daily market prices and arrivals in major markets in Rajasthan, Gujarat and Madhya Pradesh were analysed employing the central moving average from 2007 to 2021. Multiple linear regression was employed to determine the influence of price on its area. The fenugreek production and export increased at CAGR of 5.37 and 7.37 percent per annum, respectively. Productivity was comparatively more consistent than area and production. Prices in studied markets increased significantly. A negative correlation between prices and arrival was observed. There was a significant influence of producer prices on the area harvested. Price and export promotion policies will encourage farmers to put the additional area into the cultivation of fenugreek.

Fenugreek (*Trigonella foenum-graecum* L.), a native of South-Eastern Europe and West Asia, is an annual leguminous herbaceous seed spice from the *Fabaceae* family (Pal, & Mukherjee, 2020). The Indian sub-continent is thought to be its secondary centre of origin (Petropoulos 2002). The genus *Trigonella* consists of more than 50 species (Kakani & Anwer 2012). Two cultivated species of genus *Trigonella* viz. *foenum-graecum* (commonly known as fenugreek) and *corniculata* (commonly known as pan methi or *Kasuri* methi) are economically cultivated seed spices in tropical as well as temperate regions of India (Meena et al 2021). Mainly it is grown during the winter season but in South India is also grown as a rainy-season crop. Currently, it is commercially cultivated in parts of the United States, Canada, Argentina, North Africa, Mediterranean Europe, the Middle East, South Asia, China, and Australia for its seeds, tender shoots, and fresh leaves (Basu et al 2019). In India, it is cultivated on large scale with upward trend in are between 1980 to 2014-15, but its cultivation shows a downward trend since 2015-16, which needs attention. Many factors are responsible for shrinkage, but the prices of the commodity in question play a pivotal role (Singh 2012, Meena et al 2021). An integrated marketing system of a commodity following the law on one price also determine the efficient allocation of scarce resources needs to be analysed in this crop (Easwaran and Ramasundaram 2008, Trivedi and Nair 2018). Keeping all this background in view, the present study was taken to explore the dynamics of prices of fenugreek across spatially distinct markets and also at different periods in India.

MATERIAL AND METHODS

The present study is based on time series data on area, production, export, daily market prices and arrivals. To analyze production and export dynamics during 1980-81 to 2020-21, information on area, production and export was compiled from Spice Board India and other sources. For comparison whole period was divided into two sub-period i.e. period I (1980-81 to 2000-01) and period II (2001-02 to 2021-22). Growth and instability were measured to check acreage and production performances during two sub and the overall period (Meena et al, 2018) following the methodology suggested by Chand et.al. (2011).

Growth rate analysis: The compound growth rate (CGR) in the area, production, and export from India was computed using the formula:

$Y_t = ab^t e^{ut}$

Where,

Y_t= Area/ Production/ Productivity/ Export in year't'

a = Intercept, b = (1+g) regression coefficient , t = Time period in years

u_t= Disturbance term for the year 't'

Taking natural log on both sides equation (1) becomes

$LnY_t = Lna + t\,Lnb + u_t$

Growth rate = (Antilog of b – 1)*100

Instability analysis: The variations from the trend in area, production, productivity and export were estimated using the Instability Index.

Instability Index = Standard deviation of the natural logarithm (Y_{t+1}/Y_t)

Where,

Y_t = Area / Production / Productivity and export in current year 't', and

Y_{t+1} = Area / Production / Productivity and export in next year't+1'.

If the series swings more over the trend, the ratio of Y_{t+1}/Y_t also fluctuates more, and the standard deviation increases indicating higher instability among variables.

To study seasonality and variations in fenugreek prices information on daily market prices and arrivals information in major markets (based on higher arrivals) were compiled from the Agmarknet website (https://agmarknet.gov.in) during January 2007 to June 2021 (174 months). Based on the arrivals in tons, major markets in Rajasthan (Kota and Nimbhahera) Gujarat (Rajkot and Patan) and Madhya Pradesh (Mandsour and Neemach) were chosen to study seasonality and variations in price and arrival were computed using Central Moving Average Method (CMA) and Seasonality Index as used by Makama (2016) and Meena et al (2021). CMA eliminates seasonality and randomness and represents the trend and cyclical components of the original series. CMA was estimated using the following formula.

$$CMAt = \sum \frac{pi}{n}$$

i= t-1/2(n-1)

Where: CMA = Central Moving Average, P_i = Nominal price, n= number of periods

Seasonality represents the ratio of the price each month to the average annual price. Seasonal index (SI) can then be written as:

SI= TCSEi/TCi =SEi =(Pi/CMAi)*100

$$GSI= SI * 1200/\Sigma_{i=12}^{12} SI$$

SI= is the average seasonal index for a month i

Market integration in selected fenugreek markets was analyzed using time series analysis i.e. Unit root test (ADF and Philip Pheron test), Johnsons cointegration test, Granger causality test and Vector Error Correction Model (Richard et al 2016).

Cost and returns analysis: A primary survey of thirty farmers from Jhunjhunu district of Rajasthan was carried out during 2021-22 and cost and returns in fenugreek cultivation were calculated. Variable costs including the value of hired human labour, owned or hired machinery, seed (both farms produced and purchased), insecticides and pesticides, manure (owned and purchased), fertilizer, irrigation charges, and interest on working capital were calculated. Profit was worked out by subtracting cost plus the imputed value of family labour charges from the gross value of output.

Influence of prices on its acreage: In analyzing the influence of market price on its area multiple linear regression analysis was employed .

$$Y= a + b_1X1 + b_2X2 + b_3X3 + u$$

Where,

Y = Fenugreek area in current year (t)

a = Intercept, a scale parameter

X1 = Fenugreek price in current year (t)

X2 = Fenugreek price in lag year (t-1)

X2 = Fenugreek export in lag year (t-1)

bi = Regression co-efficient of the respective independent variable.

RESULTS AND DISCUSSION

Fenugreek cultivation in India: Fenugreek is the third largest grown seed spice in India next to cumin and coriander. During 2021-22, it was cultivated under 1.67 lakh ha, producing 2.48 lakh tons of fenugreek seeds at average productivity of 1482 kg ha^{-1} (Adv. Est. Spice Board India, 2022). Its area and production from 1980-81 to 2021-22, increased by more than three and six times, at a compound growth rate of 4.55 and 5.37 percent, respectively (Fig. 1). Rajasthan ranks first in its area (90469 ha) and production (110869 tones) with 54 and 45 percent share to national area and production respectively. In Rajasthan, major fenugreek growing districts are Sikar, Chittorgarh, Jaipur, Pali, and Jhalawar. Madhya Pradesh ranks second followed by, Gujarat, West Bengal, Uttaranchal and Haryana in fenugreek cultivation. Integrated nutrient management in low fertile belts, adopting high-yielding varieties and management of biotic and abiotic stresses increased its productivity in the country (Lal et al 2017). During the study period, productivity improved from 900 kg ha^{-1} in 1980-81 to 1187 kg ha^{-1} in 2000-01, and a further 1482 kg ha^{-1} in 2021-22. The multiplicative effect of area and productivity resulted in production reached to 310 thousand tons in 2017-18. In India, fenugreek cultivation became more popular in the last two decades. From 1980 to 2000 (sub-period I) area and production expanded at less than one percent CGR. Area ranged from 25 to 45 thousand ha and production ranged from 21 to 57 thousand tons. Its export demand both in volume and value term increased faster in the above period. After 2000, its area and production increased at CGR of 7 and 8 percent, respectively (Table 2).

Fenugreek export from India increased faster than their production throughout the period, indicating increasing overseas demand. In quantity and value term export increased at CGR of 7.37 and 14.88 percent per annum, respectively.

Cost and returns in fenugreek cultivation: To analyze profitability in fenugreek cultivation, a primary survey of thirty farmers from Jhunjhunu districts was carried out using pre-structured questionnaires. The average cost A2 including family labour was calculated at 34041Rsha^{-1}. Return per rupee cost was more than two rupees in fenugreek cultivation during 2021-22 in the survey area (Table 3).

Price dynamics: Prices trends in major fenugreek markets namely Kota, Nimbahera in Rajasthan, Patan and Rajkot in Gujarat and Mandsour and Neemach in Madhya Pradesh were analyzed (Fig. 2). Fenugreek seed prices in surveyed markets ranged from Rs. 1776 in May 2007 to Rs. 7543 in Oct. 2015 per 100 kg. The average price in Madhya Pradesh markets namely, Neemach, and Mandsour prevailed higher than Gujarat and Rajasthan (Table 3).

From 2007 to 2021, fenugreek prices show an increasing trend till September 2015 later decreased up to September 2017 again bounced back. In the overall period, it increased at CGR of 0.33 to 0.45 percent per annum. The highest growth in prices was measured in Nimbahera followed by Neemach and Mansour. Intra-year coefficient of variation measures variability in the prices of agricultural commodities (Sharma & Kumar 2001). Average intra-year variation was low in Madhya Pradesh markets (9.79%) than in Rajasthan (10.71) and Gujarat (10.77%; Table 4). The highest growth in fenugreek prices with the lowest variation resulted in the highest arrivals of fenugreek seeds at Mandsour markets followed by Neemach. Similar findings were also reported by Meena et al (2021).

There was a significant increase in monthly prices in (Table 5). The highest increase per month was in Nimbhahera, followed by Neemach and Mandsour. A negative correlation coefficient between prices and arrivals in Kota resulted in a significant decrease in arrivals during the study period in this market. The positive correlation coefficient between prices and arrivals at Neemach,

Table 3. Cost and returns in fenugreek cultivation during 2021-22

Particulars	Physical unit	Cost/returns Rs ha^{-1}
Land preparation	2-3 times	3766.03
Seed cost	12-14 kg ha^{-1}	846.15
Sowing cost	ha^{-1}	1698.72
Irrigation cost	3-5 times	5248.4
Plant protection chemicals	0-2 spray	3076.92
Intercultural operation	1-2 times	7339.74
Harvesting cost	17.27 may days ha^{-1}	8637.82
Threshing cost	2 Hrsha^{-1}	2275.64
Interest on working capital	7%	1151.13
Variable cost including family labour	Rsha^{-1}	34040.55
Seed yield	kgha^{-1}	1139.42
Price received	Rsqtl^{-1}	6008.00
Gross value of produce	Rsha^{-1}	68456.50
Return over cost A2+FL	Rsha^{-1}	34415.95
Return per rupee operational cost		2.01

Source: Calculated from the cost of cultivation survey conducted by authors.

Table 1. Major fenugreek growing states and districts in India 2021-22

State	Area (ha)	Production	Major districts
Rajasthan	90469 (54.02)	110869 (44.67)	Bikaner, Sikar, Jodhpur, Pratapgarh, Churu, , Jhunjhunu and Nagaur
Madhya Pradesh	52234 (31.19)	101882 (41.05)	Ratlam, Ujjain, Mandsaure, Neemuch, Rajgarh, Shajapur, Guna, Dhar , Sehore,
Gujarat	8702 (5.20)	16697 (6.73)	Mehasana , Banaskatha
India	167468 (100)	248203 (100)	

Source: Spice Board India, 2022 for area and production for major districts.
The figure in parenthesis presents the percent share to India's total

Table 2. Growth and instability analysis in Fenugreek production and export from India; 1980-81 to 2020-21

Particulars	Sub-period I		Sub-period II		Overall period	
	CGR (%)	Instability index	CGR (%)	Instability index	CGR (%)	Instability index
Area (ha)	0.33	0.32	6.74	0.32	4.55	0.32
Production (Tones)	0.75	0.34	7.81	0.33	5.37	0.33
Productivity (Kg ha^{-1})	0.42	0.20	1.00	0.09	0.79	0.15
Export (Tones)	10.38	0.41	7.90	0.38	7.37	0.39
Value (in lakh rupees)	21.22	0.35	15.10	0.33	14.88	0.34

Source: Estimated from data compiled from Spice Board, India

Nimbhaheda and Rajkot resulted in a significant increase in arrivals in above markets. The highest significant increase in arrivals was estimated in Neemach followed by Nimbhaheda and Rajkot.

Impact of price on area: Unfavorable market prices from 2015 onward resulted in the shrinkage of fenugreek acreage by more than 60 thousand ha till 2021-22 consequently decreasing production in recent years. The price of a

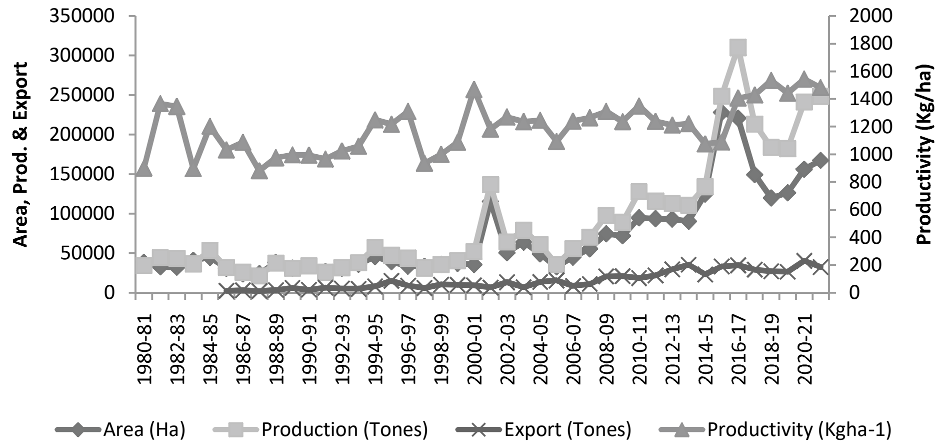

Fig. 1. Area (ha), production (tones), productivity ($Kgha^{-1}$) and export of fenugreek in India during 1980-81 to 2021-22

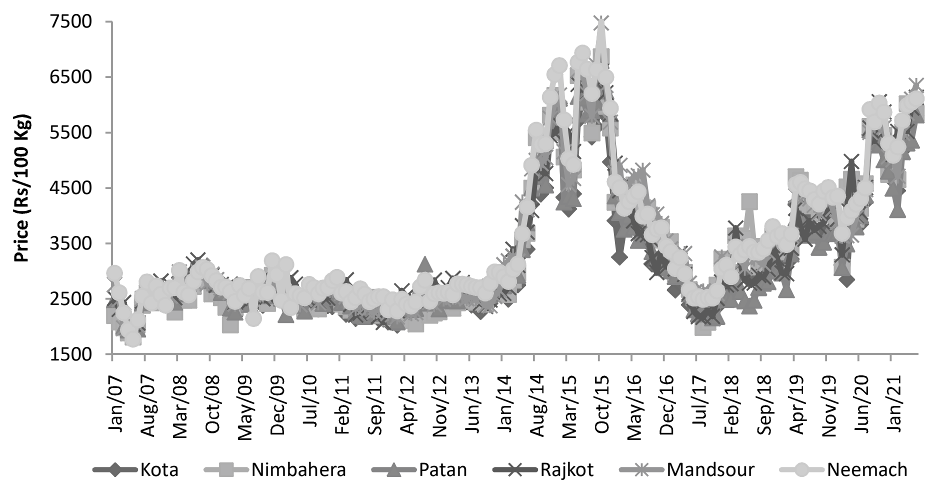

Fig. 2. Fenugreek price in major markets from Jan. 2007 to June 2021

Table 4. Descriptive statistics of monthly fenugreek prices (Rs per 100 kg) from January 2007 to June 2021

Particulars	Rajasthan		Gujarat		Madhya Pradesh	
	Kota	Nimbahera	Patan	Rajkot	Mandsour	Neemach
Mean	3168.49	3358.14	3210.71	3378.33	3456.28	3540.97
Median	2685.63	2801.88	2732.29	2841.03	2896.19	2972.97
Minimum	1941.19	1810.53	1940.42	2047.78	1871.00	1776.50
Maximum	6541.71	6869.57	6796.32	6598.91	7475.42	7542.80
CGR	0.38	0.45	0.33	0.36	0.42	0.42
Instability index	0.09	0.10	0.10	0.09	0.08	0.09

Source: Calculated from daily market prices harvested from agmarknet.

Table 5. Intra year coefficient of variation in fenugreek price

Year	Kota	Nimbahera	Patan	Rajkot	Mandsour	Neemach
2007	9.39	12.57	12.73	9.99	13.27	13.97
2008	7.52	6.98	7.67	6.89	5.23	5.80
2009	5.67	9.29	7.65	7.57	3.81	9.23
2010	4.69	8.45	5.42	6.97	4.60	7.46
2011	4.54	5.11	4.87	9.50	6.30	5.36
2012	7.16	6.44	9.63	5.79	5.65	5.85
2013	4.64	5.66	3.60	5.50	3.37	4.50
2014	27.82	29.92	25.35	23.77	22.54	28.72
2015	13.95	11.67	14.53	7.24	13.83	11.76
2016	10.08	8.93	10.67	16.19	9.79	8.55
2017	9.70	15.87	13.48	15.67	11.35	10.75
2018	7.51	10.72	8.94	10.06	6.27	6.56
2019	9.34	10.32	10.30	10.41	7.55	8.85
2020	20.63	16.68	17.92	17.84	18.19	17.20
2021	10.04	10.18	11.33	5.82	10.40	7.00

Source: Calculated from daily market prices harvested from agmarknet.

Table 6. Trends in monthly price, arrivals and correlation between arrivals and prices of fenugreek; 2007 to 2021

Market name	Price trend	Arrival trend	Correlation coefficient
Kota	2063.95+12.62*** (t)	976.62-3.64***(t)	-0.27
Nimbahera	2020.44+15.29***(t)	68.55+1.72**(t)	0.36
Patan	2231.27+11.19**(t)	81.99-0.16(t)	0.00
Rajkot	2237.88+13.03**(t)	249.52+1.48*(t)	0.11
Mandsour	2157.30+14.85***(t)	1336.13+0.94(t)	-0.19
Neemach	2228.41+15.00***(t)	-27.33+13.83***(t)	0.25

Source: Estimated from daily market prices harvested from agmarknet

Table 7. Results of multiple linear regression; Dependent variable fenugreek area in India

Particulars	Coefficients	Standard error	t Stat	P-value
Intercept	-20804.23	14454.61	-1.44	0.18
Price in current year (Rs/100 kg)	-32.76***	5.74	-5.71	0.00
Price in lag year (t-1;Rs/100 kg)	48.73***	5.37	9.08	0.00
Export in lag year (t-1; tons)	3.73***	0.65	5.77	0.00
Adjusted R Square		0.91		

*** indicates significance at 0 percent level of significance

commodity directly influences its acreage (Abu, 2017). Multiple linear regression was employed to measure the impact of its price in the current as well as the lag year (t-1) and last year's export volume on acreage in current year. More than 90 percent variation in the fenugreek area in the country is significantly determined by its prices and export demand. A unit increase in lag year price and export demand increases its acreage by 49 and 4 hectares respectively, keeping other things constant (Table 5). A significant negative response of current year price indicates higher harvest leads to prices crash in a particular year. Similar results were also obtained by Mekbib et al (2016) in wheat, corn, soybeans and rice at the global level too.

CONCLUSION

During 2080-81 to 2020-21, fenugreek production in India increased faster due to the combined effect of an increase in acreage and a productivity improvement. The significant increase in its prices coupled with increasing export demand for its seeds has played a pivotal role in its area expansion.

The markets with a negative correlation coefficient between monthly arrivals and prices have reported decreased arrivals over the period, significantly. On the other hand market with a positive correlation registered a significant increase in arrivals over the study period. The study suggests the need for price support and export promotion policies in fenugreek for further area expansion in the country.

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Economics and Marketing of Exotic Vegetables in Tribal District of Lahaul and Spiti

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Abstract: The present study was undertaken to work out economics of exotic vegetables cultivation in Lahaul valley of Lahaul and Spiti district in the state. The study is based on primary data collected through survey method using proper sampling technique during 2019-20. The total cost of cultivation per hectare for exotic vegetables was Rs 215315 and Rs 299183 for lettuce and broccoli, respectively. The net returns over total cost were highest in broccoli (Rs 1825817) followed by lettuce (Rs 565935), yielding output-input ratio of 7.10 and 3.62 which was much higher compared to traditionally grown vegetables of green pea, potato and cauliflower. The regression analysis revealed that area under crop and total labour were the important factors affecting the output of these crops. The crop output was marketed through two distinct channels: channel I - producer-trader-retailer-consumer and channel II - producer- contractor cum trader-retailer-consumer. The greater number of farmers followed channel I, through which about 3145 quintals and 1515 quintals of lettuce and broccoli, respectively was marketed. The adoption of exotic vegetables cultivation resulted in higher returns for the farmers compared to traditionally grown vegetables in the region. The policymakers should devise policies that encourage cultivation of these crops in similar areas to improve the farm income.

Keywords: Exotic vegetables, Cost, Returns, Marketing channels, Lahaul & Spiti

The diverse climate of India assures the production of a wide range of fruits and vegetables. After China, India is the world's second-largest producer of fruits and vegetables (Anonymous 2021). A large segment of the population still relies on agriculture for a living, and there is declining profitability on small farms. Therefore, strategic shift from food security to income security is still needed (Madhur 2016). Vegetables production could be the major contributor in this process. The production of vegetables in India is estimated to be 212.53 million tonnes in 2022-23 (first advance estimates) compared to 209.14 million tonnes in 2021-22 (Anonymous 2023a). In India, the North Western Himalayas and the Nilgiri hills provide good climatic conditions for the cultivation of exotic vegetables, particularly during the hotter months, whereas these vegetables can be grown in plains during the winter months (Kohli et al 2010). Despite a naturally favourable environment for growing these high-value vegetables, the country unfortunately lacks adequate export facilities and local marketing infrastructure (Rao and Mrunalinisasanka 2015).

In Himachal Pradesh, the area of 616.85 ha area was being cultivated under various exotic vegetables in Himachal Pradesh with a production of 13331.53 tonnes for the year of 2022-23 (Anonymous 2023b). The tribal district Lahaul and Spiti stands out for its exceptional agricultural productivity, particularly in vegetables and fruits as evident by the study conducted by Chand et al (2009). Among the 551 districts studied, Lahaul and Spiti was the leading district with an agricultural productivity of Rs 1.50 lakh per hectare. The decision to undertake a study on economics and marketing of exotic vegetables in the district was motivated by its notable progress in agricultural diversification towards exotic vegetable crops.

MATERIAL AND METHODS

The Lahaul and Spiti district was purposively chosen for this study as farmers are increasingly preferring growing exotic vegetables, mainly lettuce and broccoli. The study is based on primary data collected through survey method from 60 farmers selected using proportional allocation technique from 10 randomly selected villages spread in the valley in 2019-20. For computing the economics of growing these crops, standard Farm Management cost concepts (Cost A_1 to Cost C_3) used by the Commission for Agricultural Costs and Prices (CACP) have been used. Output-input ratios (returns per rupee) were estimated using the simple formula:

$$\text{Output-input ratio (returns/rupee)} = \frac{\text{Gross returns}}{\text{Total cost}}$$

Further, to examine the factors affecting the output, following Cobb-Douglas production function was employed because based on the statistical significance of regression coefficients and the value of R^2, Cobb-Douglas proved to be best fit among various multiple linear and log-linear functions.

The multiple log linear (Cobb-Douglas) model of the following form was used.

$$Y = b_0 X_1^{b1} X_2^{b2} X_3^{b3} X_4^{b4} e^u$$

Logarithm form of the model is:

$Log Y = Logb_0 + b_1 LogX_1 + b_2 Log X_2 + b_3 Log X_3 + b_4 LogX_4 + u$

where,

Y= Output of crop (q); b_0 = Constant term

X_1 = Area under crop (ha); X_2 = Human labour (man days)

X_3 = Cultivated land fragments (Number); X_4 = Fertilizers (kg)

$b_{i's}$ = Regression coefficients (Production elasticities),

I= 1,2,..,4

u = Random term

RESULTS AND DISCUSSION

Cost incurred in producing different vegetables: The similarity between Cost A_2 and Cost A_1 can be attributed to the fact that only a small number of farm households opted leased-in land for vegetable cultivation (Table 1). Cost B_2 (which includes rental value of owned land) was Rs 425315/ha and Rs 509183/ha for lettuce and broccoli, respectively. The total cost per hectare (Cost C_3) was Rs 544575 and Rs 669885 for lettuce and broccoli, respectively. The per hectare Cost B_2 for potato, cauliflower and pea was Rs 567818, Rs 478557 and Rs 417415, respectively. Cost C_3 or the total cost per hectare was Rs 740801, Rs 601827 and Rs 528925 for potato, cauliflower and pea, respectively.

Returns from different vegetables: The per hectare total variable cost accounted for around 77.0 per cent and 83.0 per cent of total cost in lettuce and broccoli, respectively (Table 2). Whereas in case of exotic vegetables, broccoli gave highest net returns per hectare (Rs 1825811) followed by lettuce (Rs 565935). In case of other vegetables, the total variable cost per hectare accounted for 86.56, 82.10 and 76.82 per cent of total cost in potato, cauliflower and pea, respectively. Potato yielded the highest gross returns per hectare of Rs 843750 followed by pea and cauliflower. The

Table 1. Cost structure of different vegetable crops

(Rs/ha)

Particulars	Exotic vegetables		Other vegetables		
	Lettuce	Broccoli	Potato	Cauliflower	Pea
Cost A_1	194709	278577	337212	247951	186809
Cost A_2	194709	278577	337212	247951	186809
Cost B_1	215315	299183	357818	268557	207415
Cost B_2	425315	509183	567818	478557	417415
Cost C1	285068	398986	463455	337116	270841
Cost C_2	495068	608986	673455	547116	480841
Cost C_3	544575	669885	740801	601827	528925

Table 2. Cost and returns from exotic vegetables

(Rs /ha)

Particulars		Exotic vegetables		Other vegetables		
		Lettuce	Broccoli	Potato	Cauliflower	Pea
Total variable cost		167234	251102	309737	220477	159333
		(77.67)	(83.93)	(86.56)	(82.10)	(76.82)
Total fixed cost		48081	48081	48081	48081	48081
		(22.33)	(16.07)	(13.44)	(17.90)	(23.18)
Total cost (1+2)		215315	299183	357818	268558	207414
		(100.00)	(100.00)	(100.00)	(100.00)	(100.00)
Gross returns		781250	2125000	843750	632500	687500
Net returns	Over Cost B_1 or Total cost	565935	1825817	485932	363942	480086
	Over Cost C_3	236675	1455115	102749	30673	158575
Output-Input ratio Over Cost B_1		3.62	7.10	2.36	2.33	3.32
Output-Input ratio Over Cost C_3		1.43	3.17	1.14	1.05	1.30

Figures in parentheses indicate percentages net returns over total cost were highest in pea (Rs 158575) followed by that of potato and cauliflower. The broccoli yielded comparatively higher output-input ratio (over Cost B_1) of 7.10 as against 3.62 in case of lettuce followed by pea (3.32), potato and cauliflower. Even relative to cost C_3, the output-input ratio for broccoli was the highest (3.17), followed by lettuce (1.43). These observations indicate that even at cost C_3, farmers were able to generate profits, highlighting the profitability of these vegetables in the study area. Lal and Sharma (2006) reported an output-input ratio of 1.03 for potato in the same study area.

Key determinants of exotic vegetables production: The area under the crop and total labour employed had a significant positive effect on exotic vegetable production, whereas fertiliser had a negative effect (because usage was two to three times higher than recommended dosages), suggesting diminishing marginal returns. The adjusted coefficient of multiple determination (R^2 explained about 90 to 96 per cent variation in output of lettuce and broccoli, respectively (Table 3).

Marketing of exotic vegetables from Lahaul valley: There was no record of utilization of exotic vegetables in the form of consumption in the family, gifts and other purposes in the study area. Since there was no utilization, the marketable surplus was also same as total production of these vegetables realized by the farmers (Fig. 1). Lettuce was being grown by 57 growers in comparison to 42 growers of broccoli. The marketed surplus was calculated by deducing the losses from the marketable surplus. The losses due to spoilage in handling and damage by pests ranged between 8.50 per cent

Table 3. Different factors influencing output of exotic vegetables

Particulars	Regression coefficients	Lettuce	Broccoli
Constant	b_0	4.9798	4.2825
		(1.1601)	(1.4941)
Area under crop 'X_1'	b_1	0.7252**	0.7072**
		(0.1855)	(0.2253)
Total labour 'X_2	b_2	0.3879*	0.5869**
		(0.1603)	(0.1626)
No. of land fragments 'X_3'	b_3	0.0741	0.0748
		(0.0576)	(0.0759)
Fertilizer 'X_4'	b_4	-0.2561*	-0.3774*
		(0.1094)	(0.1573)
Adjusted coefficient of multiple determination (R^2)		0.9040**	0.9611**
F- value		132.87	260.80

Figures in parentheses show standard errors of regression coefficients
** and * denote 1 and 5 per cent levels of significance

in lettuce and 12.35 per cent in broccoli. The marketable surplus of lettuce and broccoli was estimated to be 105.79 q/farm and 52.59 q/farm, respectively (the estimated sample farm size for lettuce was 0.37 ha and 0.24 ha for broccoli). The volume of total marketed surplus of lettuce and broccoli was estimated as 6030 q and 2209 q, respectively.

Market supply chain: The study area had two marketing channels for disposal of exotic vegetables from the farm to the consumer market. Channel-I consisted of a series of participants, including the producer, trader, retailer, and consumer, whereas Channel-II was composed of the producer, contractor-cum-trader, retailer and consumer. The main and only distinction between the two channels was that channel-II involved a mutual agreement with a trader at the time of transplanting, the crops which guaranteed the growers pre-determined prices for their produce and protected them against the market shocks of price fluctuations. Around 56 per cent of growers utilised channel-I to dispose of 3144 quintals of lettuce, while about 44 per cent used channel-II to dispose of about 2885.97 quintals. In broccoli 66.67 per cent growers disposed of their 1515.25 quintals of marketed surplus produce through channel-I and 33.33 per cent disposed of 693.53 quintals of marketed surplus produce through channel-II. This shows that channel-I was followed by a greater number of farmers in comparison to channel-II.

Marketing cost: The marketing cost borne by farmers in both the channels was almost same (Table 4). The grading/sorting cost of lettuce in both the marketing channels did not differ and it varied between Rs 26-27 per quintal. These costs in broccoli also revealed similar pattern, it ranged between Rs 39-41 per quintal. Broccoli and lettuce had a transportation cost of Rs 75 and around Rs 84 per quintal, respectively. For lettuce, grading/sorting and transportation costs varied between around 26.0-27.0 per

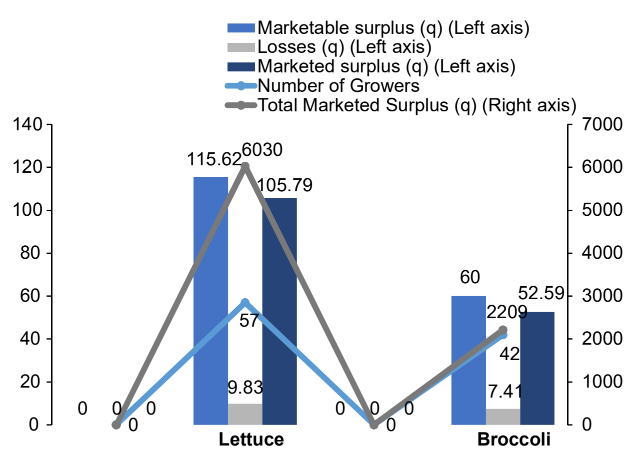

Fig. 1. Marketable and marketed surplus of exotic vegetables on sample farm

Table 4. Marketing costs incurred by producers

(Rs/q)

Particulars	Lettuce		Broccoli	
	Channel-I	Channel-II	Channel -I	Channel-II
Grading/Sorting	25.87	27.53	39.41	41.05
	(25.65)	(26.85)	(32.11)	(33.00)
Transportation cost	75.00	75.00	83.33	83.33
	(74.35)	(73.15)	(67.89)	(67.00)
Total	100.87	102.53	122.74	124.38
	(100.00)	(100.00)	(100.00)	(100.00)

Figures in parentheses indicate percentage

cent and 74.0-75.0 per cent of the total marketing expenses, respectively. In the case of broccoli, grading/sorting and transportation costs represented approximately 32.0-33.0 per cent and 67.0-68.0 per cent of the total cost.

CONCLUSIONS

The research findings indicate that cultivating exotic vegetables is more profitable compared to traditional crops like potatoes, cauliflower, and peas that have long been commercially grown in Lahaul valley. This transition not only boosts earnings from the same piece of land but also permits the land to be used twice during the cultivation season, due to the shorter growth cycle of exotic vegetables. This advantage is particularly pronounced in a region where snow covers the land for half of the year. The study recommends that state agricultural authorities should initiate efforts and implement policy measures to support the transition to exotic vegetables in Lahaul valley, aiming to replicate this success in other climatically suitable regions.

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Pre and Post-harvest Losses of Tomato in Punjab: Insights from Field Survey

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Abstract: The study was carried out to quantify the pre and post-harvest losses of tomato in Punjab. Multistage stratified and purposive sampling was used to select the 200 respondents from 21 villages of Patiala and Amritsar district of Punjab during the period, 2020-21. Blight assault accounted for the majority of output losses at the farm level (18.95%), followed by fruit borer attack (14.85%), unfavorable weather conditions (11.89%), and fruit cracks from excessive rain (3.44%). The proportion of the losses from total production was 6.18 percent at producer level, 2.60 percent at trader's level out of which 1.82 percent losses were at commission agent cum wholesaler level and 0.76 percent at retailer's level of the total quantity marketed. At various stages of production and marketing, the total post-harvest losses in tomatoes were 8.76 percent. Age of the farmer had a negative and significant coefficient (0.865) taken into account as one of the independent factors impacting post-harvest losses at the farm level. Inadequate labour (19.93) and inadequate transportation facilities (16.98) were the factors having positive and significant effect on the extent of post-harvest losses at farm level. The negative and significant coefficient (-39.154) of dummy variable for the district shows that on an average post-harvest losses of Amritsar district was significantly lower than Patiala district. The negative and significant coefficient (-15.772) of dummy variable for farm size categories indicating that the post-harvest losses in medium farm size category were lower than the large farm size category. It is recommended that providing scientific post-harvest handling and management training to vegetable farmers, together with chances for value addition, will improve their livelihoods and revenue. Extension services should be provided to the farmers regarding effective post-harvest management techniques that enhance their technical proficiency and enable them to manage post-harvest operations with precision. Pest and disease activity accounted for a larger portion of post-harvest losses on farms. Thus, it is advised that farmers apply integrated pest management techniques. More and more small and large processing units must be built in the state in order to reduce post-harvest losses.

Keywords: Tomato, Post-harvest, Losses, Factors, Punjab

Tomato (*Lycopersicon esculentum*) is a widely consumed vegetable crop worldwide. In many of the developing nations, it is a source of income for rural and peri-urban farmers. It is universally used in many parts of the world using several recipes in food processing and several industries (Sisay et al 2022). Globally, 41.37 million tonnes of tomatoes were processed into value-added products, according to the world processing tomato council (2019-20). The total tomato production in India during 2022-23 was approximately 21.18 million tonnes from 845 thousand hectares, which was declined by 2.3 percent from the previous year (FAO 2023).The decrease can be attributed to factors such as erratic weather conditions, pest and disease outbreaks, and rising input costs. India contributes 11% of the world's tomato production. Despite being the second largest producer of tomatoes in the world, India processes less than one per cent of its production (NHM 2017). Tomato pulp and paste products are imported by Indian manufacturers at high prices which entails an import duty of 30 percent (Subramanian 2016). Low quality, perishability of the crop, lack of cold storage system, lack of presence of remunerative prices, and unavailability of fresh tomatoes (Kumari et al 2022) are the barriers for processing industries in India. Therefore, a systematic marketing is required to mobilize the surplus of tomato crop with an aim to reduce the post-harvest losses significantly.

Post-harvest losses are a matter of concern. Tomato growers observed that post-harvest losses are critical for loss reduction, value addition, food security, employment creation, and income generation. Post-harvest technology is an essential component of the agriculture production and utilization system. Therefore, the nation needs a post-harvest technology revolution. Overall, post-harvest losses in India were estimated at around INR 926.51 trillion (Jha et al 2015). Among vegetables, the estimated post-harvest losses ranged from 4.82 percent in tapioca to 11.61 per cent in tomato (Ilori et al 2016, Krishna et al 2022, NABCONS 2022). Farm operations such as harvesting and sorting/grading resulted in post-harvest losses. Lack of proper storage and improper handling practices by various stakeholders in market channels were the major contributing factors towards postharvest losses. The cold chain infrastructure for vegetables in the country was still at a very nascent stage, special focus is needed for reduction in post-harvest losses as well as for retention of good quality as desirable by the consumers (NABCONS 2022).

In Punjab, tomato cultivation is one of the vegetable alternatives to wheat and paddy crop rotation. Depleting water table, escalating soil degradation, ecological problems and stagnation in the yields of the crops are the result of the intensive use of inputs and monoculture in the cropping system of Punjab (Bhatt et al 2016). Tomato is grown on an area of 10.4 thousand hectares with a production of 269.9 thousand tonnes (GoP 2022). It is one of the important vegetable crop after potato (47.36%), cauliflower (7.50%), pea (7.28%) and onion (3.80%) bestowing more than 50 percent of the total production of Punjab (GoP 2022).

Given the high perishability of tomatoes, growers must decide how to dispose of the crop as soon as it is harvested. Majority of the farmers has to rely on the markets, where prices are extremely volatile whenever there is a market glut and even a small delay in disposal can result in significant post-harvest losses to the produce (Grover et al 2003). Due to this, the current state of the market begs the question of why, despite record output levels, we have not been able to treat our farmers fairly (Tiwari et al 2021). It is crucial to give post-harvest loss procedures the same consideration as production procedures. Any decrease in post-harvest losses will undoubtedly enhance the economy's net food availability, which is of immense value and will serve to raise both the producer's returns and the consumer's satisfaction. A study of this kind will make it possible to identify the issue clearly, provide solutions, and ultimately cut down on overall waste. With this context, the current study was carried out to quantify the pre and post-harvest losses of tomato in Punjab.

MATERIAL AND METHODS

The study was primarily based on primary data collected during the period 2020-21.Two districts namely Patiala and Amritsar of Punjab state were selected purposively as these districts were contributing highest production and area of tomato cultivation. Multistage stratified random sampling technique was used for the selection of sample. Two blocks from each district i.e. Jandiala and Raiyya from Amritsar and Sanaur and Patiala from Patiala district were selected where the density of tomato growers were higher. From these selected blocks, the villages/cluster of villages with the highest concentration of tomato growers from each block were selected i.e. twenty-one villages were chosen randomly for data collection. Fifty tomato growers were randomly chosen from each designated block, 100 each from both the districts. Thus, making a total sample of 200 tomato growers were interviewed personally at the farms. The data was summarized using suitable statistical measures such as averages and percentages. For various operations such as harvesting, handling, and transportation, farmers were also asked for information about post-harvest losses. Last but not least, the sum of all these losses was assessed to be the overall post-harvest losses.

Functional Analysis

Multiple linear regression: The functional analysis was conducted to investigate the factors influencing post-harvest losses at the farm level as used by Nag et al 2000, Kumar et al 2006, Begum et al 2012, Khatun et al 2014, Alidu et al 2016. A multiple linear regression analysis was used for the present study.

$$Y=a+b_1x_1+b_2x_2+b_3x_3+b_4x_4+b_5x_5+b_6x_6+b_7x_7+b_8x_8+b_9x_9+b_{10}x_{10}$$

Where,

Y=Total Post-harvest losses (quintals), x_1= Age of the farmers (years)

x_2=Education of the farmers (years), x_3=Production (quintals)

x_4=Farm size (acres),x_5= Labour dummy (inadequate =1,0=adequate)

x_6=Weather dummy (inadequate=1,0=adequate), x_7= Transportation dummy (inadequate=1,0=adequate)

x_8=Dummy district (D_1=1forAmritsarand0=Patiala), x_9= Dummy farm size category (D_2=1for large and 0 for otherwise)

x_{10}=Dummy farm size category (D_3=1for medium and 0 for otherwise)

Table 1. Selected districts, blocks, villages and number of respondents, Punjab, 2020-21

Districts	Blocks	Selected villages	No. of villages in the cluster	Sample size
Amritsar	i) Jandiala	Teerthpur, Mallkpur, Wadhala johl, Chappa ram singh, Nawan pind, Fatehpur rajputan	6	50
	ii) Raiyya	Dhyanpur, Usma, Bhlaipur purba, Mehtampur, Sudhar rajputa, Sherbagha, Bheni ramdayal, Wadhala kala, Nangli kala, Nangli khurd, Jodhe	11	50
Patiala	i) Patiala	Lalucchi and Nwi Lalucchi	2	50
	ii) Sanaur	Sanaur and Asarpur	2	50
Grand total			21	200

RESULTS AND DISCUSSION

Pre and Post-harvest losses in tomato: Overall losses at the producer level were 14.26 quintals/acre contributing 49.15 percent share of the total pre and post-harvest losses (Table 2). The production losses at the farm level were highest due to blight disease (17.64%) in Patiala district whereas the incidence of fruit borer attack (21.24%) was highest in Amritsar district. The losses at the producer level were highest in Patiala district (43.23%) as compared to Amritsar district (39.48%). The total losses during marketing operation at the producer's level were estimated to be 6.60 quintals/acre which was 22.75 percent share of the pre and post-harvest losses. Out of the total losses, the transportation losses were highest i.e. 3.48 quintals/acre accounted for 11.99 percent share of the total pre and post-harvest losses. Total losses at the producer's level during marketing operation were 20.80 quintals/acre accounting for 71.90 percent of the total pre and post-harvest losses. The losses at the commission agent cum wholesaler level were estimated to be 56.78 quintals/acre which was 19.92 percent share of the total pre and post-harvest losses. The losses which were found highest in the case of Amritsar district constituted about 20.53 percent of the total losses. The estimated losses at the retailer level were estimated at 2.37 quintals/acre which was 8.16 percent of the total pre and post-harvest losses. Overall per acre, pre and post-harvest losses were estimated to be 29.01 quintals/acre out of which 30.32 quintals/acre from Patiala district and 26.59 quintals/acre from Amritsar district respectively. Overall percent losses from the total production were estimated as 8.60 percent.

Percent losses in tomato at different stages of production and marketing: In Patiala district, the proportion of losses at the producer level was estimated to be 8.10 per

Table 2. Pre and post-harvest losses in tomato at different stages of production and marketing

Particulars	Patiala district		Amritsar district		Overall	
	Losses (quintals/acre)	% loss	Losses (quintals/acre)	% loss	Losses (quintals/acre)	% loss
Losses at producer level						
Cracks	1.00	3.29	00.00	00.00	1.00	3.44
Fruit borer attack	4.31	14.21	5.65	21.24	4.31	14.85
Blight disease	5.35	17.64	4.85	18.23	5.50	18.95
Adverse weather condition	3.45	11.37	00.00	00.00	3.45	11.89
Sub-total	13.11	43.23	10.50	39.48	14.26	49.15
Losses during marketing operation						
Harvesting injuries	3.20	10.55	1.91	7.18	1.77	6.10
Grading/sorting	1.23	4.05	1.49	5.60	1.35	4.65
Transportation	3.64	12.00	4.33	16.28	3.48	11.99
Sub-total	8.07	26.61	7.73	29.07	6.60	22.75
Total losses at producer's level	21.18	69.85	18.23	68.55	20.86	71.90
Losses at marketing level						
Commission-agent cum wholesaler level						
Handling	2.39	7.88	2.35	8.83	2.25	7.75
Sorting/thrown	1.58	5.21	0.35	1.31	0.53	1.82
Transportation	2.00	6.59	2.76	10.37	3.00	10.34
Sub-total	5.97	19.68	5.46	20.53	5.78	19.92
Retailer level						
Sorting/thrown out	0.66	2.17	1.08	4.06	0.45	1.55
Transportation	0.39	1.28	0.63	2.36	0.52	1.79
Rotting and spoilage due to multiple handling	2.12	6.99	1.19	4.47	1.40	4.82
Sub-total	3.17	10.45	2.90	10.90	2.37	8.16
Total pre and post harvest losses	30.32	100	26.59	100	29.01	100.00
% losses of the total production	8.37		8.86		8.60	

cent share of the total production (Table 3). After the sale by the farmers in the market, the quantity sold by commission agent cum wholesaler to the retailer was 346.65 quintals and quantity of produce ultimately reached the consumer was estimated at 343.48 quintals. The proportion of losses at trader's level was 2.60 per cent share of the total quantity marketed. The total pre and post-harvest losses were estimated to 8.25 per cent share of the total production. In Amritsar district, the quantity of produce sold from producer to consumer through various channels was 273.10 quintals and the per cent loss at producer level were estimated 6.07 per cent share of the total production. The per cent loss at trader's level from the total marketed quantity was 2.98 percent and the total pre and post-harvest losses in Amritsar district from the total production were 9.05 per cent which were higher than that in Patiala district. Overall 8.76 per cent losses were occurred at various stages of production and marketing. Among total losses, 69.86 per cent of losses occurred at farm level followed by 19.68 per cent and 10.46 per cent at commission agent cum wholesaler level and retailer level, respectively.

Factors affecting post-harvest losses: Multiple linear regression was conducted to examine the impact of various socioeconomic factors on post-harvest losses at the farm level. The post-harvest losses (dependent variable) at the farm level were calculated as quintals of output lost per acre (Table 4). One of the independent variables determining post-harvest losses at the farm level was age of the farmers, with a negative and significant coefficient (0.865). The farmer's experience in post-harvest handling grows with age which reduces post-harvest losses. It suggests that growing older has a detrimental impact on post-harvest losses. The variable in the model also took the farmer's number of years of formal education into account. The amount of schooling was negatively correlated (coefficient = -0.166) with post-harvest losses at the farm level. The post-harvest losses on farms diminish with every 1% increase in education because more educated farmers will have better access to information about post-harvest procedures.

One of the factors influencing the magnitude of post-harvest losses at the farm level is the availability of workers at the time of harvest. If the farmer believed he could access the necessary number of man hours at the necessary time to complete harvesting activities, the availability of labour was deemed satisfactory. The dummy variable with value one if the farmer felt there was insufficient labour available for harvesting was used to gauge the level of labour availability. As a result, the variable's coefficient, which was 19.93, indicated that it had a favourable impact on farm-level post-harvest losses. The dummy variable was incorporated into the model that took the value one if the farmer lacked adequate transportation facilities to assess the impact of transportation facilities on post-harvest losses. The post-harvest losses at the farm level were positively and significantly impacted by this variable's coefficient (16.983), indicating that farms with adequate transportation facilities experience fewer post-harvest losses. The farmer had enough transportation if he had no issues with the roads or the mode of conveyance. The dummy variable's negative and significant coefficient (-39.154) for the district demonstrates that, on average, post-harvest losses in Amritsar were much lower than in Patiala. The negative and significant coefficient (-15.772) of dummy variable for farm size categories indicating that the post-harvest losses in medium farm size

Table 3. Percent losses in tomato at different stages of production and marketing

(Per acre in quintals)

Particulars	Patiala district	Amritsar district	Overall
Expected production	395.49	318.32	358.06
Losses at producer level	21.18	18.23	20.86
Total actual production	374.31	300.09	337.20
Total marketed quantity	352.62	281.46	317.04
Losses at commission agent cum wholesaler level	5.97	5.46	5.78
Quantity sold to retailer	346.65	276.00	311.26
Losses at retailer level	3.17	2.90	2.37
Quantity sold to consumer	343.48	273.10	308.89
Total post-harvest losses	30.32	26.59	29.01
% loss at producer level	5.65	6.07	6.18
% loss at traders level	2.60	2.98	2.58
(i) % loss at commission agent cum wholesaler level	1.69	1.93	1.82
(ii) % loss at retailer level	0.91	1.05	0.76
% loss (TPHL)	8.25	9.05	8.76

Table 4. Factors affecting post-harvest losses at farm level

Parameters	Estimates
Intercept	133.120*** (27.899)
Age (years)	-0.865** (0.379)
Education (years)	-0.166 (1.145)
Production (quintals)	0.0108 (0.061)
Farm size (acres)	0.098 (1.376)
Dummy (D_1=1for Amritsar and 0=Patiala)	-39.154* (9.904)
Dummy (D_2=1for large and 0for otherwise)	-12.762 (9.367)
Dummy (D_3=1for medium and 0for otherwise)	-15.772* (8.516)
Labour dummy (1=inadequate,0=adequate)	19.936* (7.417)
Weather dummy(1=inadequate,0=adequate)	4.800 (9.363)
Transportation dummy (1=inadequate,0=adequate)	16.983** (7.748)
R^2	0.25
F-value	5.955***

***, **,*significant at 1,5,10 percent level respectively
Figures in the parentheses indicate the standard error

category was lower than the large farm size category. Nearly 25% of the variation in the total post-harvest losses for tomatoes may be attributed to variations in the independent variables included in the regression model. The F-ratio was significant at one per cent level of significance indicating the goodness of fit of the regression model.

CONCLUSIONS

The pre and post-harvest losses in tomato varied from 0.76 per cent to 6.18 per cent. Maximum losses were observed at producer level (6.18%) followed by commission agent cum wholesaler level (1.82%) and retailer level (0.76%). Throughout different stages of production and marketing, the cumulative post-harvest losses in tomatoes amounted to 8.76 percent respectively. It should be recommended that in order to reduce post harvest losses, the state government/horticulture department should build adequate cold storage facilities for perishable commodities. This will not only minimize the losses but allow better price realization of primary producers. Educating the vegetable growing farmers on scientific post-harvest handling and management including value addition opportunities which will enhance their income and livelihoods. Pest and disease activity accounted for a larger portion of post-harvest losses on farms. More and more small and large processing units must be built in the state in order to reduce post-harvest losses. The farmers need extension services regarding effective post-harvest management techniques. This will enhance their technical proficiency and enable them to manage post-harvest operations with precision.

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Bioaccumulation of Trace Metals in Planktonic *Lucifer* (Crustacea: Decapoda) from Cochin Backwaters

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***Abstract*:** The study explores the bioaccumulation of trace metals like Fe, Ni, Zn, Cu, Cr, Mn, Cd and Pb in water and planktonic *Lucifer* samples that were collected from the Cochin backwaters during the period of March 2017 to January 2019. Significant spatial and seasonal variability for most of the trace metals was detected in water and *Lucifer*. The average concentration of trace metals in *Lucifer* samples analysed follows an order: Fe > Zn > Mn > Cu > Ni > Cr > Pb > Cd whereas the average bioaccumulation factors follow another order: Fe > Cu > Mn > Zn > Cr > Ni > Cd > Pb. *Lucifer* showed a great ability to accumulate metals by several hundred to thousand times, when compared to their concentrations detected in water, in particular for the essential elements Fe, Zn, Mn, Cu, Ni and Cr and for the non-essential metals Pb and Cd. High values of Bioaccumulation factors noted for trace metals in *Lucifer* reveal an enhanced bioavailability of the studied trace metals in the Cochin backwaters.

Keywords: Plankton, *Lucifer*, Trace metals, Bioaccumulation factor, Cochin backwaters

Trace metals are considered as major pollutants due to their bioaccumulation, high toxicity and persistence in aquatic environments (Chen et al 2011, Lee et al 2023). Some of the trace metals, such as iron (Fe), Copper (Cu), chromium (Cr), zinc (Zn), and manganese (Mn), are essential for the metabolism of organisms including plankton (Morel and Price 2003) while others like mercury (Hg), lead (Pb) and cadmium (Cd) are nonessential. All metals are toxic above a threshold bioavailability (Pandey and Madhuri 2014). The toxic effects of trace metals have been detected in a variety of aquatic organisms including plankton (Jakimska et al 2011, Jyothirmaye et al 2022). Plankton plays a major role in the accumulation, transfer and biogeochemical cycling of trace metals in aquatic environments (Baltar et al 2018). Plankton is considered one of the most sensitive indicators of environmental changes and most abundant organisms in the estuary and can accumulate trace metals at relatively high levels. Zooplankton plays a key link in the transfer of trace metals through aquatic food webs (Rejomon et al 2008a, Biju et al 2023). They accumulate trace metals from both dissolved phases and from ingested food (Rejomon et al 2008b). Genus *Lucifer* is a holoplanktonic group of organisms come under the family Luciferidae, and is one of the major constituents in zooplankton communities of the Cochin estuary (Geetha and Antony 2001). The abundance of these epiplanktonic decapodan shrimps serves as indicators of fishing and nursery grounds of prawns and fishes (Arokiasundaram et al 2014). Aquatic edible organisms like fishes are at the top of the aquatic food chain have accumulated trace metals in their tissues may be transferred to humans through fish intake, which could result in chronic or acute illnesses (Sharma and Singh 2022). Trace metal studies in zooplankton communities from the shallow coastal waters of India are very scarce and no previous studies have analysed the concentration of trace metals in the zooplankton group, *Lucifer*, from the Cochin coastal environments. The present study attempts to evaluate the concentration of trace metals like iron, zinc, manganese, copper, nickel, chromium, cadmium and lead in *Lucifer* samples collected from the Cochin estuary.

MATERIAL AND METHODS

Study area: Cochin backwaters, located on the southwest coast of India extend from Cochin to Alappuzha (9° 40.12' N and 10° 10.48'N and 76° 09.52' E and 76° 23.57'E). This backwater system is separated from the Arabian Sea by barrier spits with two permanent tidal inlets one at Cochin and the other at Azhikode. Specific geographic features, anthropogenic activities and the inflow of pollutants from different sources were the major criteria for the selection of sampling stations. Five sampling stations were fixed along the Cochin backwaters (Fig. 1). They are Fort Kochi (S1), the freshwater from the perennial rivers of the Western Ghats meets the Arabian Sea at the Fort Kochi area. High saline water forms a major environmental characteristic of this region. The Cochin Shipyard and Cochin Port Trust as well as various industrial plants and their functioning are in the vicinity of this site; Bolghatty (S2), effluents from chemical factories in the northern zone of the estuaries are discharged into the Periyar River and are mixed into the Bolghatty region of the estuary by tides and freshwater flows; Arookutty (S3), is a receptor of urban sewage as well as effluents from chemical industries discharged into the Chithrapuzha River; Vaikom (S4) is an important fish landing centre in the Kottayam district. Muvattupuzha River drains into the Cochin backwater near Vaikom and carries industrial effluents from the Hindustan newsprint factory; Thanneermukkom north station (S5) located on the northern side of the Thannermukkom bund. This station is located 40 km away from the Fort Kochi. The bund regulates the free flow of water into the Arabian Sea and the intrusion of saline water into the southern sector from post-monsoon till the onset of monsoon.

Sampling: Bimonthly field sampling was carried out from five selected stations during three seasons from March 2017 to January 2019. Standard Protocols were followed for water sample collection and preservation (Strickland and Parsons 1972, APHA 2012). Zooplankton samples were collected using a W.P net (mesh size 200 µm, mouth area 0.6m²).

Trace metal analysis: In the laboratory, sorted *Lucifer* samples were rinsed with Milli-Q water to remove salts. Water adhering to the samples was removed by using good-quality laboratory filter paper. Samples were completely dried

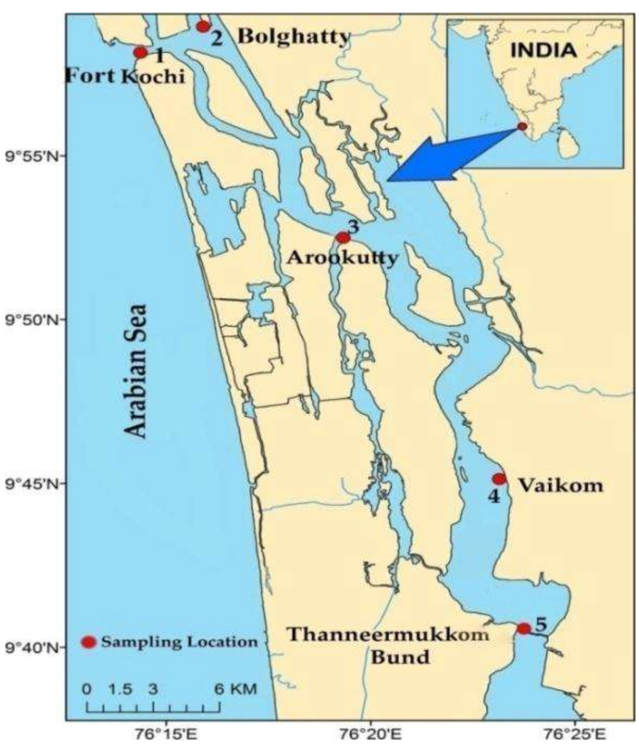

Fig. 1. Sampling stations in the Cochin backwaters

overnight in an oven at 65°C. The dried *Lucifer* samples were first powdered and a portion of about 300 mg was digested for 3 hours at 80°Cwith 3 ml of HNO_3 and 1 ml of $HClO_4$. The digests were made up to 25 mL with Milli-Q water. The concentration of trace metals (Fe, Ni, Zn, Cu, Cr, Mn, Cd and Pb) in *Lucifer* and water samples was determined with an Atomic Absorption Spectrophotometer (Perkin Elmer India Pvt. Ltd; model: PinAAcle 900 H). The water samples were pre-concentrated before spectrophotometer analysis following a standard protocol (Grasshoff et al 1983).

Concentration of trace metal in the sample

$$= \frac{\text{AAS reading} \times \text{Volume of the sample (ml)} \times \text{dilution factor (if any)}}{\text{Dry weight of the sample taken}}$$

Bioaccumulation factor and metal pollution index: The bioaccumulation factor (BAF) is calculated as the ratio of metal present in the organism to the metal present in the surrounding medium (Karlsson et al 2002).

$$BAF = \frac{\text{The mental concentration in organism}}{\text{Metal concentration in the surrounding medium (Water)}}$$

Metal pollution indices (MPI) were calculated following the equation (Usero et al 2005). Here; Cf_1= Concentration of Ist metal, Cf_2= Concentration of IInd metal, Cf_n= Concentration of nth metal.

$$MPI = (Cf_1 \times Cf_2 \ldots \ldots Cf_n)^{1/n}$$

Statistical analysis: Data on trace metal concentrations in *Lucifer* and water were analysed statistically by using the XL-STAT Pro software package. Two-factor without replication analysis of variance (ANOVA) was used to determine seasonal and temporal variations of trace metals in *Lucifer* during the present study.

RESULTS AND DISCUSSION

Trace metals in water : Spatial variation of dissolved Fe, Ni, Zn, Cu, Cr, Mn, Cd and Pb showed distinctive enrichment patterns from stations 1 to 5 (Table 1). The spatial variation of most metals in water showed a higher enrichment in the north estuary (stations 1 and 2) when compared to the south estuary (station 5). The dissolved metals like Fe, Zn, Cu, Mn, and Cd showed higher values (0.85, 0.25, 0.029, 0.044 and 0.011 ppm) at station 2 of the north estuary when compared to other stations (Table 1). Similarly, dissolved metals like Ni and Pb showed higher values (0.061 ppm) at station 1 of the north estuary when compared to other stations. However, dissolved Cr showed a higher value (0.037 ppm) at station 4 of the south estuary when compared to other stations. The increased levels of dissolved metals like Fe, Zn, Cu, Mn and Cd at station 2 (Bolghatty) are probably due to industrial effluent discharges from industries located at Eloor which reaching at this region by tidal currents and freshwater flows through the Periyar River (Rejomon et al 2016, 2021).

Likewise, the pulsed levels of dissolved metals like Ni and Pb at station 1 of the Bar mouth region might be due to the extensive dredging operations, shipyard and port activities at the nearby region (Robin et al 2012, Anas et al 2015). The elevated levels of dissolved Cr at station 4 of the south estuary are possibly due to industrial effluent discharges reaching this region from the Hindustan newsprint factory located at Piravam by tidal currents and freshwater flows through the Muvattupuzha River (Rejomon et al 2012). Elamin et al (2021), observed increased concentration of trace metals in the water and might be due to the large quantities of solid wastes mixed with the wastes of factories, market and industrial wastes that discharge directly or indirectly into the water bodies. The increased levels of dissolved metals noted during non-monsoon seasons (Table 2) can be attributed to their enrichment caused by enhanced evaporation and increased dissolution from bottom-contaminated sediments due to the prevailing higher water column temperature (Rejomon et al 2016). In most of the dissolved trace metal showed significant spatial and seasonal variation ($p \leq 0.05$) at Cochin backwaters (Table 1 and 2).

Trace metals in *Lucifer:* The average concentration of trace metals in studied *Lucifer* samples followed the sequence: Fe > Zn > Mn > Cu > Ni > Cr > Pb > Cd. The high enrichment of trace metals like Fe, Ni, Zn, Cu and Cd in *Lucifer* at station 2 is might be due to the effluent discharges from the nearby chemical industries and domestic sewage inputs in this area from Cochin City through the Periyar River (Rejomon et al 2012, Biju and Rejomon 2020) (Table 3). The high enrichment of trace metals like Fe, Zn and Cr in *Lucifer* at station 1 is due to the influence of effluent discharges associated with port and shipyard activities at this locality (Balachandran et al 2005). A similar high enrichment of trace metal like Mn in *Lucifer* at station 5 is due to the influence of agricultural effluent discharges at this locality from the Kuttanad agricultural fields (Rejomon et al 2013). During the present study, except Cu and Cd all the studied trace metals in *Lucifer* showed significant spatial variations ($p \leq 0.05$) (Table 3). The spatial variability of metals observed in *Lucifer* during the present study laid out emphasis on the hot spot of each metal contamination site that exists in Cochin backwaters.

Metals like Fe, Ni, Zn and Cd in *Lucifer* showed higher values (4029.28 , 38.75, 310.16 and 2.63 ppm respectively) at station 2 and lowest was at station 5 (571.75 , 10.65 and 145.75 ppm) except Cd where the lowest value was at station 4 (1.17 ppm). The highest mean value of Fe and Zi was during monsoon and Ni and Cd was during post- monsoon (Fig. 2). The highest and lowest seasonal Cu concentration in *Lucifer* were at station 1 (61.8 ppm) and station 5 (12.7 ppm) respectively (Fig. 2). Metals like Cr and Mn in *Lucifer*, showed a higher value (38.93 and 88.62 ppm) at station 4 of the central estuary during monsoon and premonsoon periods respectively, and the lowest Cr (12.7 ppm) and Mn (24.1 ppm) at station 5 (Fig. 2). In contrast, Pb concentration in *Lucifer* were peak at station 3 (19.9 ppm) during post-monsoon and the lowest was at station 4 (4.37 ppm) during the pre-monsoon season (Fig. 2). The seasonal variations of Fe, Ni, Zn, Cu, Cr, Mn, Cd and Pb contents in *Lucifer* were statistically significant.

Lucifer has accumulated Fe and Zn in higher concentrations than other metals irrespective of seasons. High Fe concentrations noted in *Lucifer* are due to its function in mitochondria which catalyses redox reactions during respiration (Chen 2011). Zooplankton have accumulated a high amount of zinc as a result of co-precipitating zinc with calcium carbonate (Paimpillil et al 2010). For aquatic animals, diet is the primary source of zinc, and it plays a

Table 1. Average concentration of dissolved trace metals (ppm) in the Cochin backwaters

Trace metals (ppm)	Stations					ANOVA *p*-value
	S1	S2	S3	S4	S5	
Fe	0.680 ± 0.18	0.850 ± 0.26	0.620 ± 0.29	0.570 ± 0.32	0.430 ± 0.18	0.05*
Ni	0.061 ± 0.03	0.056 ± 0.03	0.044 ± 0.02	0.027 ± 0.02	0.015 ± 0.01	0.002**
Zn	0.210 ± 0.06	0.250 ± 0.07	0.200 ± 0.05	0.150 ± 0.07	0.080 ± 0.05	0.000**
Cu	0.025 ± 0.01	0.029 ± 0.01	0.028 ± 0.01	0.024 ± 0.01	0.016 ± 0.01	0.03*
Cr	0.031 ± 0.02	0.029 ± 0.01	0.028 ± 0.01	0.037 ± 0.02	0.029 ± 0.01	0.57
Mn	0.032 ± 0.01	0.044 ± 0.02	0.032 ± 0.01	0.043 ± 0.02	0.036 ± 0.01	0.35
Cd	0.010 ± 0.01	0.011 ± 0.01	0.008 ± 0.01	0.003 ± 0.01	0.003 ± 0.01	0.026*
Pb	0.061 ± 0.01	0.059 ± 0.02	0.035 ± 0.02	0.027 ± 0.01	0.034 ± 0.03	0.007**

* Significant at 0.05 level; ** significant at 0.01 level

significant role in zinc concentration than zinc absorption from seawater (Battuello et al 2016). Wide fluctuation in the bio concentration of metals in the present study is attributed to the trace metals availability in the respective stations. High Cu concentrations noted in *Lucifer* are due to the Cu requirement for respiratory pigment hemocyanin. Mn, Cu, Ni, and Cd concentrations noted during the present quite agree with the Mn, Cu, Ni, and Cd concentrations reported for other groups of zooplankton including *Lucifer* which were based on bioassay studies in laboratory conditions (Subrahmanyam

Table 2. Seasonal variation of dissolved trace metals (ppm) in the Cochin backwaters

Trace metals (ppm)		Stations					ANOVA *p*-value
		S1	S2	S3	S4	S5	
Fe	Pre-monsoon	0.60 ± 0.18	0.97 ± 0.37	0.78 ± 0.34	0.93 ± 0.24	0.54 ± 0.16	0.07
	Monsoon	0.63 ± 0.15	0.66 ± 0.16	0.44 ± 0.14	0.36 ± 0.15	0.37 ± 0.13	
	Post-monsoon	0.82 ± 0.18	0.92 ± 0.16	0.62 ± 0.31	0.41 ± 0.17	0.38 ± 0.23	
Ni	Pre-monsoon	0.04 ± 0.26	0.05 ± 0.23	0.04 ± 0.24	0.02 ± 0.009	0.06 ± 0.01	0.001**
	Monsoon	0.05 ± 0.03	0.03 ± 0.021	0.03 ± 0.02	0.02 ± 0.011	0.01 ± 0.01	
	Post-monsoon	0.09 ± 0.01	0.08 ± 0.01	0.06 ± 0.01	0.04 ± 0.02	0.02 ± 0.01	
Zn	Pre-monsoon	0.25 ± 0.07	0.30 ± 0.08	0.23 ± 0.07	0.18 ± 0.10	0.06 ± 0.04	0.04*
	Monsoon	0.17 ± 0.03	0.20 ± 0.03	0.17 ± 0.02	0.12 ± 0.06	0.12 ± 0.06	
	Post-monsoon	0.21 ± 0.08	0.24 ± 0.05	0.19 ± 0.04	0.14 ± 0.05	0.08 ± 0.06	
Cu	Pre-monsoon	0.02 ± 0.01	0.03 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	0.01 ± 0.01	0.004**
	Monsoon	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.02	
	Post-monsoon	0.04 ± 0.01	0.04 ± 0.02	0.04 ± 0.01	0.03 ± 0.01	0.02 ± 0.02	
Cr	Pre-monsoon	0.03 ± 0.02	0.04 ± 0.02	0.03 ± 0.02	0.05 ± 0.02	0.04 ± 0.02	0.002**
	Monsoon	0.01 ± 0.01	0.01 ± 0.01	0.02 ± 0.01	0.02 ± 0.11	0.01 ± 0.01	
	Post-monsoon	0.05 ± 0.03	0.02 ± 0.01	0.03 ± 0.02	0.04 ±.016	0.03 ± 0.01	
Mn	Pre-monsoon	0.03± 0.01	0.05 ± 0.03	0.04 ± 0.02	0.06 ± 0.02	0.05 ± 0.01	0.02*
	Monsoon	0.02 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	0.01 ± 0.01	0.03 ± 0.02	
	Post-monsoon	0.06 ± 0.01	0.05 ± 0.01	0.03 ± 0.02	0.04 ± 0.01	0.03 ± 0.01	
Cd	Pre-monsoon	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.01	0.014*
	Monsoon	0.01 ± 0.00	0.01 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	
	Post-monsoon	0.01 ± 0.03	0.02 ± 0.02	0.01 ± 0.02	0.01 ± 0.00	0.01 ± 0.00	
Pb	Pre-monsoon	0.07 ± 0.00	0.05 ± 0.01	0.02 ± 0.02	0.03 ± 0.02	0.02 ± 0.01	0.04*
	Monsoon	0.04 ± 0.02	0.05 ± 0.03	0.04 ± 0.03	0.03 ± 0.02	0.03 ± 0.03	
	Post-monsoon	0.07 ± 0.01	0.07 ± 0.01	0.04 ± 0.01	0.03 ± 0.01	0.05 ± 0.04	

* Significant at 0.05 level; **Significant at 0.01 level

Table 3. Average concentration of trace metals (ppm) in *Lucifer* at Cochin backwaters

Trace metals (ppm)	Stations					ANOVA *p*-value
	S1	S2	S3	S4	S5	
Fe	1908.83 ± 1303.60	2531.63 ± 1711.06	1862.84 ± 1042.14	1779.42 ± 864.78	926.07 ± 528.56	0.04*
Ni	25.28 ± 12.96	31.98 ± 10.27	28.02 ± 09.12	22.09 ± 5.25	18.05 ± 8.09	0.04*
Zn	256.81 ± 95.08	263.45 ± 67.02	229.11 ± 69.77	173.33 ± 58.84	173.58 ± 81.60	0.003**
Cu	43.11 ± 18.07	45.07 ± 13.62	36.20 ± 19.87	31.80 ±15.22	28.03 ± 12.05	0.36
Cr	26.03 ± 08.11	23.61 ± 08.37	24.47 ± 10.57	30.64 ± 14.02	18.49 ± 07.44	0.02*
Mn	35.99 ± 09.66	35.96 ± 19.34	38.38 ± 12.25	79.55 ± 41.74	43.03 ± 24.75	0.003**
Cd	1.98 ± 00.51	2.19 ± 00.76	2.10 ± 00.59	1.66 ± 00.57	1.77 ± 00.50	0.04*
Pb	10.50 ± 06.31	11.52 ± 07.31	12.88 ± 06.26	10.86 ± 06.90	11.74 ± 08.08	0.88

* Significant at 0.05 level; **Significant at 0.01 level

1990). Bioaccumulation of metals in zooplankton is reported to be dependent on bioavailability, the amount of dissolved metal absorption, the physiological efficiency of the organism to excrete metals, as well as the feeding rate and prey availability (Chouvelon et al 2019).

Table 4. Average BAF of trace metals in *Lucifer*

Trace metals	Trace metal concentration in *Lucifer* (ppm)	Trace metal concentration in surface water (ppm)	Bioaccumulation factor (BAF)
Fe	1801.76	0.63	2859.93
Ni	25.10	0.04	612.19
Zn	219.25	0.18	1224.86
Cu	36.84	0.03	1473.60
Cr	24.65	0.03	795.00
Mn	46.60	0.04	1259.00
Cd	1.94	0.01	276.00
Pb	11.50	0.04	262.00

Average BAFs and MPI for trace metals in *Lucifer* of Cochin backwaters: The average BAF value of different trace metals in *Lucifer* of Cochin backwater are maximum in Fe: 2859.93, followed by Ni, Zn, Cu, Cr, Mn, Cd and Pb (Table 4). Seasonal variations of BAF for trace metals in *Lucifer* observed at different sites are given in Table 5.

MPI values for *Lucifer* ranged from 23.10 to 34.46, 41.38 to 56.06 and 40.85 to 51.46, respectively, for pre-monsoon, monsoon and post-monsoon periods (Table 6). MPI values of *Lucifer* exhibited higher values during the monsoon period when compared to post-monsoon or pre-monsoon periods. MPI values of *Lucifer* during the pre-monsoon, monsoon and post-monsoon periods showed higher values at station 2 (Bolghatty) when compared to station 5 (Thanneermukkom).

Bioaccumulation factor is a model which considers a ratio of contaminant concentration in biota to its medium of exposure (water) (Battuello et al 2018, Mc Geer et al 2003). This factor gives information about how enriched an organism in a certain trace element with its relation to the

Table 5. Seasonal variations of BAF for trace metals in *Lucifer* observed at different stations at Cochin backwaters

Trace metals (ppm)		Stations				
		S1	S2	S3	S4	S5
Fe	Pre-monsoon	3005.27	1620.61	1354.12	1832.45	1052.95
	Monsoon	3274.32	6063.63	6148.95	5839.99	3531.75
	Post-monsoon	2280.98	2169.35	2910.86	3627.58	2290.37
Ni	Pre-monsoon	449.89	503.06	578.01	1020.93	710.00
	Monsoon	418.99	964.44	1033.85	913.51	2188.94
	Post-monsoon	396.98	457.50	526.44	668.42	976.54
Zn	Pre-monsoon	786.74	737.77	725.46	826.83	2322.71
	Monsoon	1794.99	1513.01	1374.04	1665.60	1690.66
	Post-monsoon	1274.97	1064.11	1387.27	1212.35	2484.62
Cu	Pre-monsoon	1016.18	1700.59	584.49	912.58	1667.51
	Monsoon	3572.25	2403.64	1971.68	2557.91	1978.94
	Post-monsoon	1247.71	909.31	1496.43	929.82	1636.36
Cr	Pre-monsoon	71.00	485.64	432.69	386.53	282.22
	Monsoon	2641.67	1848.28	1961.08	2017.49	1322.54
	Post-monsoon	497.03	824.02	764.30	756.61	616.07
Mn	Pre-monsoon	1294.12	604.46	763.21	1423.70	769.12
	Monsoon	1509.9	1681.83	2171.55	3314.85	2630.00
	Post-monsoon	847.68	471.64	1069.97	1613.75	759.06
Cd	Pre-monsoon	115.86	139.67	267.86	392.50	498.67
	Monsoon	758.33	531.25	531.25	812.50	812.50
	Post-monsoon	156.73	164.06	164.11	543.75	549.38
Pb	Pre-monsoon	145.71	89.18	266.81	159.85	378.27
	Monsoon	177.65	268.72	331.148	488.51	445.60
	Post-monsoon	193.49	222.26	443.50	509.92	258.12

Table 6. Seasonal variation of metal pollution index (MPI) in *Lucifer* at Cochin backwaters

Seasons	Stations				
	S1	S2	S3	S4	S5
Pre-monsoon	34.17	34.46	27.70	32.08	23.10
Monsoon	44.37	56.06	47.25	46.54	41.38
Post-monsoon	42.66	51.46	46.26	45.47	40.85

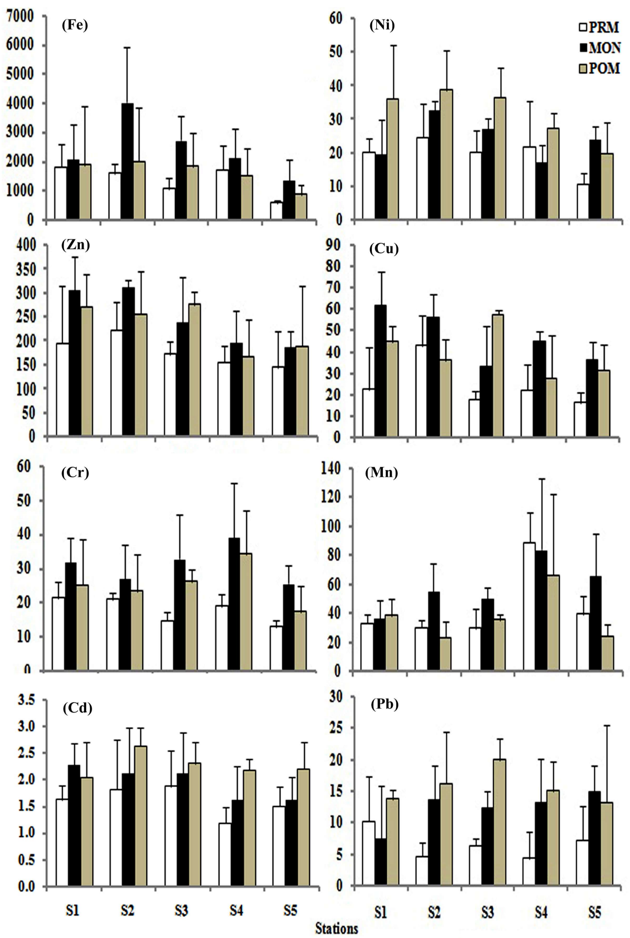

Fig. 2. Seasonal variations of trace metal (ppm) concentrations in *Lucifer* at Cochin backwaters

surrounding medium. The average BAFs in *Lucifer* were in the following order: Fe > Cu > Mn > Zn > Cr > Ni > Cd > Pb. The observed BAFs of each metal remained >100 which indicates that the *Lucifer* has a strong ability to bioconcentrate metals effectively. The high concentrations of metals and high bioaccumulation values indicate that the studied zooplankton group, *Lucifer* has an enormous capacity for the accumulation of trace metals and are thus potentially excellent bioindicator for the evaluation of the contamination of estuarine ecosystems by metals (Rejomon et al 2008a, 2010, Achary et al 2020). The high enrichment of MPI values at station 2, when compared to station 5 of the estuary, could be due to the effluent discharges in this area from the industries that are located at the downstream regions of the river Periyar.

CONCLUSION

Bioaccumulation of trace metals in *Lucifer* collected from the Cochin backwaters showed marked spatial and seasonal variations. *Lucifer* showed a great ability to accumulate metals when compared to their concentrations detected in water. High values of Bioaccumulation factors for trace metals in *Lucifer* reveal an enhanced bioavailability of the studied trace metals in the Cochin backwaters. The high concentrations of metals and high bioaccumulation values indicate that *Lucifer* has an enormous capacity for the accumulation of trace metals and are thus potentially excellent bioindicator for the evaluation of the contamination of estuarine ecosystems by metals.

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