INDIAN JOURNAL OF *ECOLOGY*

ISSN 0304-5250

Volume 49 Issue-2 April 2022

THE INDIAN ECOLOGICAL SOCIETY

The Indian Journal of Ecology is an official organ of the Indian Ecological Society and is published bimonthly in February, April, June, August, October and December. Research papers in all fields of ecology are accepted for publication from the members. The annual and life membership fee is Rs (INR) 800 and Rs 8000, respectively within India and US $ 100 and 350 for overseas. The annual subscription for institutions is Rs 8000 and US $ 300 within India and overseas, respectively. All payments should be in favour of the Indian Ecological Society payable at Ludhiana. See details at web site. The manuscript registration is Rs 500.

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Indian Journal of Ecology (2022) 49(2): 313-323
DOI: https://doi.org/10.55362/IJE/2022/3523

Manuscript Number: 3523
NAAS Rating: 5.79

Application of Geoinformatics with Frequency Ratio (FR) Model to Delineate Different Groundwater Potential Zones in Ken Basin, India

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Abstract: The goal of present study was to make groundwater potential zones map using the frequency ratio (FR) model (i.e., probabilistic based bivariate statistical approach) and Geoinformatics technique in Ken Basin, India. Very few studies have been done yet to demarcate the groundwater potential zones using FR model in India. This research contains the analysis of spatial relationships between groundwater and its contributing factors viz., geology, geomorphology, lineament density, land use/ land cover, soil texture, rainfall, slope, drainage density, depth to water level – pre monsoon and depth to water level – post monsoon. The ten groundwater contributing factors were collected from different resources and prepared in 10 m spatial resolution in ArcGIS 10.8.There are 425 observation wells located in the study area, out of these, 296 (70%) observation wells were randomly selected as training datasets for the model and the remaining 129 (30%) were used as a training dataset for the validation purpose. The final output of groundwater potential zones map was classified into five different zones as very high, high, moderate, low, and very low. A more significant portion of the Ken Basin, nearly 30.66%, falls within the moderate groundwater potential zone followed by poor and good potential zones. For quantitative validation, ROC curve analysis was executed through the IBM SPSS software by comparing existing groundwater well locations in the validation datasets (well yield data) with the groundwater potential map obtained by the FR model. The validation results illustrated that the area under the curve (AUC) for the frequency ratio model is 78.1% which achieved fair satisfactory prediction accuracy. The outcome of this study is highly reliable which can serve as a guideline for the planning of exploration, exploitation, and sustainable management of groundwater resources in the study area.

Keywords: Groundwater potential zones, Frequency ratio, Geoinformatics, Ken Basin

Water is the essential resource of all living things and it ought to be accessible adequately for all the required demands like domiciliary, agriculture, manufacturing & engineering, recreational and environmental needs. Groundwater is one of the most valuable natural resources which support human health and economic development. As a result of its constant accessibility and excellent natural quality, groundwater turns into a significant source of water supply in several rural and urban areas of the world (Todd and Mays 2005). Groundwater is a hidden natural resource that cannot be directly distinguished, consequently, mapping of this asset could be a challenging task. Illustration of groundwater potential zones (GPZs) is essential for the optimum utilization of accessible water resources to address the needs of the communities (Etikala et al 2019).

The unsustainable management of groundwater resources is transforming into an evident problem for many developing countries (Hussein et al 2017). The unavailability of updated spatial information on the volume and movement of groundwater isa huge problem in the sustainable management of groundwater. Presently days, there is a solid need to utilize groundwater for the socio-economic advancement in the country, especially for rustic regions. As well as practical knowledge of groundwater potential assessment should be required before exploitation and managing it. Presently, the Geoinformatics technique (an RS & GIS integrated approach) is becoming a powerful tool for the assessment of earth's natural resources. The assessment of groundwater potential zones mapping is less time taking and very cost-effective using these techniques. These geoinformatics approaches make the analysis easier as compared to conventional methods like ground drilling, geophysical assessment of lineament features, and field observations. In earlier years, various types of studies have been accomplished through the implementation of different multi-criteria decision making approaches. Most of the researchers have endeavoured to demarcate the groundwater potential zoning maps viamulti influencing factors and the AHP method around the world. FR model has been widely used for the assessment of landslide susceptibility mapping. A very few works are found to demarcate the groundwater potential zones using the frequency ratio model (Das and Pardeshi 2018, Prasad et al 2020, Arjun KC et al 2021). All these approaches are taken by various researchers for groundwater investigation, which are simpler, cost, and time saving.

Due to the highly variable geological conditions in the Ken Basin, groundwater potential mapping is more complex and challenging. However, the demarcation of the groundwater potential areas in the Ken Basin is still not studied well. Hence, an attempt has been made in this study to demarcate different groundwater potential areas in Ken Basin by using the Frequency Ratio model with the help of geoinformatics techniques.

MATERIAL AND METHODS

Study area: The Ken River Basin is an interstate river between Madhya Pradesh and Uttar Pradesh. The total length of the river from its origin place to confluence point with the river Yamuna is 427 km, out of which 292 km lies in Madhya Pradesh, 84 km in Uttar Pradesh and 51 km forms the common boundary between Madhya Pradesh and Uttar Pradesh. The study area extends over approximately of 28,671 km^2, and lies between 23°07' – 25°51' N latitudes and 78°30'-80°38' E longitudes. The Ken River originates near the Ahirgawan village on the north-west slopes of Barner Range in Katni district and confluence in Yamuna River at Chilla village, Banda district in Uttar Pradesh. About 86.73% area of this basin lies in Madhya Pradesh and the remaining 13.27% of the area lies in Uttar Pradesh. The basin covers eight districts (i.e., Katni, Sagar, Damoh, Chhatarpur, Panna, Satna, Narsinghpur, & Raisen) of Madhya Pradesh and three districts (i.e., Hamirpur, Mahoba, and Banda) of Uttar Pradesh. It is bounded by Vindhyan range in the south, Betwa basin on west, a free catchment of Yamuna below Ken on east, and the river Yamuna on north. The important tributaries of Ken Basin are Alona, Bearma, Sonar, Mirhasan, Shyamari, Banne, Kutni, Urmil, Kail, and Chandrawal. Ken Basin consists of central high lands of Vindhyan and Bundelkhand region. The Vindhyans have sedimentary rocks, granites, and alluvium whereas Bundelkhand have granite gneisses. The 10 years (2011-2020) average annual rainfall in the basin is 1050 mm. The average maximum and minimum temperatures are 44.2°C and 6.7°C respectively.

Data collected: Satellite imageries of SENTINEL-2B, (10 m spatial resolution) were downloaded from Earth Explorer portal of USGS having data acquisition of February 2021. Digital Elevation Model (DEM) of Shuttle Radar Topography Mission (SRTM) (30 m spatial resolution) was also acquired from USGS Earth Explorer. SRTM DEM data were used to prepare basin map of Ken River through ArcSWAT tool in ArcGIS 10.8 software as well as drainage density and slope map. The vector data on geomorphology and lineament at 1:250,000 scale and geology at 1:50,000 scale was derived from Bhukosh portal of the Geological Surveyof India. Average monsoon rainfall data (0.25 x 0.25 degree gridded data) for the year 2020 were collected from India Meteorological Department (IMD) website. The data on soil parameters at 1:500,000 scale was acquired from the National Bureau of Soil Survey and Land Use planning (NBSS&LUP), Nagpur to prepare a soil texture map. Observation Wells (POWs) data of Ken Basin was obtained from State Ground Water Data Center, Bhopal and Ground Water Department, Lucknow.

Primarily, ArcSWAT model was employed to delineate the Ken Basin map using SRTM DEM (30 m spatial resolution) in ArcGIS 10.8 environment. Also, the Drainage map, Drainage Density map, and Slope map were organized by analysing the SRTM DEM data. After acquisition of geology, geomorphology, and lineament data from Bhukosh portal of GSI, these data were rectified and then employed in ArcGIS 10.8. After the construction of lineament map, line density tool was employed to prepare lineament density map. Soil texture map was prepared using the digitization technique in GIS environment with the help of soil texture data map sheets acquired from NBSSLUP. The rainfall gridded data of the year 2020 was obtained from IMD, Pune, and prepared monsoon rainfall map of Ken Basin. Also, the Observation Wells (OWs) data of Ken Basin were acquired from both the GW centers and prepared pre and post depth to water level maps using IDW tool in ArcGIS environment. Sentinel-2B imagery of 10 m spatial resolution was considered in this study for the making of a land use/ land cover (LULC) map of Ken Basin using ERDAS IMAGINE 2020 software. As well as, the accuracy assessment was employed for land use/ land cover and calculated kappa coefficient using ArcGIS 10.8.

The collected thematic data which was primarily not in projected system was projected in WGS_1984_UTM_ Zone_44N projected coordinate system (PCS) using ArcGIS 10.8 software. Vector data of the different theme were converted to raster form using spatial analyst tool in GIS environment. Line density conversion tool was considered to converting polyline to raster data format. As ever, all the raster dataset of different groundwater contributing themes were prepared, these data were reclassified based on the utility and then exported into 10 m x 10 m cell size raster data for further integration analysis for Groundwater Potential Zoning using Frequency Ratio model. After the making of Groundwater Potential Zones map, the Receiver Operating Characteristics (ROC) method was employed for the validation purpose to estimate area under curve (AUC) considering observation wells (training data set) and groundwater potentiality zones. The overall methodology adopted in the current study are shown in Figure. 2.

Frequency ratio model: Frequency ratio model can be characterized as the possibility of event of a specific factor (Bonham-carter, 1994).The value of frequency ratio of a certain factor can be simply determined using the following equation:

$$FR = \frac{\left(\frac{W_x}{W_y}\right)}{\left(\frac{A_x}{A_y}\right)} = \frac{W}{A} \qquad (1)$$

Where,

Wx = number of observation wells exists in each class of certain factor

Wy = total number of observation wells exists in the study area

Ax = area covered by each class of certain factor (sq km)

Ay = total area of the study area (sq km)

W = percentage of observation wells

A = percentage of area

FR = value of frequency ratio of a class for the certain factor

If the FR value is lesser than 1 that shows to lower importance of the groundwater potentiality and a value greater than 1 depicts more importance of the groundwater potentiality.

To prepare the groundwater potential zones map, all the groundwater governing factors with their frequency ratio values were integrated in ArcGIS 10.8 and summed using the below given expression:

$$GPZ = \sum_{i=1}^{n} FR$$

$$= GL_{FR} + GM_{FR} + LD_{FR} + LULC_{FR} + ST_{FR} + RF_{FR} + SL_{FR} + DD_{FR} + DTWL\_Pre_{FR} + DTWL\_Post_{FR} \qquad (2)$$

Where,

GPZ = groundwater potential zones

GL_{FR} = reclassified layer of geology using FR values

GM_{FR} = reclassified layer of geomorphology using FR values

LD_{FR} = reclassified layer of lineament density using FR values

$LULC_{FR}$ = reclassified layer of land use/ land cover using FR values

ST_{FR} = reclassified layer of soil texture using FR values

RF_{FR} = reclassified layer of rainfall using FR values

SL_{FR} = reclassified layer of slope using FR values

DD_{FR} = reclassified layer of drainage density using FR values

$DTWL\_Pre_{FR}$ = reclassified layer of depth to water level-pre monsoon using FR values

$DTWL\_Post_{FR}$ = reclassified layer of depth to water level-post monsoon using FR values

To perform FR model, a total number of 296 observation wells were randomly selected as training datasets for the model and the remaining 129 observation wells were used as a training dataset for the validation purpose.

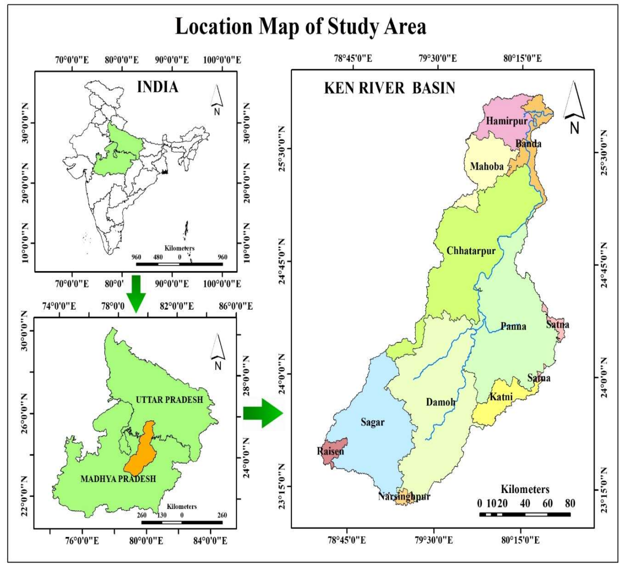

Fig. 1. Location map of Ken Basin

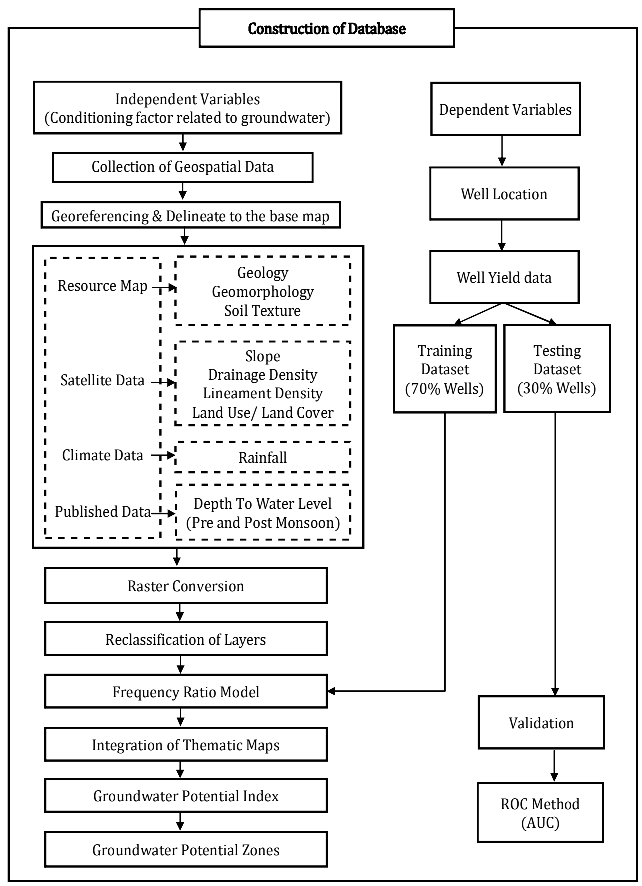

Fig. 2. The overall methodology adopted in the current study

RESULTS AND DISCUSSION

Assessment of Factors Contributing to Groundwater Potential

Geology: Geology Map of the Ken Basin was prepared using the raw gridded vector data of Geology (scale of 1:50,000) downloaded from Bhukosh portal of Geological Survey of India. The geology of the study area has been comprised mainly of ten major groups which are given as below: Alluvium, Bhander, Bijawar, Bundelkhand Granite Complex, Kaimur, Lameta, Laterite, Malwa, Rewa, and Semri group.Bhander group covered most of the area of Ken Basin.

Geomorphology: The raw vector data of Geomorphology (scale of 1:250,000) was downloaded from the Bhukosh portal of GSI. Ken Basin is covered by various types of geomorphological features such as alluvial plain, flood plain, dissected hills and valleys, pediment pediplain complex, piedmont undulating upland, etc. Ken basin is mostly covered by pediment pediplain complex.

Lineament density: Lineaments play a vital role in the recharge process of groundwater in hard rock territories. Vector data of Lineaments (scale of 1:250,000) was downloaded from Bhukosh portal of Geological Survey of India. This data has been clipped by the Shape file of Ken River Basin. Used the clipped lineament file and applied the line density tool in ArcGIS 10.8 software. Then, the Lineament Density map has been finalized. Lineaments on a surface level have been perceived early as conduits for groundwater flow in fractured aquifers and henceforth it will be helpful to focus on the area of creation wells. The lineament density is high in the southern and central parts of the Ken Basin.

Land use/ land cover: LU/LC influences evapotranspiration volume, duration, and recharge of the groundwater system. The false color composite (FCC) image was prepared using Sentinel-2B imagery with a band combination of 2,3,4 and 8. Then the satellite image was classified by the onscreen visual interpretation technique, based on the available auxiliary data, previous knowledge, and appropriate ground truth points using ERDAS IMAGINE®2020 software. After the visual interpretation, six major classes were identified, viz. water bodies, agricultural land, forest, grasslands, wasteland, and built-up. Then, the area of interests (AOI) of all classes was prepared and further recoded on the unsupervised classified image. Finally, classified raster output was used as LULC map. Accuracy assessment of land use/ land cover was accomplished and overall accuracy was calculated as 92.0%.

Soil texture: Different soil map sheets with scale of 1:5,00,000 of Ken River Basin has been geo referenced in ERDAS IMAGINE 2020 and then digitization was done in ArcGIS 10.8 software. Soil texture map has been finalized. Most of the area of Ken River Basin is covered by the loamy soil and very least area comes under the silty soils.

Rainfall: The rainfall factor plays a key role in the groundwater recharge system which surface water infiltrates into subsurface media by fractures and soils. About 90% of the rainfall occurs from June to September. The Ken basin is fed by south-west monsoon which starts from mid of June and lasts till the end of September. The spatial map of monsoon rainfall has been prepared using ArcGIS 10.8 software. The monsoon rainfall found ranges between 572.72 to 1225.53 mm in the year 2020 over the study area. The decreasing trend of rainfall pattern demonstrates from south to north within the basin.

Slope: The slope is also an important factor in groundwater prospect mapping which influences the runoff because of its direct proportionality. Groundwater recharge will be less in steep slope due to increasing of runoff and decreasing percolation & infiltration. Commonly, in gentle slopes, groundwater recharge will be more because of greater infiltration and percolation. A slope map of Ken Basin was prepared using the SRTM DEM data by slope tool under spatial analysis tool in ArcGIS 10.8 software. Most parts of the study area have slopes within the range of 103 percentage.

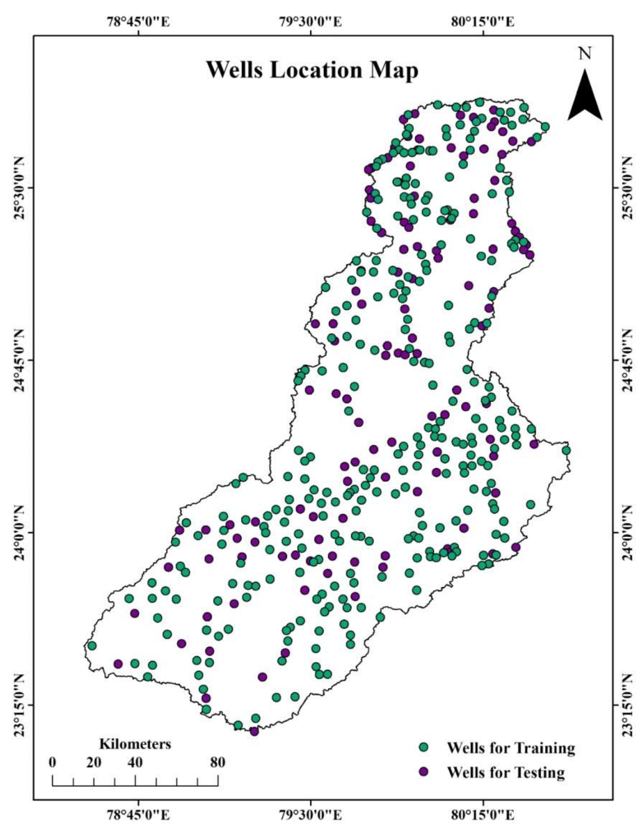

Fig. 3. Well location map of Ken Basin, India

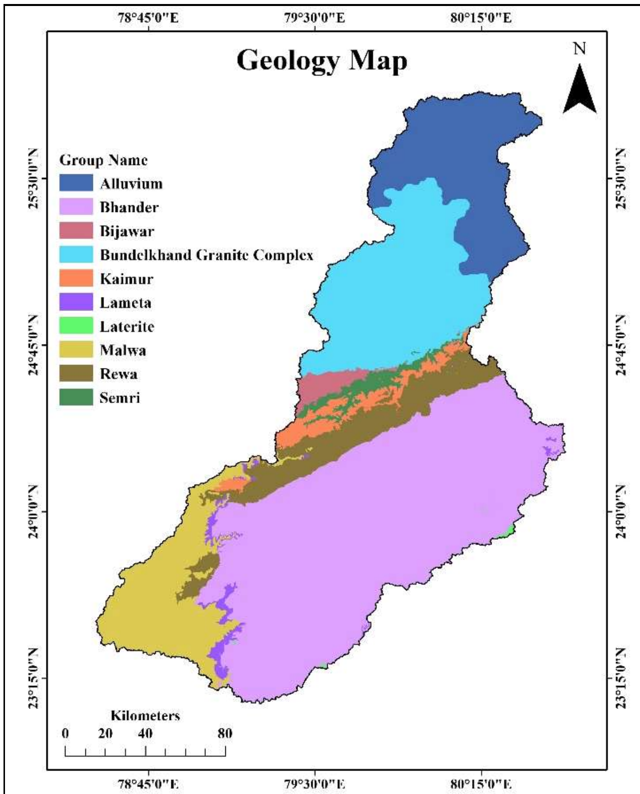

Fig. 4. Geology map of the Ken Basin

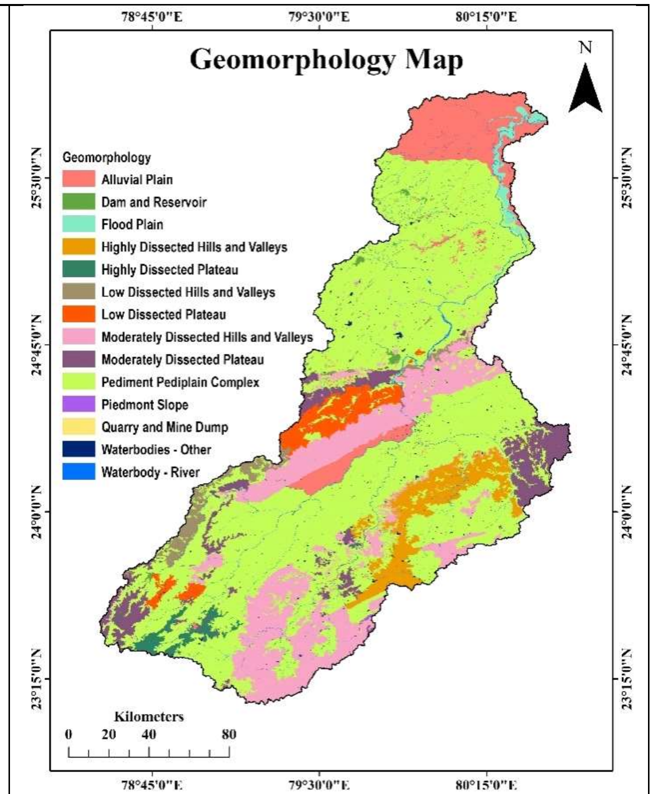

Fig. 5. Geomorphology map of the Ken Basin

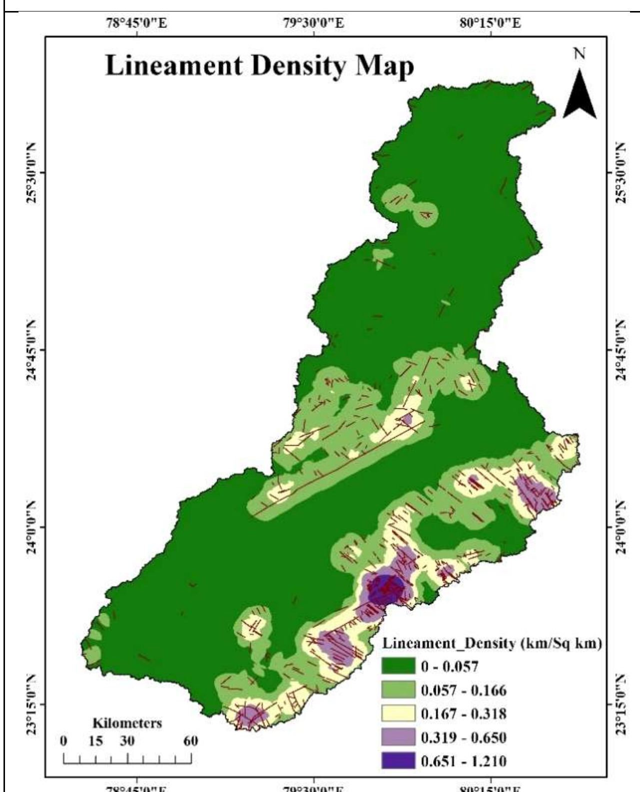

Fig. 6. Lineament density map of the Ken Basin

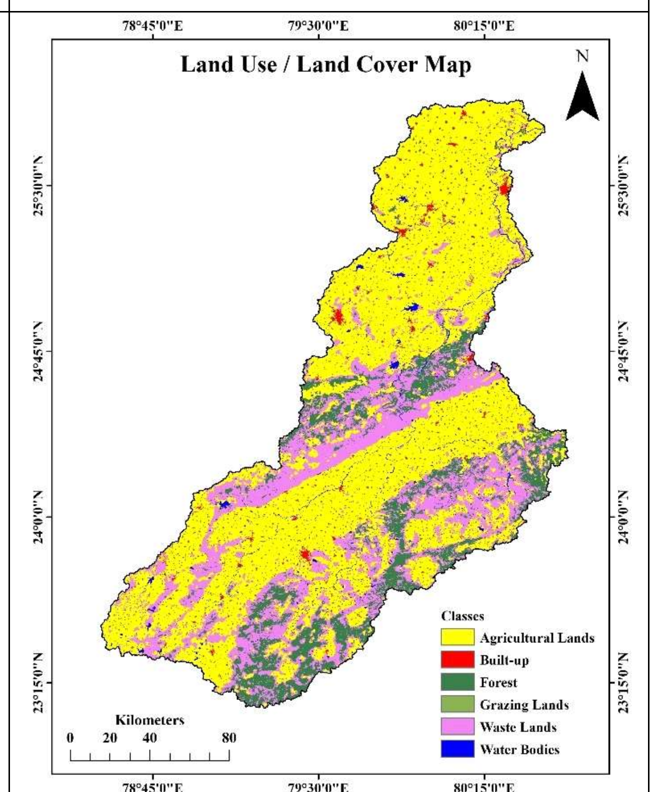

Fig. 7. Land use/ land cover map of the Ken Basin

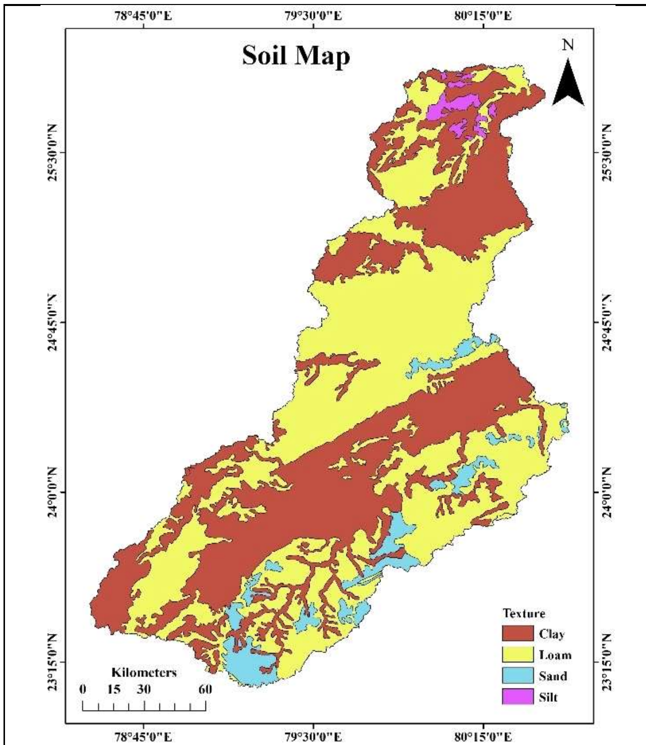

Fig. 8. Soil texture map of the Ken Basin

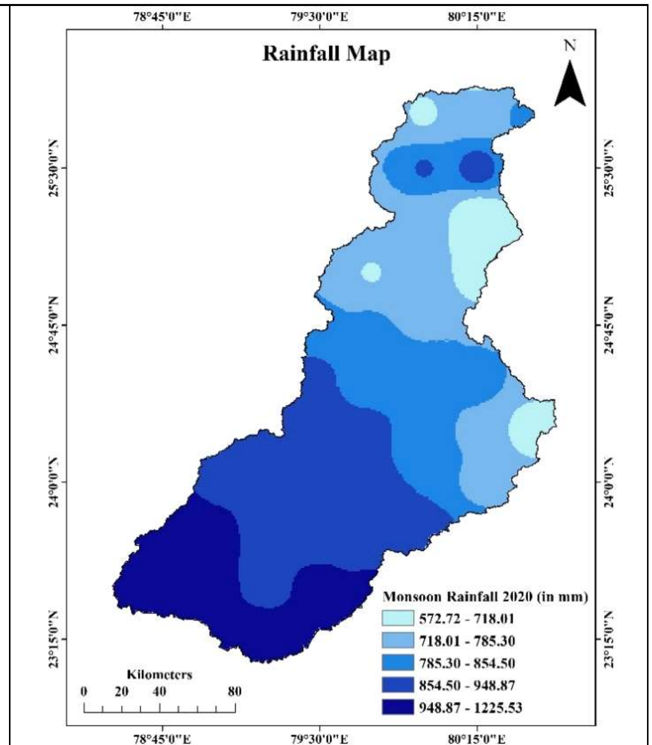

Fig. 9. Rainfall map of the Ken Basin

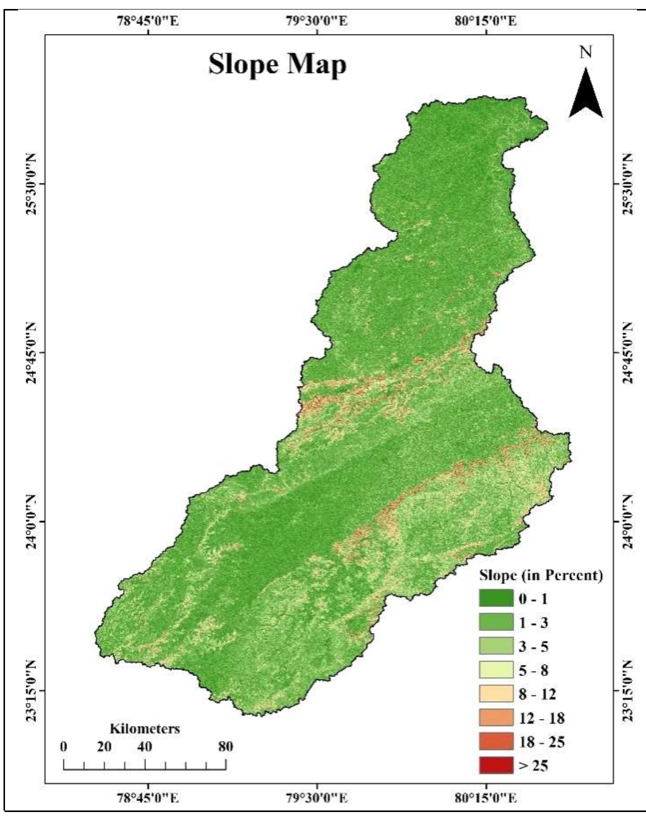

Fig. 10. Slope map of the Ken Basin

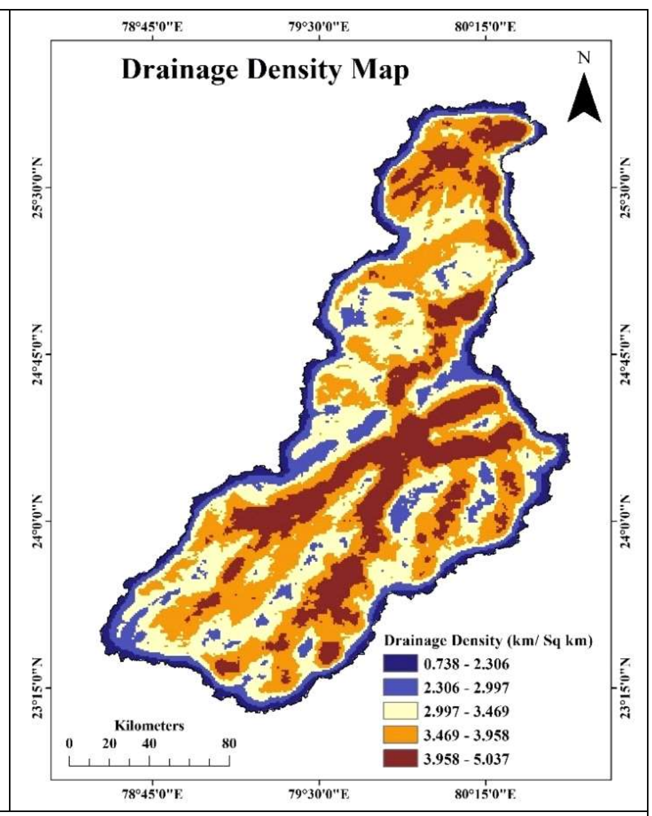

Fig. 11. Drainage Density map of the Ken Basin

Southern part of the Ken Basin displays a steeper slope, whereas the northern parts are associated with lower slopes.

Drainage density: Drainage of Ken Basin was produced from SRTM DEM data and verified with the Survey of India toposheets (scale of 1:50,000). Drainage density of the study area in km/km^2 was calculated by line density tool under spatial analyst tool in ArcGIS 10.8 software. The drainage pattern in the area was dendritic & pinnate type and the southern portion of the Ken Basin is associated with very high drainage density. About 40% of the area upstream of the medium drainage density. The higher the drainage density, the lower is the infiltration and the faster is the movement of the surface flow. The drainage density in the study area was found to range from 0.738 to 5.037 km/km^2.

Depth to water level – pre monsoon: The depth to water level map for pre-monsoon was produced by the inverse distance weighting (IDW) interpolation technique using ArcGIS 10.8. In Pre-monsoon season, depth to water level within the study area ranges between 1.11 to 27.59 m bgl. Broadly, Shallow groundwater levels indicate high groundwater potentiality whereas the deeper groundwater level shows fewer groundwater potential zones. This parameter is important for the groundwater potential zone.

Depth of water level – post monsoon: The depth to water level map of post-monsoon was also generated by the inverse distance weighting (IDW) interpolation method using ArcGIS 10.8 software. During the post-monsoon season, depth to water level within the study area varies 1.0 to 26 m bgl. In the post monsoon season, water level depth in the wells nearby the lineaments rises considerably. The depth to water level map of post-monsoon is more reliable factor to understanding the groundwater recharge in any area. After the preparation of thematic maps, training data (296 observation wells) was overlaid on each theme and the percentage of wells in every class (or category) of each factor was estimated. The area and the percentage of area for each class of each factor were calculated. Then FR value was calculated for every class of each theme by the ratio of the percentage of observation wells to the percentage of area in the basin. Frequency Ratio values of different thematic layers and their attributes were illustrated in given Table 1.

Development of groundwater potential zones: Once the FR values were obtained, all the thematic layers with their attributes were reclassified by FR values through ArcGIS 10.8 software. All the reclassified raster themes were integrated using the raster calculator tool in ArcGIS 10.8 ® environment and summed using equation 2. Resulted Groundwater Potential Index (GPI) was found ranging from 1.39 to 4.37.High GPI denotes high groundwater potentiality whereas low GPI depicts low groundwater potentiality. The GPI was classified into five different groundwater potential zones using Natural Jenks Classification method. The study

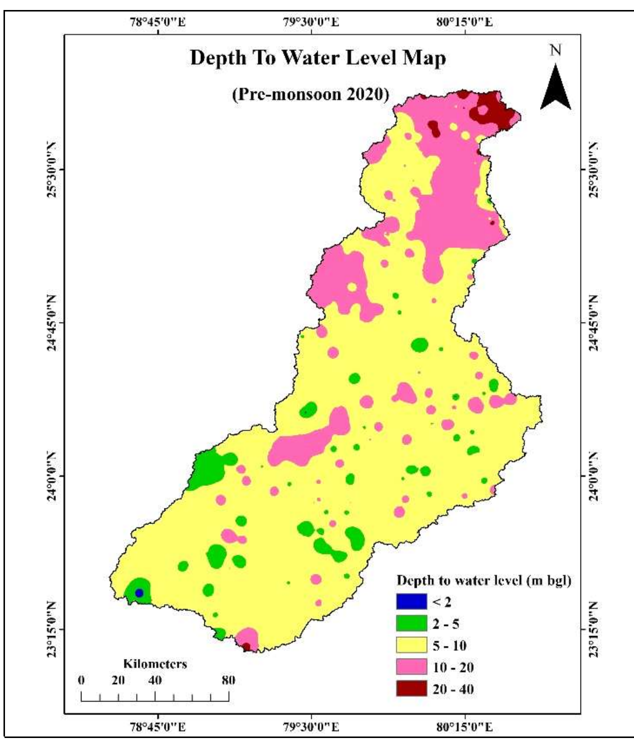

Fig. 12. Depth to water level – pre monsoon map of the Ken Basin

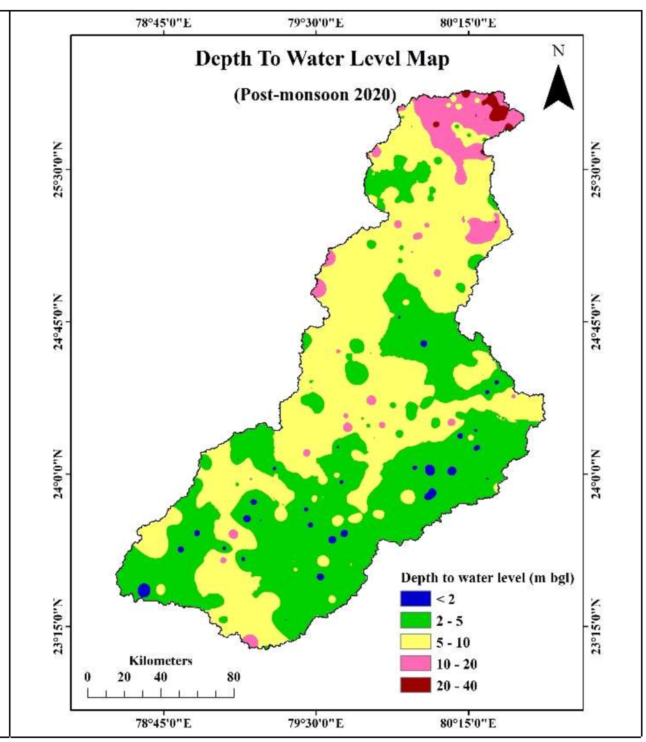

Fig. 13. Depth to water level – post monsoon map of the Ken Basin

Table 1. Frequency ratio values of different thematic layers and their attributes

Factors / Themes	Classes / Ranges	No. of wells	Total no of wells	% of wells	Area (km^2)	Total area (km^2)	% of area	FR value
Geology	Alluvium	56	296	18.919	3730.023	28671	13.010	1.454
	Bundelkhand Granitoid Complex	56	296	18.919	4999.094	28671	17.436	1.085
	Bijawar	1	296	0.338	352.646	28671	1.230	0.275
	Semri	1	296	0.338	462.374	28671	1.613	0.209
	Kaimur	2	296	0.676	766.588	28671	2.674	0.253
	Rewa	13	296	4.392	2186.252	28671	7.625	0.576
	Malwa	24	296	8.108	2950.570	28671	10.291	0.788
	Bhander	142	296	47.973	12849.619	28671	44.817	1.070
	Lameta	1	296	0.338	340.538	28671	1.188	0.284
	Laterite	0	296	0.000	33.297	28671	0.116	0.000
Geomorphology	Alluvial plain	40	296	13.514	2189.002	28671	7.635	1.770
	Dam and reservoir	1	296	0.338	70.842	28671	0.247	1.367
	Flood plain	4	296	1.351	277.497	28671	0.968	1.396
	Highly dissected hills and valleys	5	296	1.689	1316.055	28671	4.590	0.368
	Highly dissected plateau	2	296	0.676	312.419	28671	1.090	0.620
	Low dissected hills and valleys	5	296	1.689	530.451	28671	1.850	0.913
	Low dissected plateau	2	296	0.676	846.640	28671	2.953	0.229
	Moderately dissected hills and valleys	16	296	5.405	4519.933	28671	15.765	0.343
	Moderately dissected plateau	2	296	0.676	1657.014	28671	5.779	0.117
	Pediment pediplain complex	215	296	72.635	16528.139	28671	57.648	1.260
	Piedmont slope	0	296	0.000	5.595	28671	0.020	0.000
	Quarry and mine dump	0	296	0.000	1.468	28671	0.005	0.000
	Waterbodies-Other	2	296	0.676	129.264	28671	0.451	1.499
	Waterbody - River	2	296	0.676	286.681	28671	1.000	0.676
Lineament Density (km/ km^2)	0.000 - 0.056	222	296	75.000	18968.603	28671	66.160	1.134
	0.056 - 0.166	54	296	18.243	6172.920	28671	21.530	0.847
	0.166 - 0.317	15	296	5.068	2418.630	28671	8.436	0.601
	0.317 - 0.650	5	296	1.689	933.886	28671	3.257	0.519
	0.650 - 1.210	0	296	0.000	176.961	28671	0.617	0.000
Land use / land cover	Water bodies	2	296	0.676	351.189	28671	1.225	0.552
	Forest	6	296	2.027	3191.585	28671	11.132	0.182
	Grazing lands	0	296	0.000	1.035	28671	0.004	0.000
	Agricultural lands	219	296	73.986	17363.506	28671	60.561	1.222
	Waste lands	23	296	7.770	6862.150	28671	23.934	0.325
	Built-up	46	296	15.541	901.504	28671	3.144	4.942
Soil texture	Clayey soil	167	296	56.419	13446.139	28671	46.898	1.203
	Loamy soil	121	296	40.878	13807.438	28671	48.158	0.849
	Sandy soil	8	296	2.703	1387.604	28671	4.840	0.558
	Silty soil	0	296	0.000	29.819	28671	0.104	0.000
Monsoon rainfall (mm)	572.72 - 718.01	14	296	4.730	1919.886	28671	6.696	0.706
	718.01 - 785.30	99	296	33.446	6837.454	28671	23.848	1.402
	785.30 - 854.50	68	296	22.973	6262.335	28671	21.842	1.052
	854.50 - 948.87	79	296	26.689	8528.477	28671	29.746	0.897
	948.87 - 1225.53	36	296	12.162	5122.847	28671	17.868	0.681

Cont...

Table 1. Frequency ratio values of different thematic layers and their attributes

Factors / Themes	Classes / Ranges	No. of wells	Total no of wells	% of wells	Area (km^2)	Total area (km^2)	% of area	FR value
Slope (%)	0 - 1	60	296	20.270	4163.355	28671	14.521	1.396
	1 - 3	103	296	34.797	9016.265	28671	31.447	1.107
	3 - 5	73	296	24.662	6681.979	28671	23.306	1.058
	5 - 8	39	296	13.176	4661.162	28671	16.257	0.810
	8 - 12	14	296	4.730	2027.528	28671	7.072	0.669
	12 - 18	4	296	1.351	1056.904	28671	3.686	0.367
	18 - 25	2	296	0.676	488.829	28671	1.705	0.396
	> 25	1	296	0.338	574.979	28671	2.005	0.168
Drainage density (km/ km^2)	0.738 - 2.306	37	296	12.500	2174.224	28671	7.583	1.648
	2.306 - 2.997	32	296	10.811	4366.489	28671	15.230	0.710
	2.997 - 3.469	64	296	21.622	8588.034	28671	29.954	0.722
	3.470 - 3.958	102	296	34.459	8699.349	28671	30.342	1.136
	3.958 - 5.037	61	296	20.608	4842.904	28671	16.891	1.220
Depth to water level – pre monsoon (m bgl)	< 2	5	296	1.689	23.638	28671	0.082	20.489
	2 - 5	39	296	13.176	1348.632	28671	4.704	2.801
	5 - 10	162	296	54.730	21487.381	28671	74.945	0.730
	10 - 20	78	296	26.351	5455.830	28671	19.029	1.385
	20 - 40	12	296	4.054	355.519	28671	1.240	3.269
Depth to water level – post monsoon (m bgl)	< 2	29	296	9.797	264.721	28671	0.923	10.611
	2 - 5	117	296	39.527	12798.282	28671	44.638	0.885
	5 - 10	115	296	38.851	13804.663	28671	48.149	0.807
	10 - 20	26	296	8.784	1657.123	28671	5.780	1.520
	20 - 40	9	296	3.041	146.211	28671	0.510	5.962

area under the very poor, poor, moderate, good and very good zones contributing to 3157.82 km^2, 7497.75 km^2, 8789.82 km^2, 2032.30 km^2, and 7193.31 km^2. The Groundwater Potential Zones map of Ken Basin is shown in Figure 14.

Validation of groundwater potential zones: The area under curve (AUC) of ROC shows the accuracy of a prediction system by representing the model's capability to correctly or incorrectly identify the successful event. In ROC method, the AUC ranges from 0.5 to 1 which 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 (excellent) (Yesilnacar 2005). Well Yield data of the Testing dataset (30% Wells) has been superimposed on the GPZ raster data in the ArcGIS Platform for validation purposes. Groundwater Potential Zones has been verified with well yield data and a prepared table that includes true data and false data for each well. Sensitivity has been calculated using POWs Groundwater Yield data with their classes. After that, 1-Specificity has been calculated using the Groundwater Potential Zones data with their classes. IBM SPSS software was used to calculate the area under curve.

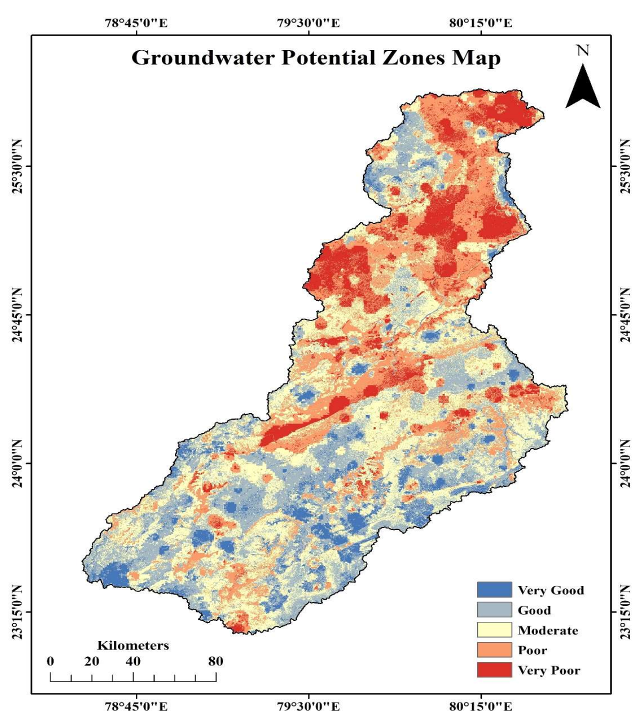

Fig. 14. Groundwater potential zone map of the Ken Basin

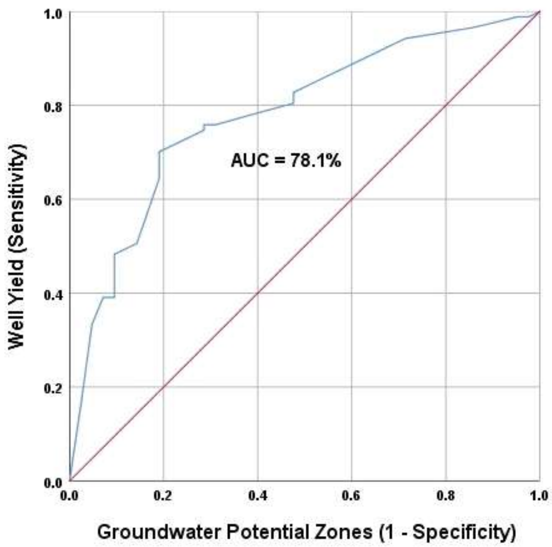

Fig. 15. Validation of groundwater potential map of Ken Basin through ROC curve method

The AUC has been obtained 78.1%, which was in the fairly accepted condition.

The Geoinformatics approach is a prevailing tool for assessing groundwater potential zones as well as identifying suitable and unsuitable locations for groundwater extractions (Awasthi and Patle 2019, Patle and Awasthi 2019, Awasthi and Patle 2020).The Frequency Ratio model is more efficient for geospatial assessment of groundwater potential zones based on relationships between dependent variable viz. groundwater well data and independent variables like groundwater contributing factors (Trabelsi et al 2019, Rajasekhar et al 2021). Such types of studies will help in the identification of prospective areas for reducing targets to detailed hydrogeological and geophysical surveys at suitable places for drilling.

CONCLUSIONS

Geoinformatics techniques are more powerful tools to delineate groundwater potential zones, which helps to save money, reduce time and provide relatively an accurate outcome. In the current study, a frequency ratio (FR) model was employed for groundwater potential zoning in Ken Basin using geoinformatics techniques. Geology, geomorphology, lineament density, land use/ land cover, soil texture, rainfall, slope, drainage density, depth to water level – pre monsoon and depth to water level – post monsoon were used as vital contribution factors for the FR model. All the factors were reclassified with obtained FR values and integrated into the GIS environment and resulted Groundwater Potential Index found. GPI was classified in different groundwater potential zones whereas the study area falls mostly covered in moderate groundwater potential zones followed by poor and good potential zones. Validation of the result shows that the output of groundwater potential zones through FR model was found fairly satisfactory. This study will be beneficial for the planning of drought mitigation strategies and the identification of critical sites for groundwater recharge plans. The generated groundwater potential map can help policymakers and engineers to the enhancement of groundwater resources in hard regions also.

ACKNOWLEDGMENTS

The authors thankfully acknowledge the CSDA-CAAST, NAHEP, College of Agricultural Engineering, JNKVV Jabalpur for providing the necessary facilities. The authors are also grateful to State Ground Water Data Center, Bhopal as well as CGWB, Bhopal for providing the required data and necessary information for this research.

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Indian Journal of Ecology (2022) 49(2): 324-331
DOI: https://doi.org/10.55362/IJE/2022/3524

Manuscript Number: 3524
NAAS Rating: 5.79

Prediction and Assessment of Minerals Contamination in Groundwater: Analytical Tools Approach

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***Abstract*:** Accumulation of minerals in groundwater over years degrades the water quality and thus affects the surrounding ecosystem if left untreated. Rapid urbanization and industrialization paves way for serious harm to the natural resources; particularly for the water bodies. One such study area is chosen for this analytical investigation to predict the consecutive concentration of important minerals for the next five years with some prediction tools. Artificial Neural Network, Support Vector Machine, and, Deep Learning methods are adopted for prediction analysis. The results of MSE, RMSE, and MAPE in each mentioned method were compared and concluded which performed better for the collected data of mineral concentration. Among these tools, SVM showed better results with less error and efficient accuracy (MSE-64.31, RMSE-8.07, and MAPE-3.92) though the other two techniques gave slight accuracy. The annual rainfall values are highly correlated with the mineral values in which the decreasing trend shows the mineral values when rainfall is higher and vice versa. These predicted values aids in creating awareness among the local residents as well as preventing the further pollution of the groundwater by the accumulation of minerals.

***Keywords*:** Minerals, Neural network, Support vector machine, Deep learning, Water Quality

Groundwater being the major source of water often gets degraded by the acute dumping of solid as well as liquid wastes into it. These wastes turn out to be the major pollutant of the groundwater making it undrinkable. There are more than 4000 minerals so far identified upon the earth's crust. Among which few are very common ones; particularly the different forms of silicate mineral comprise more than 90 percent of the total minerals on the earth's crust. Mineral pollution has become more common in water which predominantly causes health risks in humans as well as other living species. This pollution also affects the environment (Ukah et al 2019) and the ecosystem (Belkhiri et al 2018). Identification of mineral types effectuates the physicochemical properties which impact groundwater quality (Goswami et al 2020). Groundwater quality and assessment of human health risk in Bangladesh were reported to be acidic to, alkaline. The findings also depicted exceeding limits of iron and manganese which is then sighted for safe and sustainable groundwater management (Bodrud-Doza et al 2020). Drinking water of good quality is very important for human life, particularly in developing countries with large populations (Ayedun et al 2015). Wetland areas are mostly affected by pollution of the minerals in the surrounded water bodies (Pandiyan et al 2020) often by rapid industrialization and urbanization leading the poor water quality (Cao et al 2019). Multivariate statistical analysis and hydro geochemical analysis has been integrated to determine the groundwater quality in which the source of contamination water intrusion from the nearby tailings pond is studied (Huang et al 2015). Fluoride enrichment in groundwater is found to affect human health with the high concentration of total dissolved solids along with the presence of Ca, Na, Mg, and Cl (Li et al 2020). Water contamination with heavy chromium ion concentrations is observed to affect children's health more than adults, leaving behind the water no portable (Wu et al 2020). Study the presence of trace elements in groundwater very essential to be alarming in another area (Suman et al 2017). The concentration of minerals is effectuated on soil water, and vegetation by means of irrigation sources, in Iran which in turn affects humans (Cheshmazar et al 2018). The groundwater quality is assessed for use in irrigation alone in some studies (Bhat et al 2016, Kumar et al 2019). The higher humus concentration in soil and the neutral pH values in the soil solution validate the presence of enough microorganisms to resist the pollutants. (Sidhu et al 2021). Hence it is highly important to identify the intrusion of minerals including high concentration of fluorides in groundwater (Jothimani et al 2017).

The progression of minerals in drinking water may harm the natural resources as well as the ecosystem and this alarming situation calls for an apt solution in which the effects can be predicted well before the degradation of the groundwater quality. To protect the ecosystem, future prediction of minerals contamination is necessary and it helps to take initiative measures prior by the policymakers. It is very essential to manage the water quality problem by prediction technique, particularly in urban areas. Future prediction is often executed with advanced forecasting methods such as Support Vector Machine (SVM), Artificial Neural Network (ANN), and Deep Learning methods. Neural networks are found to be effective in analyzing data in a simpler and faster way even for solving non-linear problems. (Xin et al 2004). Despite the accuracy in neural networks, Support Vector Machine that works on the principle of kernel technique is effectively used to solve complex issues faced in neural networks (Kramer et al 2011). Compared to both classification and regression approaches, deep learning methods showed outstanding performance serving as a traditional machine learning method (Doppalapudi et al 2021).

In this study Artificial Neural Network, Support Vector Machine and, Deep Learning methods were adopted for water quality prediction analysis by means of MSE, RMSE, MAPE using the data of dependent variable pH, Ec, Na, K, SO_4, TH, Ca, Cl and independent variable of rainfall, water level, population, year, temperature, humidity, wind speed, evaporation of the study region.

MATERIAL AND METHODS

Study area and data collection: Padmanabhapuram [8.1444N&77.1855E], in Southern India, is chosen as the study area for this research investigation owing to the varying annual rainfall and increasing groundwater.

The factors affecting the groundwater quality were identified as rainfall, water level, population increase, consecutive years, temperature, humidity, wind speed, and evaporation. The groundwater quality data were collected from the Central Ground Water Board, a government organization. Parameters such as pH, electrical conductivity (EC), sodium (Na), calcium, potassium(K), sulphate (SO4), and Total Hardness (TH)were found to be the major contributors to the accumulation of minerals in water sources (Table 1). The missed data were calculated based on time series analysis (Wilson et al 2002) as well as forecasting formulae. Though more minerals were discussed in the Bureau of Indian Standards for water, limited minerals that contributed more in the past two decades were only considered in this prediction analysis. As per the Bureau of Indian Standards, the minerals identified are listed along with their permissible limits for water usage by humans (BIS, 2012) are presented (Table 2). The concentration of minerals regarding these standards is taken over for the groundwater quality analysis.

Research methodology: Initially, identification of the accumulated minerals in groundwater is done followed by the prediction in the concentration of these minerals in the future. The collected factors of the study area are used as variables for executing the analysis process. The correlation method is carried out for the collected factors by using the standard formula. Correlation is taken over between individual factors that were collected and each mineral. The factors that correlate well with minerals are selected for further analysis. The ideal correlation factor value in this analysis is 0.75. The highly correlated factors are taken for further data analysis whereas correlated factors with a value of less than 0.75 are not considered for further analysis. These correlated factors are then analyzed for further prediction methods using ANN network, SVM technique, and Deep Learning methods in which correlated factors are analyzed for better results by developing models. The results of these prediction tools are compared for accurate results. The comparison is done with the errors that resulted in each prediction model such as MSE, RMSE, and MAPE. According to the results of the error obtained, prediction can be compared effectively. The

Table 1. Parameters involved for analysis

Dependent variable	Independent variable
pH	Rainfall
EC	Water level
Na	Population
K	Year
SO4	Temperature
TH	Humidity
Ca	Wind speed
Cl	Evaporation

Table 2. Permissible limit as per BIS

Minerals	Permissible limit (mg/L)
pH	6.5-8.5
EC	1000 µS/cm
Ca	75
Na	50
K	20
Mg	30
F	1
Cl	250
TH	200
NO_3	45
SO_4	200
HCO_3	120

prediction results can be used to analyze the future accumulation of minerals and thereby mitigating groundwater contamination. The detailed research methodology is presented as a flow chart in Figure 2.

Artificial neural network: Upon the selection of minerals based on high correlation with the variables, further analysis is carried out initially using an artificial neural network. Usually, a correlated value with a factor above 0.75 is considered as a highly correlated value and if it is 1, then those are very effective in prediction therefore the parameters which have a correlation factor above 0.75 are considered for further process. Correlated factors are selected based on formula 1 in which x, y is an independent/dependent data and x's, y' is an average value of the data.

$$Correl\ (x, y) = \frac{\Sigma(x - x')(y - y')}{sqrt\ [\Sigma(x - x')^2 \Sigma)(y - y')^2]} .....(1)$$

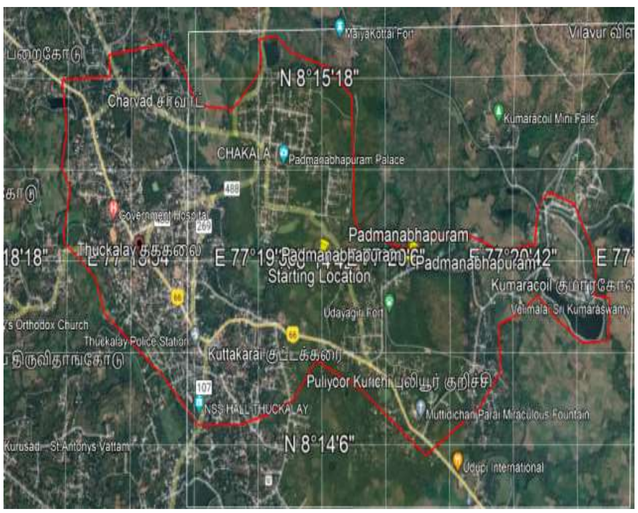

Fig. 1. Study area from Google earth (8.1444N & 77.1855E)

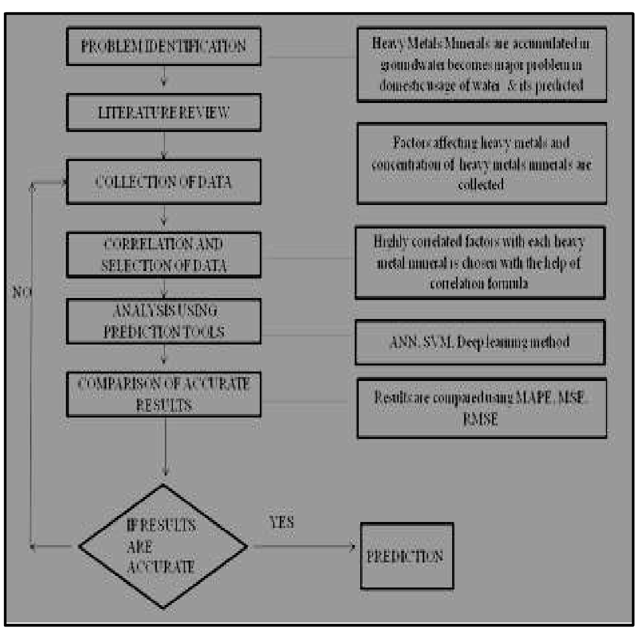

Fig. 2. Research methodology process chart

The neural network tool seems to work as an analytical tool in this investigation that improved the accuracy in an efficient way for a lot of prediction models much similar to a previous investigation (Cetkovic et al 2018).

Support vector machine: Among the statistical methods, SVM is a proposed model and its learning process is used in finding prediction functions (Kramer et al 2011). The tool assigns to the class of Kernel methods is SVM. Time series analysis is adapted to use historical data (Zeng et al 2012). Since ANN shows better accuracy and perfect results, it is involved to predict output in various criteria whereas ANN also noted to have limitations in a few cases which show some inaccuracy in its results. Therefore, to overcome those disadvantages SVM tool is introduced in some cases (Zendehboudi et al 2018). The working process of SVM is presented in Figure 4.

Generally, SVM is classified into two methods namely the least square SVM and ƐSVM which were based on

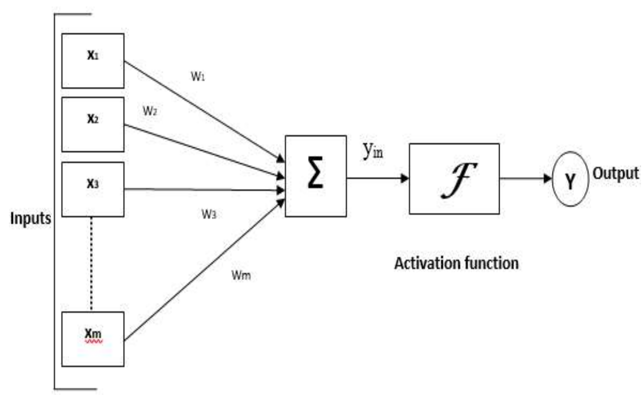

Fig. 3. Model of artificial neural network

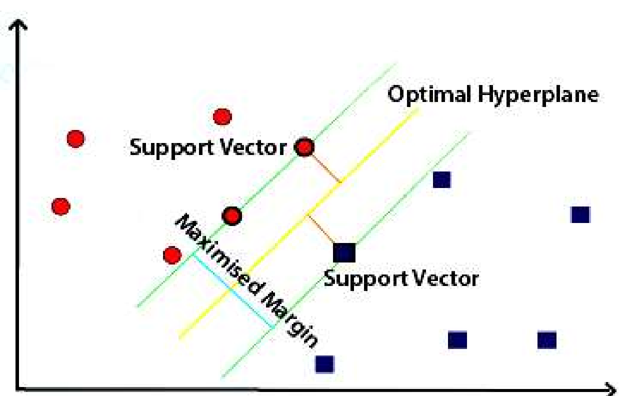

Fig. 4. Support vector machine working process

augmentation problem functions (Zeng et al 2012). Upon the prediction of wind power, SVM and ANN are then compared for results as well as better accuracy shown by SVM (Giorgi et al 2014). In this paper, the prediction of mineral accumulations was carried out with the help of the SVM technique, whereas the comparison is done with ANN and SVM results.

Deep learning: Deep learning is considered an important subset of all machine learning techniques and its models are set with the aid of neural networks. Neural networks intake input data which are processed in hidden layers and then are adjusted in the training model. Furthermore, the model takes into prediction and adjusted weights are used to make better results in prediction. The deep learning process includes a deeper level of knowledge as well as learning that takes place in two phases such as 1) nonlinear transformation of input with the output of statistical model 2) with the mathematical method, upon which the model is improved (Ingle et al 2021). A deep network with multiple layer process is shown in Figure 5.

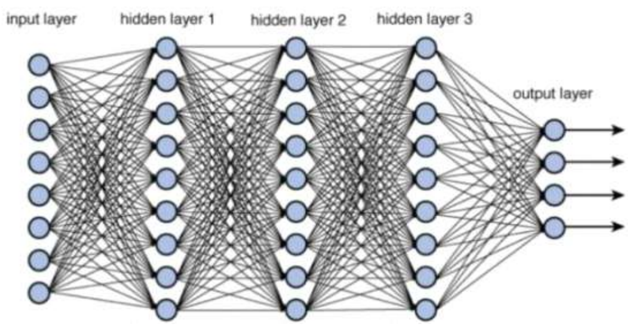

Fig. 5. Deep network with multiple layers

Complex and nonlinear relations that are hidden within huge data can be defined by deep learning algorithms. These algorithm works on the principle of neural networks which is composed of many layers (Patterson et al 2017). A neural network becomes complicated when it gets mixed by adding many weights in sub-layers which is called as deep. Some projects have used even more than 128 layers (Kumar et al 2020). Deep learning is found to be a trending method in machine learning because it executed few expected results where the processing function seems to be complex and the data used were very large (Ingle et al 2021). Conventional algorithms are surpassed by the deep learning method in terms of accuracy for most of the data types with less tuning and human works (Rajendrakumar et al 2019). Hence this study thrives to deal with the prediction of minerals accumulation for apposite results.

RESULTS AND DISCUSSION

MSE, RMSE, and MAPE are the errors that are used for developing the comparative analysis in this prediction. On comparing all the results, SVM shows more accurate results than neural networks and deep learning. Though all three techniques showcased an increased rate of mineral accumulation, SVM predicted the data with more accuracy. Table 3 shows the results of prediction tools whereas Figure 6 series presents the details of the relationship between the dependent variables and independent variables. The X-axis represents the independent variables whereas the Y-axis represents the dependent variables, such as pH, EC, Calcium, Chloride, Potassium, sodium, sulfate, total hardness.

The annual rainfall values are highly correlated with the mineral values in which the decreasing trend shows the mineral values when rainfall is higher and vice versa (Figure 6). An alternate location for safe disposal after proper segregation and appropriate treatment is mandatory for mitigating the further pollution of the study area. The best prediction tools are identified using MAPE, MSE, RMSE, and MAD. The line of best fit of data points is measured using MSE (Table 3). The smaller value of RMSE indicates the higher accuracy of the best fit for the data points. The behavior of MAPE and MAD remained much similar throughout the study. The difference between the actual and predicted values deviation is calculated using MAD and percentages were calculated using MAPE. The Prediction error and accuracy is measured widely using MAPE.

$$MAPE = \frac{100}{n}\Sigma_i^n(\frac{A-P}{P}) \text{......... ...}(2)$$

$$MSE = \frac{1}{n}\Sigma_i^n(A-P)^2 \text{.......... ..}(3)$$

$$RMSE = Sq.rt(\frac{1}{n}\Sigma_i^n A-P)^2 \text{.......... ..}(4)$$

$$MAD = \frac{1}{n}\Sigma_i^n|A-P| \text{.......... ..}(5)$$

Where

n is a no of data

Table 3. Permissible limit and level of positioning

Minerals	Permissible limit	Increasing level
pH	6.5-8.5	Moderate
EC	0-800	Fluctuating & increase
Ca	75	Moderate
Na	50	Increasing
K	20	Fluctuating & increase
Cl	250	Extremely high
TH	200	Extremely high
SO_4	200	Increasing

A is an actual value

P is a predicted value

For the prediction analysis in this study, the average value of MAPE, MSE, and RMSE values of different minerals was chosen. These error values (Table 4) are compared with the results of three prediction tools and the average values are presented in table 3. The detailed value of error for the individual parameters obtained through prediction is given in Table 5.

The predicted groundwater mineral values using Artificial Neural Network, Support Vector Machine, and Deep

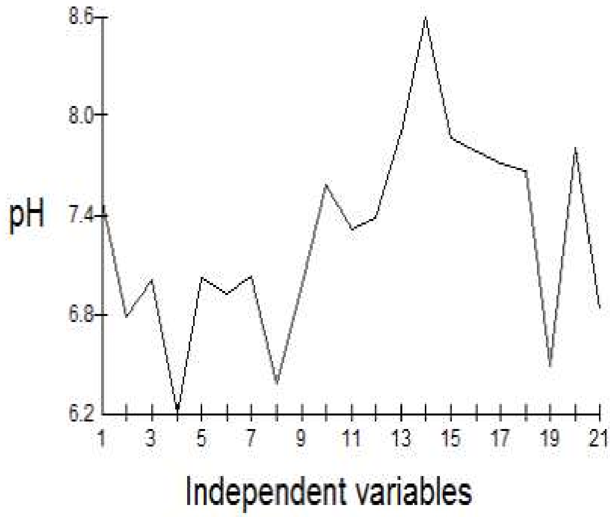

Fig. 6.1. Relationship between the dependent variables and independent variables for pH

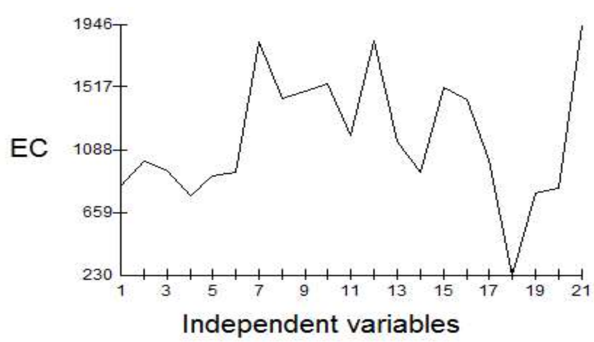

Fig. 6.2. Relationship between the dependent variables and independent variables for EC

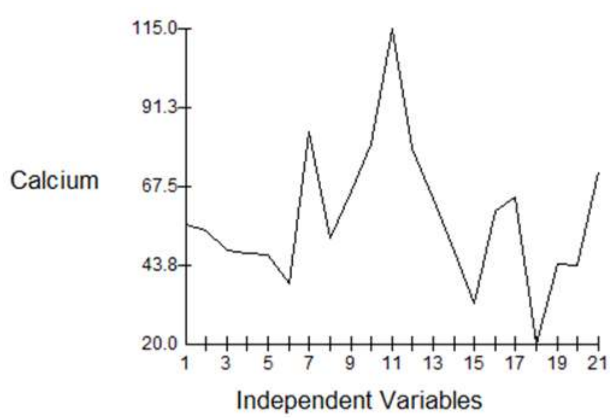

Fig. 6.3. Relationship between the dependent variables and independent variables for calcium

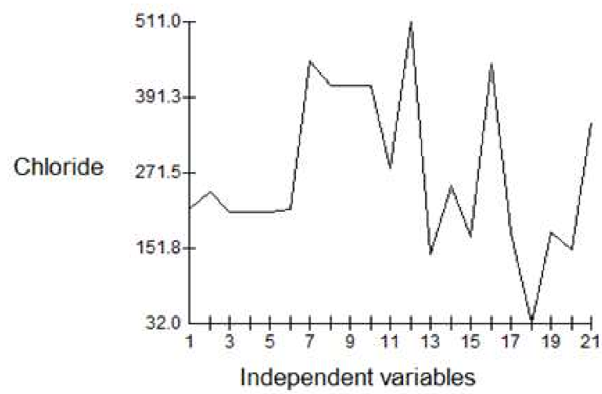

Fig. 6.4. Relationship between the dependent variables and independent variables for chloride

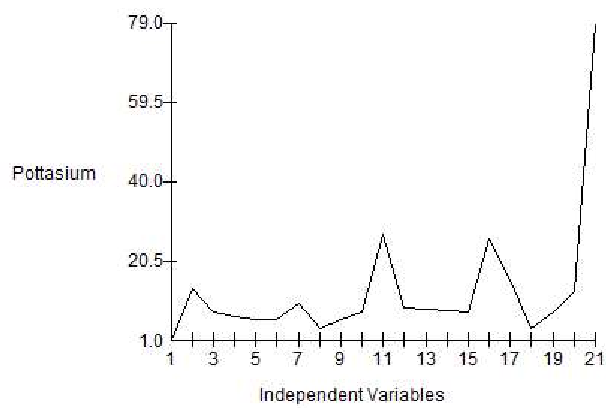

Fig. 6.5. Relationship between the dependent variables and independent variables for potassium

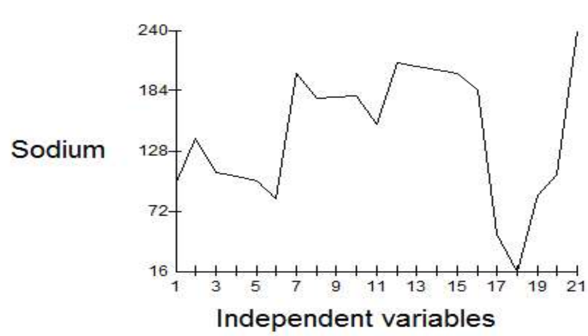

Fig. 6.6. Relationship between the dependent variables and independent variables for sodium

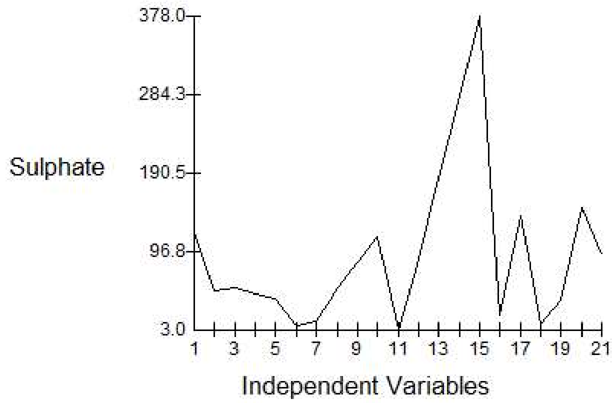

Fig. 6.7. Relationship between the dependent variables and independent variables for sulphate

Table 4. Error-values comparison for different tools

Error	Parameters	ANN	SVM	DL
MSE	pH	106.32	63.20	136.90
	EC	112.81	61.11	133.48
	Ca	109.76	62.97	132.73
	Na	110.49	70.34	140.67
	K	108.51	66.28	140.16
	Cl	107.37	63.83	138.25
	TH	113.92	61.72	134.79
	SO_4	109.55	65.04	138.98
RMSE	pH	10.62	7.82	11.55
	EC	10.32	8.12	13.27
	Ca	9.60	7.53	11.99
	Na	10.95	7.02	10.53
	K	10.98	8.54	15.17
	Cl	11.07	9.13	13.06
	TH	11.42	8.20	8.58
	SO_4	10.42	8.20	13.40
MAPE	pH	4.80	4.96	7.37
	EC	6.92	2.98	7.40
	Ca	4.72	3.46	7.51
	Na	5.67	2.99	8.86
	K	7.04	4.24	6.43
	Cl	4.85	5.00	7.44
	TH	6.99	3.01	7.47
	SO_4	6.01	4.74	6.50

Table 5. Value of error for the individual parameters

Prediction tools	Artificial neural network	Support vector machine	Deep learning network
MSE	109.84	64.31	137
RMSE	10.67	8.07	12.19
MAPE	5.88	3.92	7.37

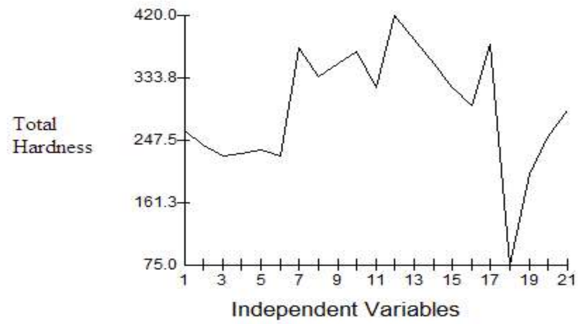

Fig. 6.8. Relationship between the dependent variables and independent variables for total hardness

Table 6. Predicted groundwater mineral values using ANN, SVM and DL

Parameter	Year	ANN	SVM	DL
pH	2021	7.75	7.74	8.28
	2022	7.79	7.78	8.32
	2023	7.83	7.81	8.36
	2024	7.87	7.85	8.40
	2025	7.91	7.89	8.44
EC	2021	1302.63	1278.52	1320.96
	2022	1308.66	1284.44	1327.08
	2023	1314.70	1290.36	1333.20
	2024	1320.73	1296.28	1339.32
	2025	1326.76	1302.20	1345.43
Ca	2021	58.57	57.48	59.39
	2022	58.33	57.25	59.15
	2023	58.09	57.02	58.91
	2024	57.86	56.78	58.67
	2025	57.62	56.55	58.43
Na	2021	163.08	160.06	165.37
	2022	164.03	161.00	166.34
	2023	164.99	161.93	167.31
	2024	165.94	162.87	168.28
	2025	166.90	163.81	169.25
K	2021	27.89	27.37	28.28
	2022	29.15	28.61	29.56
	2023	30.42	29.86	30.85
	2024	31.69	31.10	32.13
	2025	32.95	32.34	33.41
Cl	2021	254.75	250.04	258.34
	2022	252.04	247.37	255.58
	2023	249.32	244.70	252.83
	2024	246.60	242.04	250.07
	2025	243.88	239.37	247.32
TH	2021	313.71	307.90	318.12
	2022	314.10	308.29	318.52
	2023	314.50	308.68	318.92
	2024	314.89	309.06	319.32
	2025	315.29	309.45	319.72
SO_4	2021	147.96	145.22	150.04
	2022	152.39	149.57	154.54
	2023	156.82	153.92	159.03
	2024	161.25	158.27	163.52
	2025	165.68	162.61	168.01

Learning were observed to degrade the groundwater quality further and therefore apt suggestions were proposed (Table 6). Based on these error accuracy reports, the future value can also be predicted to control groundwater contamination in the future.

CONCLUSIONS

Based on the results obtained for the prediction of minerals in groundwater using Artificial Neural Network (MSE-109.84, RMSE-10.67, MAPE-5.88), Support Vector Machine (MSE-64.31, RMSE-8.07, MAPE-3.92), and Deep Learning (MSE-137, RMSE-12.19, MAPE-7.37) the following conclusions were obtained:

- An increased rate in the concentration of minerals over years is observed.
- Considering the number of data available and correlated data, SVM performed well with less error with the predicted values. (MSE-64.31, RMSE-8.07, MAPE-3.92)
- Since the foundation of minerals seems to be fluctuating as well as increasing, this results in serious harm to the ecosystem.
- This predicted mineral accumulation aids in creating awareness among the nearby residents and visitors to secure the groundwater quality, in the study area.
- The annual rainfall values are highly correlated with the mineral values in which the decreasing trend shows the mineral values when rainfall is higher and vice versa.

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Indian Journal of Ecology (2022) 49(2): 332-338
DOI: https://doi.org/10.55362/IJE/2022/3525

Manuscript Number: 3525
NAAS Rating: 5.79

Performance of the *Cana indica* Plant in Treatment of Waste Water by Vertical Flow Method for the Touggourt Region, Algeria

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***Abstract*:** The effectiveness of the *Canna indica* plant in treating waste water with a vertical flow system under dry and hot atmosphere was studied. This study included a comparison between a basin planted with *C. Indica* and a non-planted one (witness), with the study of the ability of the *C. Indica* plant to filter waste water. The study was carried out through an experimental model at the National Institute of Disinfection (ONA) in Touggourt, Algeria. This model consists of circular basins with a capacity of 52L filled from bottom to top on a thickness of 18cm with gravel (25/15) mm. The process of supplying the basins with urban waste water after primary treatment (physical treatment) with 15L per day at a regular rate once every week and the water obtained after Its stay in the tank for 5 days is collected through a container placed under the sink. After the study that lasted for six months from December 2019 to May 2020, obtained the removal of pollutants, with percentages of DCO (83.95%), N-NO_2^- (81.81%), P-PO_4^{-3} (90.49%), and bacteria *E. Coli* (99.86%).These percentages comply with the recommended standards for the safe use of this water in the agricultural field.

Keywords: Arid climate, Wastewater, Hydrophyte treatment, *Canna Indica,* Touggourt region

The scarcity of water resources, especially in arid regions, is a global issue (Yi L et al 2011) and some scientific studies on natural treatment of urban wastewater have shown that treatment by plants is the best technique that is simple and easy to use and requires few possibilities and a natural treatment method in removing pollution through artificial wetlands (Wu et al 2016). The use of this technology is widespread in different regions and under different climates (Bebba et al 2019) and depends on providing the same conditions as natural wet areas, called the lung of the earth, due to the ability to treat dirty water and this thanks to the activity and the great role played by plants and microorganisms (Wu et al 2015). The alternative for water in these areas is the use of treated wastewater (Cirelli et al 2012), where the treatment system consists of a thick layer of gravel or sand or a combination of both, where the environment is always full or saturated with water.

The effectiveness of the basin of treated water by plants depends on the time of setting the water inside this unit, and the preferred time for the water to remain inside the basin is from 5 to 4 days, and therefore it is desirable that the garden basin be large so that the water allows a residence time in order to obtain a high-quality treatment. In order to obtain positive results, need a method of ventilation, which increases the activity of microorganisms in the dismantling of pollutants, and it has also been shown that the use of treatment technology by plants is very satisfactory and the water purified by plants is considered to have roughly the same quality as that which comes out of a good traditional system equipped with nitrogenation units. (Bebba et al 2019). The aim of this study is to measure the efficacy of *Canna indica* in wastewater purification using a vertical flow system in a dry and hot atmosphere. and compare it to an uncultivated basin.

MATERIAL AND METHODS

Experimental protocol: The experimental gear consists of circular tubs of 52L capacity, filled from bottom to top at 18cm thickness with gravel (25 / 15mm) planted with young stems of the *Canna Indica* plant at densities (36 tiges / m^2) this criterion has been taken from previous studies(Tiglyene et al 2005). Basin I: planted with *Canna indica* and non-cultivated basin (as witness). The process of supplying the tubs with urban wastewater after the initial treatment (physical treatment) with 15L per day, by the method of vertical flow, at a regular rate once a week, and the water obtained after staying for 5 days in the tubs is collected through a container placed at the bottom of the basin.

Physiochemical properties of used packing materials: It is characterized by pH of pH = 14.7 neutral medium and conveyor CE = 3.88ms / cm. *Canna indica*, a plant species belonging to the Canna species, from the Cannaceae family (Choudhary et al 2011) was used. This plant was taken from the Model basin which is located in Tamasin - Touggourt. The aim is to treat urban wastewater, exploit wastewater and reuse it for irrigation.*Canna*can be used to treat industrial wastewater through artificial wetlands and it is effective to remove organic loads, color and chlorinated organic compounds from wastewater (Charge) from paper factories, for example(Choudhary et al 2011). The study took place over a period of six months, from December 2019 to May 2020. The analyzes were performed for physiochemistry at the laboratory of the National Office for Disinfection (ONA) in Touggourt, Algeria and Bacteriology in the laboratory of food and water analysis at Soliman Amirat Hospital, Algeria.

Physiochemical and Bacteriological Parameters

Identification of suspended matter MES: The amount of suspended matter MES (NF T90-105) was estimated according the filtration method and was used when the water is low in suspended matter. The centrifugation method when the water is of high density with suspended matter. The centrifuge has a rate of speed 3200-2800 revolutions per minutes.

Determination of the chemical demand for DCO: DCO was determined by oxidation by potassium picromate in an acidic environment with heating for two hours in the presence of AgSO4 and HgSO4 by spectrophotometer DR3900. By using the Digestion par réacteur method, in r measurement of DCO, used capsules containing a previously prepared commercial reagent.

Biochemical oxygen: This was quantified using a manométrique DBO-meter

Nitrite NO_2^-: The amount of NO_3-nitrate was determined with Diazotation spectrophotometer DR3900

Artphosphate: This was quantified with the spectrophotometer DR3900 as per the Phos Ver3 method (ascorbic Acid).

Dissolved oxygen: This was measured by the Ampérométrique method According to (AFNOR; T90-106) Oxymétrie BPL Inolab meter.

pH: pH was measured with a pH meter of the type PH meter sension1 (AFNOR, X31-103)

Electrical conductivity: This was measured with a condictiveté sension5 conductivity meter.

Counts of *Coliformes totaux et Fécaux* and *E. Coli)* : Thèse in culture were estimated in liquid environment (AFNOR T90-433)

Purification yield: This was determined the purification efficiency of the measured environment by the following equation:

R% = $(C_E - C_S) / C_E \times 100$

R: the payoff of the purification, C_E: Media concentration in the wastewater entering the basin (mg / l), C_S: The concentration of the used existing environments in wastewater out of the basin (mg / l). The results presented for each medium represent the mean values measured and obtained from the two independent basins (culture and control). Characteristics of wastewater used in feeding tubes are given in Table 1.

RESULTS AND DISCUSSION

Evolution of temperature T (c°): The average values of the temperature decrease in the treated water in the various basins compared to the used water (Fig. 2). The highest was 27.7°C in May and the lowest 20.7°C in December, that is, the temperature is sandwiched between the two 20.7 ≤ T (°C) ≤ 27.7. The decrease in temperature in the treated basins is explained by the decrease in the number of bacteria and the lack of biochemical reactions. As for the treated water in the cultivated basin and the non-cultivated basin, they are close to the length of the study period at the bottom of the tubs at a depth of 20 cm. This difference in temperature does not affect the selection of the microorganisms responsible for purification.

Dissolved oxygen (DO**):** The average dissolved oxygen increase in the treated tubs compared to the wastewater, 0.04 mg / l in April in the wastewater and 5.74 mg / l in March in treated water.

The dissolved oxygen (DO) increases gradually in the used water lowest inApril, and this reflects the huge number of microorganisms (bacteria, fungi) that consume a large amount of oxygen and in addition to an increase in turbidity that impeded the permeability of air oxygen in the wastewater. Generally, dissolved oxygen changes in contrast to the organic density of the wastewater and in the depth of the treated tubs, and there is a difference in the amount of dissolved oxygen for the plant-grown tub and the non-cultivated tub and this is due to the presence of the plant as it works to transport oxygen from air into the tank from the leaves to the stems and roots (Almuktar et al 2018). The young plants are more effective in delivering oxygen through their roots to the bottom of the tub compared to older plants, whose roots form a fatty layer that prevents oxygen leakage.

pH: The average PH decreases in treated water in various

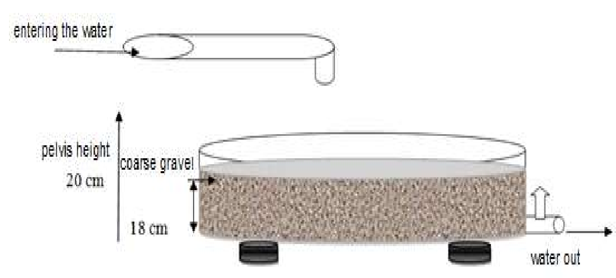

Fig. 1. Components of a vertical flow pretreatment basin

basins compared to wastewater, it decreases by a rate of 7.73 to 07.2 for the tub cultivated with plants and 7.70 for the non-cultivated pond (witness) compared to the national standard set at 6.5-8.5 (Fig. 4).

Several factors explain this decrease in the pH (acidity of the environment), including oxidation of nitrite and DCO (Münch et al 2004, Labed et al 2014) . The oxidation of DCO that produces CO_2, which in turn leads to acidity of the environment and oxidation of nitrites leads to nitrate, and the reason for this is hydrogen pool as a result of the activity of the bacteria responsible for nitrification, CO_2 accumulation as a result of plant metabolism or the breakdown of organic matter by bacteria (Bebba et al 2020), production of H^+ ions by the plant to replace some of the cations involved in the mineral nutrition of the plant and production of some secretions (organic acids) by the roots of the plant (Bebba et al 2020)

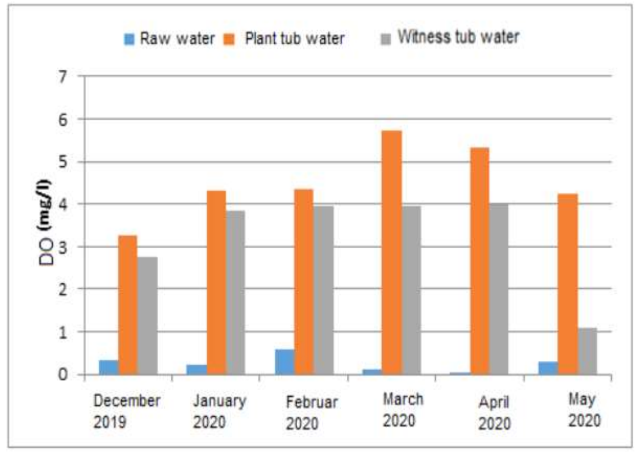

Fig. 3. Dissolved oxygen at the inlet and outlet for both the culture and control

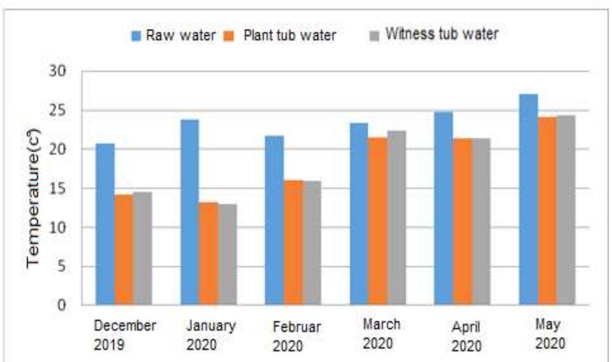

Fig. 2. Time evolution of the temperature T (°C) at the inlet and outlet for both the cultivated tub and the control

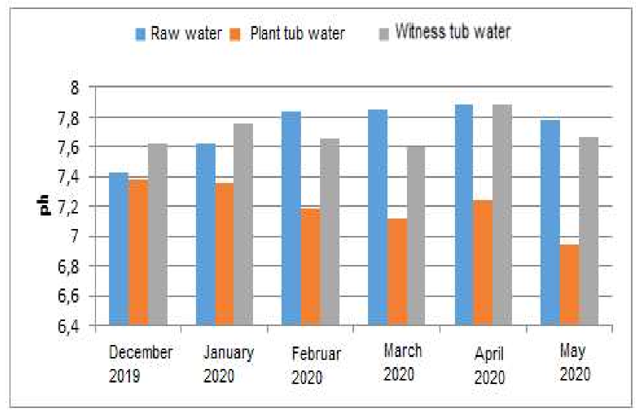

Fig. 4. Time evolution of the pH of the inlet and outlet for each of the cultivated ponds and the control

Table 1. Parameters of wastewater used in ponds

Parameters	Number of samples	Minimum value	Maximum value	Average values
T(C°)	12	20.7	27.1	23.58
pH	12	7.43	7.88	7.73
Conductivities (ms/cm)	12	5.88	6.57	6.25
Dissolved oxygen (DO) (mg/l)	12	0.04	0.58	0.26
MES (mg/l)	12	121.6	548	298.43
DCO (mg/l)	12	109.8	322	202.5
DBO_5 (mg/l)	12	50	140	87
NO_2^- (mg/l)	12	0.092	0.122	0.110
NO_3^- (mg/l)	12	15.8	39.4	29.6
Po_4^{-3} (mg/l)	12	7.10	39.6	30.48
Coliformes totaux (UFC/100ml)	12	$1.2E^{+6}$	$E^{+6}4.0$	$2.3E^{+6}$
Coliformes fécaux (UFC/100ml)	6	$E^{+6}1.0$	$E^{+6}2.5$	$1.6E^{+6}$
E. coli (UFC/100ml)	6	$3.2E^{+6}$	$E^{+6}2.4$	$1.4E^{+5}$

Electrical conductivity (CE): The electrical conductivity of treated water in the cultivated basin is always greater than the electrical conductivity of treated water in the non-cultivated basin (the witness) and the wastewater (Fig. 5). The electrical conductivity is high in the basin planted with plants compared to the witness basin and the electrical conductivity is high due to plant sweating and the change of organic materials to mineral substances (Amiri et al 2019).

Evolution of suspended matter MES: Evolution of suspended matter MES ranged between 121.6 mg / l and 548 mg/ lat a rate of 298.43 mg / l in urban wastewater, and for treated water the MES value in the basin cultivated with plants 54.5mg / l*Canna Indica* with a yield of 81.73% and in the non-cultivated pond (witness) 72 mg/l with a yield of 75.87% compared to the national standard set at 30 mg / l. The decrease in the concentration of MES in the various treated waters is mainly a result of a physical treatment such as filtration, where coarse materials remain suspended and fine materials are trapped in the filter pores.

Evolution of chemical demand oxygen (DCO): The chemical demand for DCO oxygen in wastewater changes between 109.8 and 322mg/ l, and through the time evolution of DCO (Fig. 7). The evolution of the chemical demand for DCO shows that its concentration decreases in treated water compared to wastewater, as it changes in the wastewater at a rate of 202.5mgo$_2$ / l, as for treated water, DCO values: 32.58Mgo$_2$ / l in the *Canna Indica* cultivated tub (83.95%), and 48.4Mgo$_2$ / l in the non-cultivated tub (control) (76.09).

The cultivated basin and the witness basin gave water with less DCO concentration than the wastewater. This is due to the physical absorption of organic materials in the wastewater of the filter and the aeration of the environment by the bacterial organisms. This cultivated tub gave better yield compared to the non-cultivated tub. This decrease is due to the presence of the plant that provides physiochemical conditions that provide oxygen to the filtered environment through the leaves to the stems and then the roots and rhizomes by the bacterial organisms that cause DCO oxidation (Yi L et al 2011,Randerson et al 2012,Stefanakis 2019).

Biochemical demand for oxygen DBO$_5$: The biochemical demand for DBO$_5$ varied between 50 and 140mg / l in wastewater. Through the time evolution of DBO$_5$ the highest removal amount was in December and May, with a yield of 86.20% for the tub cultivated with plants, and the lowest

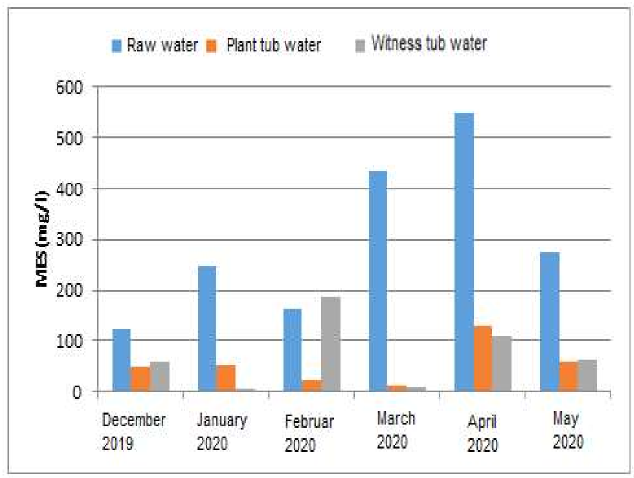

Fig. 6. Time evolution of the MES suspended material for the inlet and outlet for both the cultivated tub and the witness

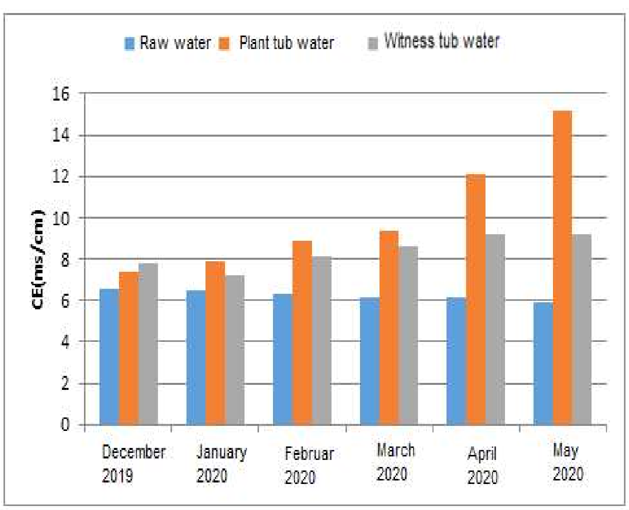

Fig. 5. Time evolution of the CE electrical conductivity of the inlet and outlet for both the control basin and the witness

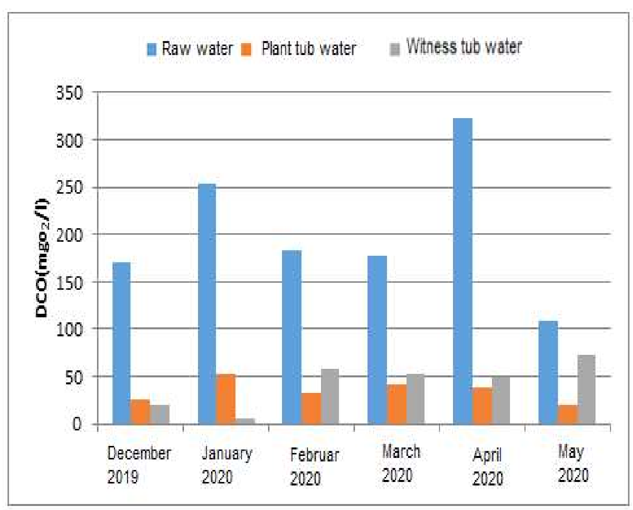

Fig. 7. Time evolution of the chemical oxygen demand (DCO) at the inlet and outlet for both cultivated and witness tubs

removal rate for DBO_5 was in March, with a rate of 65.51% for the tub planted with plants (Fig. 8) in general the concentration of DBO_5 in wastewater. Urban is greater than DBO_5 as the wastewater 87mg / l concentration of DBO_5 is reduced to 21 and 21.5 mg / l for cultivated pond and control pond, respectively. The removal of DBO_5 in the cultivated tub of plants was 75.86 and 75.28% for witness. The difference in removing DBO_5 between the planted tub and the witness tub is due to the presence of aquatic plants that have the property to absorb oxygen from the air to release it through their roots in the area surrounding the roots. This oxygen activates the bacteria, as they work to oxidize and break down organic materials (Feigin et al 2012).

No_2^- nitrite: Through the time evolution of NO_2^-nitrite in the wastewater changes with time, and it is greater than the concentration of NO_2^-in the treated water as the NO_2^- concentration decreases (0.110 mg / l) in the wastewater and 0.12 mg / l in the *Canna indica* plant tub and 0.0263 mg/l for the witness tub (Fig. 9).

There were contrasted difference between witness cultivated with plants and the witness one. The yield of nitrite removal NO_2^- is 81.81% for the *Canna Indica* tub, and 76.09%) for the witness tub. The difference in removing NO_2^- between the cultivated tub and the witness one is due to the presence of an aquatic plant that has the property of absorbing oxygen from the air and is transported through the leaves and then the stems to the roots and rhizomes. This oxygen activates the bacteria that convert NO_2^- into NO_3^- nitrite in the root zone. This process is called nitrification (Jan Vymazal 2007).

Nitrate $N\text{-}NO_3^-$: Through the time evolution of $N\text{-}NO_3^-$ nitrate decreases in all treated tubs compared to wastewater, as the nitrate concentration decreases from 29.6 mg / l to6.38 mg / l in the *Canna Indica* tub and 2.41 in the non-cultivated tub (witness) (Fig. 10).

The concentration of nitrates after treatment in the plant basin is higher than its concentration in the basin of the witness, and this is due to the availability of oxygen during the vertical flow of water and the presence of the plant helps to transfer oxygen to the basin, which leads the dissolved oxygen to oxidation of nitrite into nitrate (Białowiec et al 2012). This change in the amount removed from $N\text{-}NO_3^-$ nitrate is caused by the use of nitrates by the plant is during the day or in the presence of photosynthesis. The development of nitrates gives a decrease in the amount after filtering with plants. Plants absorb the removed organic nitrogen (Jan Vymazal 2007), and the remaining nitrogen is removed by nitrification, denitrification and aerial oxidation of ammonium (Ling et al 2009).

Arto-phosphorous $P\text{-}PO_4^{3-}$: In general, the concentration of $P\text{-}PO_4^{3-}$ for wastewater changes with time and is greater than the concentration of $P\text{-}PO_4^{3-}$ in the treated water, where the concentration of $P\text{-}PO_4^{3-}$ in the wastewater decreased by 30.48mg / l in the wastewater to, 2.89mg / lfor *Canna indica*

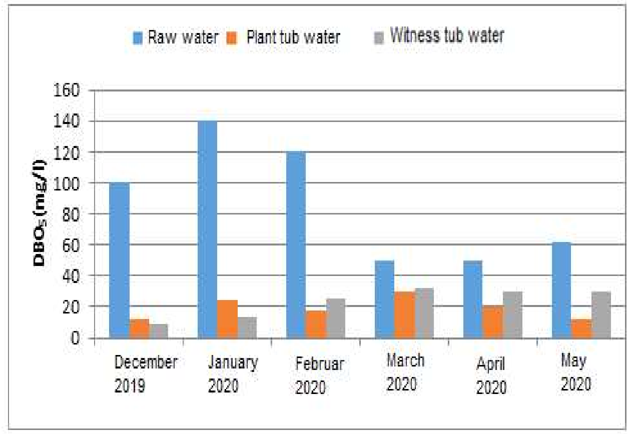

Fig. 8. Time evolution of the DBO_5 biochemical oxygen demand in the inlet and outlet for both the witness and cultivated tubs

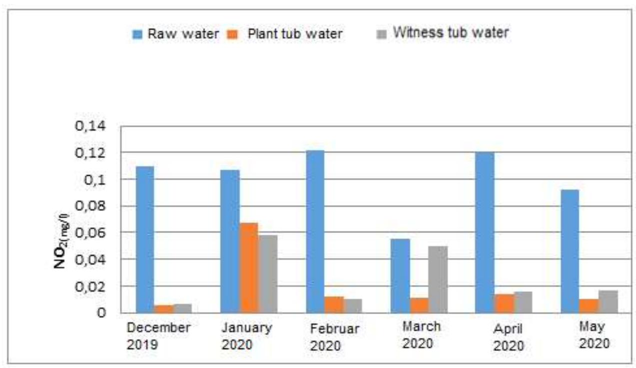

Fig. 9. Time evolution of NO2-nitrite of the inlet and outlet for both the cultivated and witness tubs

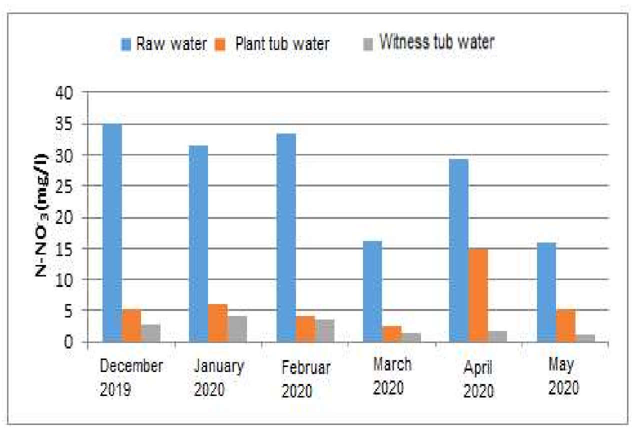

Fig. 10. Time evolution of the $N\text{-}NO_3^-$ nitrate to the input and outlet for both cultivated and witness tubs

and 4.49 mg / l in the non-cultivated tub (witness) (Fig. 11). The filtration yield in the *Canna indica* tub is 90.49 and 85.26 mg / l for the non-cultivated tub. The concentration of orthophosphorous in the treated water in all basins is caused by the absorption of P-PO_4^{3-} in the filter (filter), as well as the quality of the gravel favors the absorption of P-PO_4^{3-}(Vohla et al 2011). The high removal of arto-phosphorous in the cultivated tub is caused by the interaction of bacteria and plants and the absorption of P-PO_4^{3-} by the plant to its physiological needs (Jan Vymazal 2007, Białowiec et al 2012, Verma and Suthar 2018, Al-ani et al 2019).

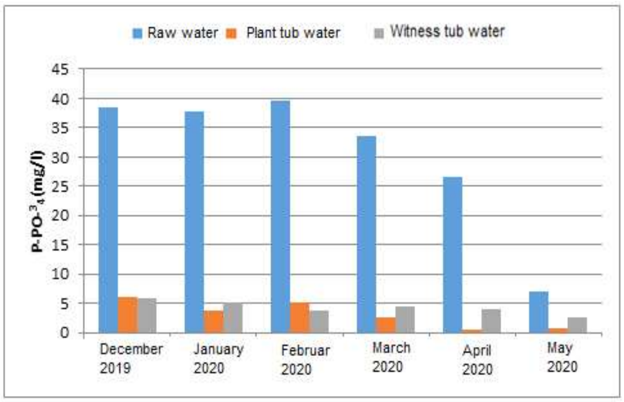

Fig. 11. Evolution of arto-phosphorous P-PO_4^{3-} inlet and outlet for both cultivated and witness tubs

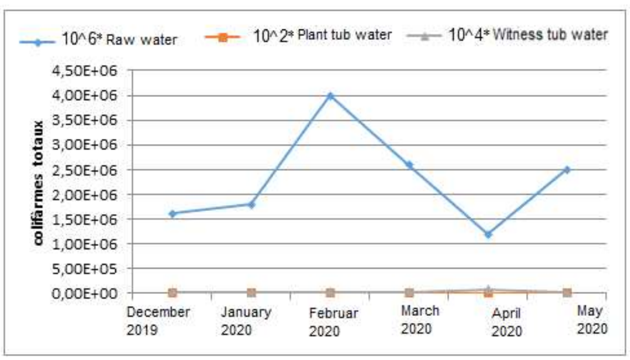

Fig. 12. Chronological evolution of *Coliformes totaux* for the inlet and outlet inlet and control tubs

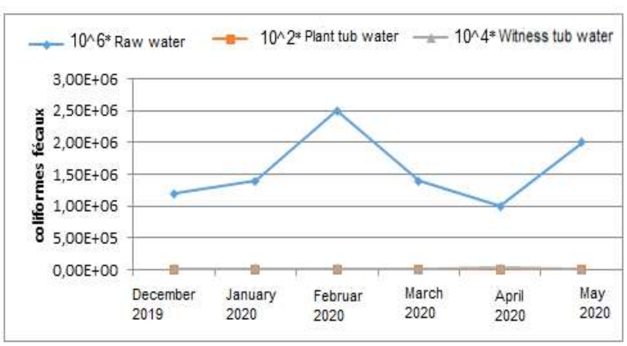

Fig. 13. *Coliformes fécaux* chronological evolution of the inlet and outlet for both the cultivated and the witness basins

Bacterial removal (*E. Coli, Coliformes Fécaux ,Coliformes totaux*): The chronological evolution of the bacteria in the shapes shows the number of colonies (*E. Coli, Coliformes Fécaux, Coliformes totaux*) in wastewater is greater than the treated water in the cultivated basin and the non-cultivated basin.

The removal of the bacteria *E. Coli, Coliformes fécaux, Coliformes totaux* almost completely after treatment in cultivated ponds and may reaches 100%. These results are similar to the study of Duggan and Bates (2001). Therefore, the decrease in bacteria is in compliance with the WHO 2012 standards for unrestricted watering. Vymazal (2005) also noted that the purification tubs in 1and 2 m area are better in cultivated tubs than in non-cultivated tubs. Confirmed by (Oueslati et al 2000) that it obtained in Tunisia.

During this study, the plant treated tub showed that there is a significant decrease in the removal of bacteria and pathogens, and this is explained by the natural death of bacteria as a result of a change in the living environment or destruction with organic materials, and the difference in removing bacteria between the pond cultivated with plants and the control basin Is that the roots of the plant secrete biological acids (toxic substances) that work to kill bacteria. Vincent (1994) explained that *E. coli* decreased in cultivated ponds compared to the control by the probability that the roots secrete inhibitors (toxic substances) "exudats" that contribute to the eradication of *E. coli*.

CONCLUSION

The preset study demonstrated the ability of the plant *Canna indica* to purify wastewater, as the results indicated significant reduction in the main types of pollution organic, nitrogen, and phosphorous. In the aquarium planted with plants, it was better than in the unplanted aquarium (the witness), where the water staying for five days inside the basin was sufficient to remove pollutants in an acceptable manner. The presence of the plant has a positive effect on biological activity using vertical irrigation , so that the plant began to adapt and coexist by using this water in the semi-arid climate of the region, and reaching the permissible limits for the use of water resulting from the treatment basins of plants in agriculture (watering trees, fruits and grains), which has the ability to withstand the salinity of this water.

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Received 31 January, 2022; Accepted 02 April, 2022

Indian Journal of Ecology (2022) 49(2): 339-345
DOI: https://doi.org/10.55362/IJE/2022/3526

Manuscript Number: 3526
NAAS Rating: 5.79

Bioindicator Based Water Quality Assessment of Warbo and Dabo Streams in Awash Catchment, Dendi Woreda, Ethiopia

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Abstract: The present study was aimed at assessing the water quality of Warbo and Dabo streams in awash catchment using macroinvertebrates as biological indicators. The status of water quality was assessed in terms of presence or absence of indicator organisms in relation to physico-chemical parameters. Hilsenhoff Family-level Biotic Index (H-FBI) results have shown that the site 6 had relatively higher value (6.5) followed by site 5 (5.8). The site 1 recorded least H-FBI value which accounts for 3.2 followed by site 4 (3.74). For ETHbios index, highest score was recorded at site 3 (120) followed by site 4 (102) while the lowest score was obtained for the site 6 and site 1 which accounts for 54 and 57 respectively. The ASPT value was comparatively higher for sites 1 (6.67) and site 3 (6.31) than other sites. Principal components analysis of physico-chemical variables showed wide variation among the study sites. Axis 1 and axis 2 of the PCA explained 97.5% of the total variance regarding the sites versus physico-chemical association, where the first axis and second axis contributed 73.04% and 24.56% to the variation, respectively. Results of Pearson correlation reaveled that there exists significant relation between variuos pollutant parameters.

Keywords: Bio-indicators, ASPT, ETHbios, Macro invertebrates, Correlation

In most of the Sub-Saharan Africa, wetlands are under high pressure due to land use degradation, while they are increasingly being recognized as vital resources for achieving food security and rural livelihoods (Schuyt 2005). Aquatic bodies located in those areas receive all types of wastes from human activities including domestic, agriculture, industrial sources (Dixon and Wood 2003). In fact, land uses, and practices are probably the most important factors in determining the water quality. The direct and in direct effects of human activities are the major drivers of land use land cover change. Land use change is primary factor causing water quality and habitat degradation (Lakew and Moog 2015). Among the biological communities that are considered bio indicators of water quality, the most commonly used are the benthic macro invertebrates because they have several characteristics that make them easy to study and show clear responses when faced with adverse environmental conditions (Bonada et al 2006). Different groups of macroinvertebrates are excellent indicators of human impacts especially contamination (Kassahun et al 2013). The structure of the benthic communities in an aquatic ecosystem reflects its ecological conditions, including habitat heterogeneity and water quality (Burgmer et al 2007). The use of benthic invertebrate communities as indicators of environmental degradation or restoration has become widespread and reliable for bioassessment since the benthos broadly reflects environmental conditions. Most of them have quite narrow ecological requirements and are very useful as bioindicators in determining the characteristics of aquatic environments (Benetti and Garrido 2010). Intensive studies have been carried out on the impact of environment degradation especially due to pollution in various river systems in various parts of Ethiopia but studies related to land use impacts on the water quality on various streams of catchment area of Awash basin are very few or much limited. Hence in the present study an attempt has been made to assess the status of water quality of selected streams in Awash using benthic macroinvertebrates as bio-indicators of pollution. This study will help as a base line information on the major human induced land use practices and their effects on the water quality which in turn guide planners to take necessary steps to reduce further pollution of these streams.

MATERIAL AND METHODS

Study area and sites selection: The study area is in the Dendi Woreda of West Showa Zone of Oromia Regional state, Ethiopia (Fig. 1). The present study area is lying between latitude 40°28'E and 40°59'E and longitude, 9°99'N and 10°03'N with an altitude ranging between 2145 to 2464 msl. Study sites were selected based on their exposure to land use practices and various human activities such as agricultural practices, grazing, chemical fertilizers from the surrounding lands that pollute river basin (Table 1).

Accordingly, six sampling sites were selected which approximately cover 10- 12 km long with about 2-5 km apart from each other.

Measurement of physicochemical parameters: Water samples were collected from study sites for analysis of physico-chemical parameters and estimated using standard procedures (APHA 1999). All the samples were collected simultaneously along with the samples for macroinvertebrates analysis at same locations.

Benthic macro invertebrate sampling and analysis: For the collection of macro invertebrate from the selected sites, Multi-Habitat Sampling (MHS) scheme was implemented according to (Thomas et al 2010). Benthic macro invertebrates were collected using a standard hand net (625 cm^2, net mesh size 500 μm from multi-habitat units). Mega-lithal stones were sampled by brushing the surface approximately equal to the size of the sampling net. Macro-lithal stones were picked by hand and their surfaces were brushed to dislodge clingers and sessile organisms. Samples were then preserved in 4 % formaldehyde for further analysis with proper coding. Each sample was passed through a set of sieves of different sizes (5000, 3000, 2000, 1000 and 500 μm) to separate different size classes of macro invertebrate groups. Identification was done using South African Aquatic Invertebrates Identification key up to family level.

Water quality index (WQI): Water quality index of study sites was estimated using method described by (USEPA 2002).

Benthic macro invertebrate indices (BMI): Shannon and Weiner (1963) index was used to assess the diversity of macroinvertebrates in these rivers. Hilsenhoff Family of Biotic Index (H-FBI) (Hilsenhoff 1988) was calculated to assess the pollution tolerance of each collected taxa in each site. Other benthic macro invertebrate indices were used to evaluate abundance and pollution status of study sites according to (Lakew and Moog 2015).

Statistical analysis : Data collected for benthic macro

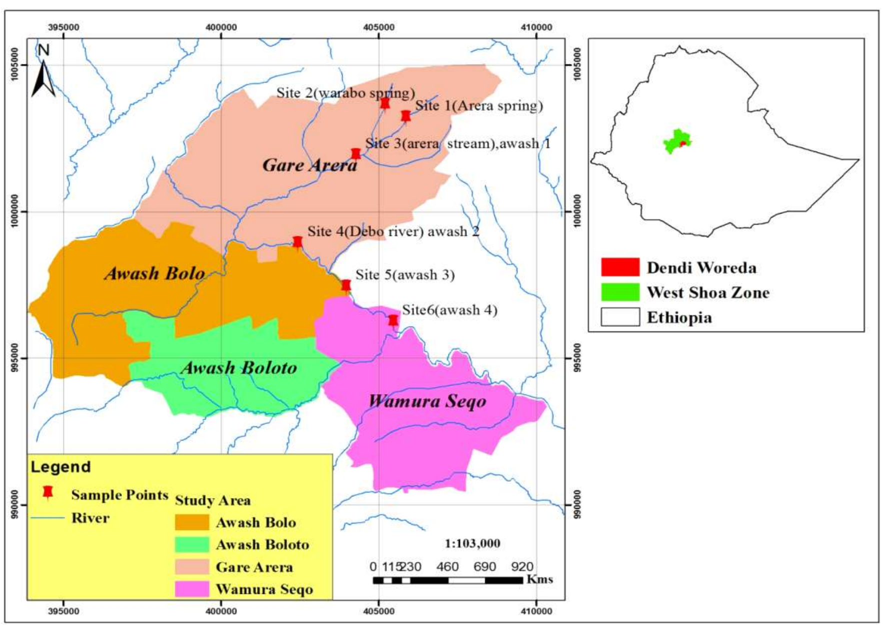

Fig. 1. Map of the study area & study sites

Table 1. Criteria for selection of study sites

Site ID	Characteristics of the site	Type of human intervention
S1	Arera spring from Arera stream	Less anthropogenic activities
S2	Warabo spring from Warabo stream	Moderate anthropogenic activities
S3	At confluence of the Warabo and Arera streams	Considerable anthropogenic activities
S4	Dabo stream	High anthropogenic activities and lack of canopy
S5	Located downside of Dabo stream after the bridge of the Ginchi town near to paper mill factory	Very high anthropogenic activities and direct discharge of effluents into the stream
S6	Located downstream of Awash River after the paper mill factory	Very high anthropogenic activities with discharge of effluents down stream

invertebrates and physico-chemical parameters were statistically analyzed by using Excel spread sheet and statistical software like SPSS version 21 (Statistical package for social science). Coefficient correlation was used to assess the significant relation between chemical and biotic parameters. Origin Pro 8.5 software was used to generate graphs. Multivariate analysis (Canonical Correspondence Analysis (CCA) was used to study the association between macro invertebrate abundance and physicochemical factors. Principal component analysis (PCA) was used to observe how sites varied with respect to physico-chemical variables or to observe the physico- chemical gradient along the sites using PAST software as the relation was unconstrained (Tar Barrk 1987).

RESULTS AND DISCUSSION

Minimum pH (7.98) was ats6, while the maximum (8.53) was at S4 with a mean value of 8.4 (Table 2). The mean pH level among the six sites having F-value 2.287 and p-value 0.112 implies there was no significance difference in pH level among the six sites. Clean water is an essential requirement for the establishment and maintenance of ecological integrity (Berger et al 2018). However, improper liquid waste discharge and solid wastes produced by human settlements and industrial activities leads to negative effect to human health and environment as pollution to river water source (Amble et al 2013). pH is an important variable in ecological water quality assessment as it influences many biological and chemical processes within the water body and influenced by various factors and processes including temperature, discharge of effluents, runoff, acidic perception, microbial activity. The minimum pH was recorded at S6 (7.89) might be explained due to anthropogenic activities such as waste discharge, cloth washing and open bathing as observed. The highest value (8.62 mg L^{-1}) of dissolved oxygen was recorded from site S4, which is under the agricultural land use, while the lowest values 6.32 and 6.39 mg L^{-1} were recorded from site, S3 and S1 respectively under forest land use. At site S6 (at downstream of paper mill), the dissolved oxygen concentration was found to be 6.46. The mean comparison of DO concentration among the six sites indicated that there was a significance difference in DO level. The BOD values of study sites ranged from 0.51 mg L^{-1} to 2.38 mg L^{-1}. The considerable variations in DO and BOD values can be attributed to the level of impact of anthropogenic activities among the study sites. The maximum concentrations of $NH4^{+H}$ (0.49 mg L^{-1}) was recorded from site, S1, which was under forest land use while the minimum concentration (0.07 mg L^{-1}), was recorded for the site, S6 under urban land use. The mean comparison of $NH4^{+H}$ concentration among the six sites indicated there was no significance difference in $NH4^{+H}$ concentration among the six sites. The maximum NO^-_3 concentration (0.97 mg L^{-1}) was in the forest and agricultural land use, site S3, while the minimum (0.210 mg L^{-1}) was in site, S5 and there was no significance difference in NO^-_3 concentration among the six sites. It was expected that nitrate nitrogen concentration would be more in site S6 due to discharges of paper mill effluent, but the low values were observed and this was possibly due to denitrification process of microbial communities. The maximum PO_4^{3-}concentration (0.05 mg L^{-1}) was for the samples collected from S2 while the minimum (0.03 mg L^{-1}) was for water samples collected from S1. The mean comparison of PO_4^{3-} concentration among the six sites 2 implies that there was no significance difference in PO_4^{3-} concentration among the six sites. The PO_4^{3-} in the studied area was possibly from the agricultural land use might be due to use of phosphate fertilizers in agricultural fields and animal manure. There exists significant relation between variuos pollutant parameters (Table 3). PO_4^{3-} showed a strong positive correlation with pH, BOD and NO^-_3 but not significant at 0.05 level. Dissolved oxygen and BOD showed a very strong negative correlation which is significant at 0.05 level. Both DO and BOD showed a strong negative correlation with $NO^-_{3.}$

An attempt has been made to assess the water quality status of study sites using water quality index (Fig. 2) which indicate about cumulative effect of various chemical pollutants on water bodies. In the present study sites S1, S3 and S2, S4 showed equal water quality indexes of 65 and 64

Table 2. Physico-chemical analysis of study sites

	Minimum	Maximum	Mean	Std. Deviation	P-value
PH	7.98	8.53	8.4050	.21548	0.112
DO	6.32	8.62	7.2767	1.06566	0.000
BOD	.51	2.38	1.2683	.64179	0.000
NH_4^+	.07	.49	.2567	.15122	0.055
NO^-_3	.21	.93	.5400	.30424	0.056
PO_4^{3-}	.03	.05	.0367	.00816	0.292

respectively. The least water quality index was obtained with site S5 (61) which is near to a paper mill factory. The highest water quality index was recorded at site S6 (68) which is situated at downstream of paper mill factory. Even though site 6 is under intensive pressure from human activities, the comparative high-water quality obtained may be attributed to factors such as self-purification capacity and distance of sampling point from the source of pollution. The water quality of all the study sites was considered to be of medium quality as evident from WQI analysis.

Analysis of relation between indicator organisms and water quality of the study sites clearly indicated that water quality has a strong influence on presence or absence of indicator organisms as shown in (Fig. 3-5).

Composition and abundance of invertebrate: During the study period a total three classes (Oligochaeta, Insect and Gastropod), 10 orders and 37 families of macro invertebrate were identified from the six study sites (Fig. 6). There were 7 orders of the class Insecta namely Plecoptera, Ephemeroptera, Odonata, Hemiptera, Trichoptera, Coleoptera and Diptera. The nymph and larva stage of the insects identified belongs to 33 families, while Gastropoda and Oligochaeta were the non-insect macro invertebrates representing 4 families. The order Diptera was represented

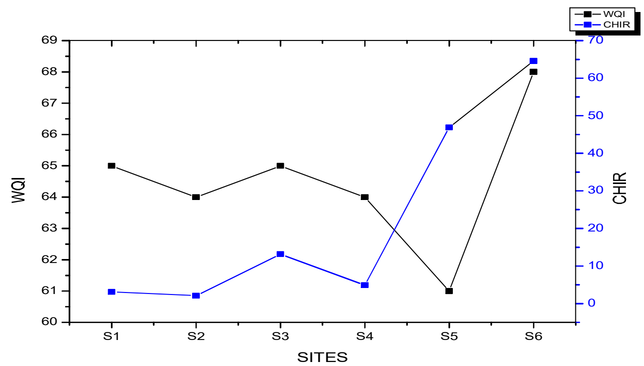

Fig. 3. Effect of water quality index on CHIR in study sites

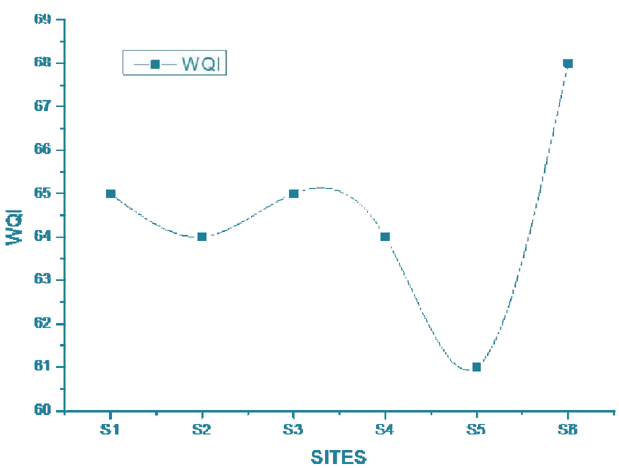

Fig. 2. Water quality index of the study sites

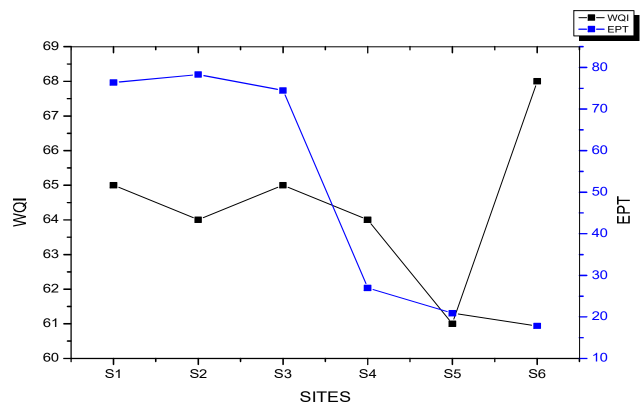

Fig. 4. Effect of water quality index on EPT in study sites

Table 3. Correlation matrix of physico-chemical parameters

		PH	DO	BOD	NH3	NO3	PO4
PH	Pearson Correlation	1	.492	.246	.412	.095	-.102
	Sig. (2-tailed)		.321	.638	.416	.859	.847
DO	Pearson Correlation	.492	1	-.858*	-.343	-.809	.164
	Sig. (2-tailed)	.321		.029	.506	.051	.756
BOD	Pearson Correlation	.246	-.858*	1	-.233	-.820*	-.001
	Sig. (2-tailed)	.638	.029		.657	.046	.998
NH3	Pearson Correlation	.412	-.343	-.233	1	.590	-.643
	Sig. (2-tailed)	.416	.506	.657		.217	.169
NO3	Pearson Correlation	.095	-.809	-.820*	.590	1	-.105
	Sig. (2-tailed)	.859	.051	.046	.217		.844
PO4	Pearson Correlation	-.102	.164	-.001	-.643	-.105	1
	Sig. (2-tailed)	.847	.756	.998	.169	.844	

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

by 8 families constituted (22 %) of the total fauna and Trichoptera formed (16%), followed by Coleoptera (13%), and Ehpemeroptera (13%). Odonata and Hemiptera each accounted for 11 % and Gastropoda accounted for 8%. Both Plecoptera and Oligochaeta accounted for 3% each.

Benthic Macroinvertebrate Indices (BMI) and Spatial diversity: Comparison of benthic macro invertebrates among six study sites showed considerable variation in spatial diversity (Fig 7). The percentage of dominant taxa (%DT) increased from least impacted site 2 to the more impacted site 6 and also site 2 had the highest abundance of benthic macro invertebrates followed by site1 and regarding the diversity and species richness site 4 had the highest number of species diversity and richness. The percentage of Ephemeroptera, Heptageniidae and Plecoptera (EPT) increased from more impacted site to least impacted sites. The percentage of chironomidae decreased from more impacted site to least impacted site. In the study area, the river was subjected to human influenced factors such as agricultural activities, grazing and urbanization (discharge of paper mill wastes. Luo et al (2017) correlated water quality deterioration with lack of proper soil and water conservation

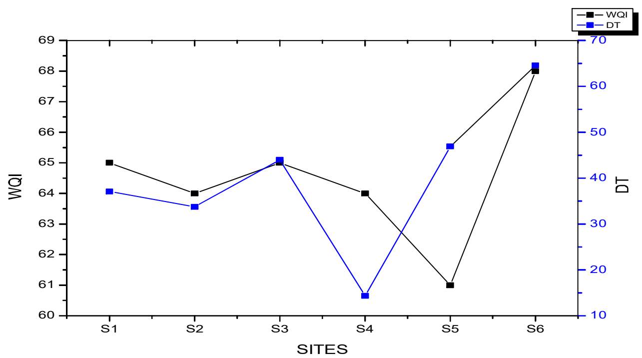

Fig. 5. Effect of water quality index on DT in study sites

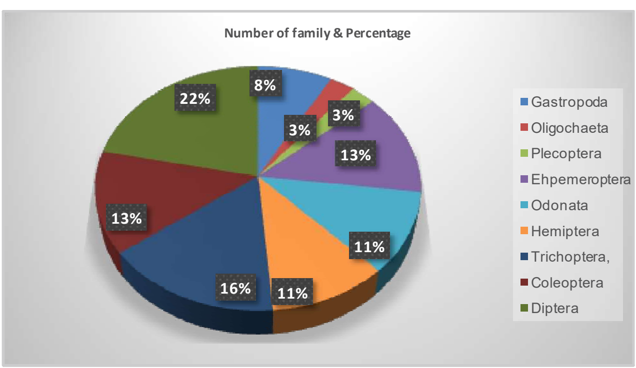

Fig. 6. Macroinvertebrate families and their percentage of occurrence

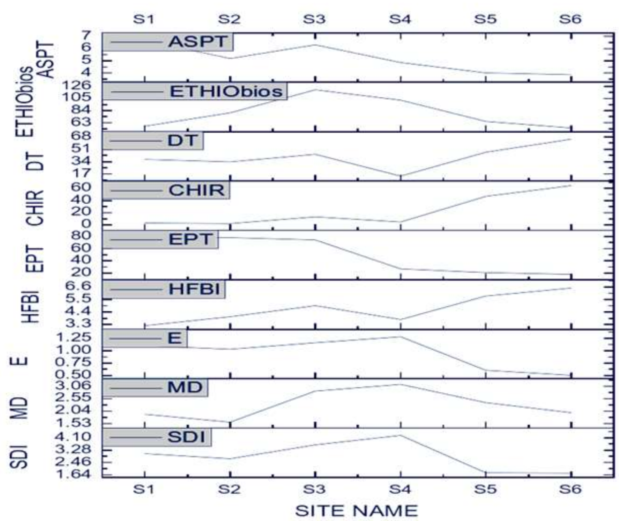

Fig. 7. Macroinvertebrate families and their spatial diversity

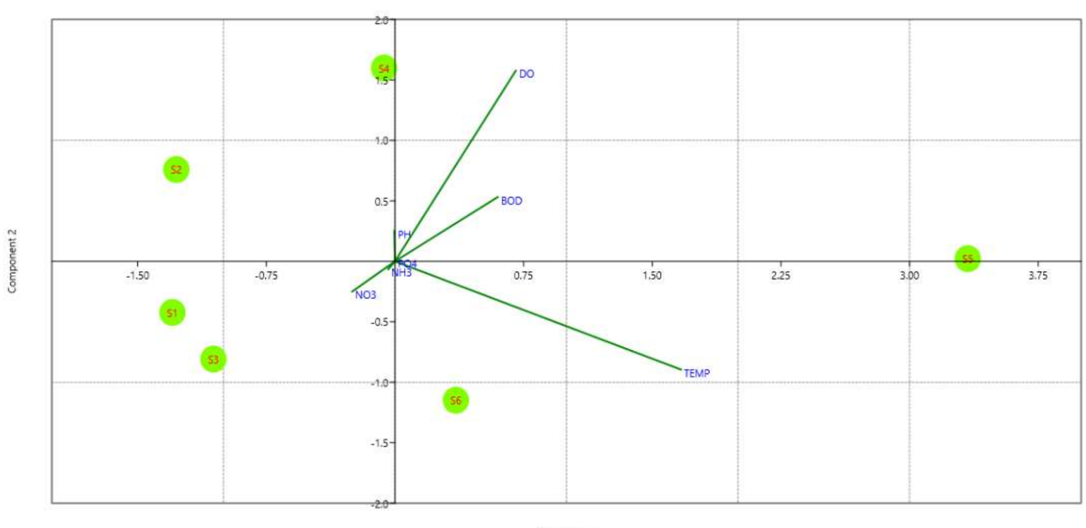

Fig. 8. PCA analysis of the physicochemical factors

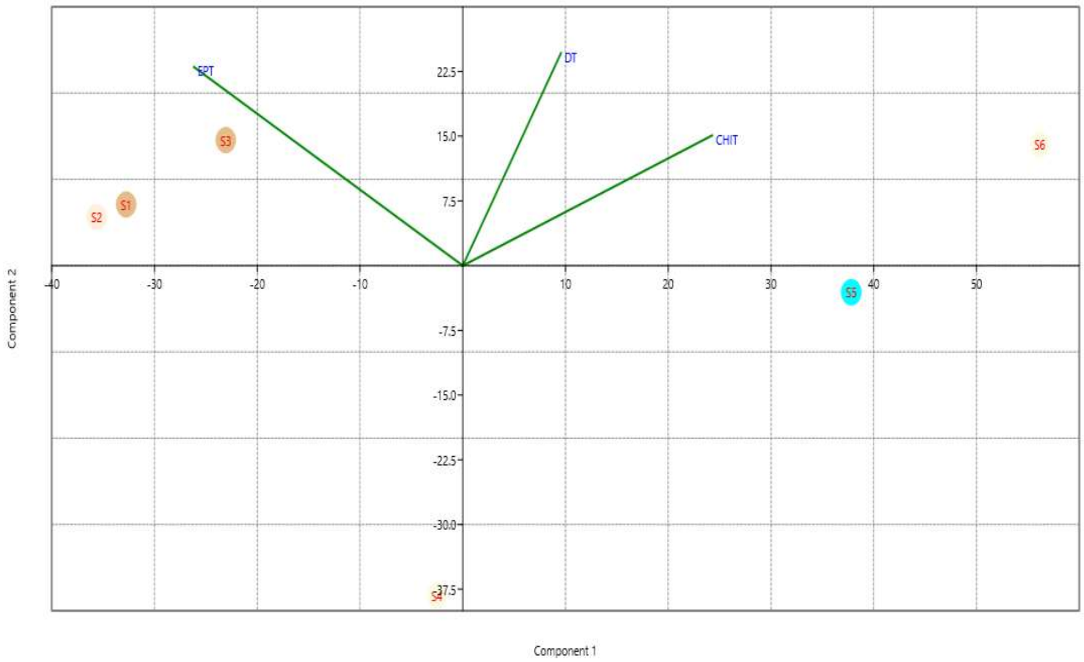

Fig. 9. PCA analysis of macroinvertebrate families and their spatial diversity

measures, high number of cattle grazing, deforestation, and siltation, conversion of forest land into farmlands and effluent discharge from factories. In the study area, benthic population showed an inverse relationship with anthropogenic activities that the macro invertebrates declined correspondingly with the increase in anthropogenic activities. This study agrees with the findings of Berger et al (2018). Results of present study revealed that as habitat and water quality are degraded, number and percentage of EPT decreased, while percentages of Diptera and blood red chironomids increased.

Variation in physico-chemical variables among sites: Principal components analysis of physico-chemical variables showed wide variation among the study sites (Fig. 8). Axis 1 and axis 2 of the PCA explained 97.5 % of the total variance regarding the sites versus physico-chemical association, where the first axis and second axis contributed 73.04% and 24.56% to the variation, respectively. Highest temperature, BOD and DO are strongly associated with site 5. High nitrate contents are positively associated with site 3 and ammonia is strongly correlated with site 1.

Variation in macro invertebrate assemblages among sites: PCA analysis of macro invertebrate taxa in study area indicated that CHIR and DT is strongly associated with site S6 and S5 whereas DT is strongly associated with site S3 (Fig. 9).

CONCLUSION

Based on foregoing analysis, it was clearly shown that water quality of streams in awash catchment was directly correlated with human influences and in turn affected the distribution of benthic macroinvertebrate community. The mean of pH, PO_4^{3-} NO_3^{-}, $NH4^{+H}$ were among the six sites had no significance differences in the study area and the mean T, DO, EC, BOD_5 were had a significance difference among the six sites. The percentage of dominant taxa was increased from least impacted site to the more impacted sites. Site 2 had the highest abundance of benthic macro invertebrates followed by site 1. The percentage of Ephemeroptera, Heptageniid and Plecopteran (EPT) increased from more impacted site to least impacted sites. The percentage of chironomidae decreased from more impacted site to least impacted site. The H-FBI values were significantly lower at the upper stream and higher at downstream of the study areas.

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Received 18 November, 2021; Accepted 21 December, 2021

Indian Journal of Ecology (2022) 49(2): 346-352
DOI: https://doi.org/10.55362/IJE/2022/3527

Manuscript Number: 3527
NAAS Rating: 5.79

Study of Physicochemical and Bacteriological Properties of Wastewaters Released Directly into The Natural Environment of Annaba City (North-East Algeria)

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***Abstract*:** The present study was aimed to assess the quality of wastewaters released in different regions of Annaba city (northeast Algeria). The physicochemical and bacteriological parameters (pH, temperature, conductivity, 5-Day biochemical oxygen demand (BOD5), chemical oxygen demand (COD), coliform and faecal loads, faecal streptococci and sulfur-reducing bacteria of wastewaters) released into the natural environment of this city, and their comparison with those applicable in the national legislation have been determined using standard methods. The results showed marked variations in the studied parameters of Annaba wastewaters during the four seasons. The pH, water conductivity, temperature, and COD were increased in seasons, but in winter the conductivity was decreased. Further, the maximum level of total dissolved oxygen (10 mg/l) and suspended matters of wastewaters (1700 mg/l) were observed during winter, since the maximum level of BOD was 515 mg/l, and a lower value (300 mg/l) during winter. The level of minerals (nitrates, nitrites, and phosphorous) was increased in seasons for both waste sites. In addition, the bacterial loads in wastewaters were higher during autumn, spring, and summer than those seen during winter for both waste sites. Consequently, wastewaters released into Annaba natural environment are responsible for serious effects on the health of citizens.

Keywords: Faecal pollution, Wastewater, Collectors, Annaba city

Annaba city is considered a tourist city and one of the largest Algerian cities because its provides all life facilities, including industry, trade, and agriculture. Thus this city is a place of attracting residential and industrial gatherings, charactrized by increased level of which a part is involved in mixed-design wastewater system with equipped mono-type grids (the oldest inherited from the colonial era**).** Nevertheless, it was observed that the effluents are usually mixed in separated networks, whereas the system includes 13 pumping stations. In the theoretical system, all effluents resulting from wastewaters gather in one site point in the northeast of the city named Sidi Brahim (Sayada et al 2017) and accordingly are drained to the unique station that was created in 2007 and became fully operational in 2010. This station ensures the filtration of the city wastewaters is associated with only 40% of the city wastewater network since the others are in progress of realization. In addition, currently filtrates 10% of the waters coming to it, and as a result, 90% of the untreated wastewaters are released into the natural environment. In recent years, this number has doubled, making it a matter of concern due to its negative impact on the health status of the population inhabiting near valleys, in addition to the spread of water-borne diseases, the disgusting smells, and the inappropriate appearance of the city.

MATERIAL AND METHODS

Study site: This study was conducted on the wastewaters of Annaba city whose area is only 42 kilometer-square, including several watercourses of 34.205 kilometers in length, which are respectively the rivers of Boudjemaa (11,130 Km), Bouhdid (9 Km), SidiHarb (5 Km), Fourcha (5,250 Km) and Kouba (3,825 Km). All these rivers end up to the Boudjemaa river and then to the sea.

Geographical aspect: Annaba city is located in the northeast of Algeria, 600 far from Algiers (capital of Algeria), and faces the sea on a coastline of 80km in length and occupies a part of river estuaries into the Seybouse River, the second river in Algeria and then leans to the huge Edough coast (Fig. 1).

Geomorphological and hydrological aspects: The southern slope basins of Edough are characterized by their proximity to Annaba city at a wide drop that is interspersed with chain of hills, including three distinct areas. The northern plain flowing from Wadi al-Qubbah River and its tributaries. The western plain, which includes the region of Zafaraniya and neighbouring rivers (Farsha, SidiHarb, and BouHadid) and Kharaza plain, located in the southwest part of the city (Wadi Boujmaa Basin).

Importantly, these different and flat lowlands characterized by weak to extremely weak slopes make these parts of the city suitable areas for water stagnation, flooded by strong and steep slopes. Hence, a dense and high-speed hydrographic network with a temporary and abundant inflow on the slopes becomes developed, but it is vulnerable to valley floods flooding large areas with every flood (Fig. 3). Thus, all water drains (Chaabets) are gathered in a one-course direction (Oued Boudjemaa river), where their inflow faces difficulty to reach the natural exit (Sea) between Syebouse and ASMIDAL towns.

The rainwater gathers either directly in the rain channels or trenches, or the pumping stations "Sidi Ibrahim" or "the old station" or "Eliza", which pushes it to the sea and the belt channel. Whereas, all the slopes flow in the direction of the

Fig. 1. Geographical location of Annaba city

Fig. 3. Oued Boudjemaa River is covered by rain waters of the regions: Kharaza, Oued E-Nil, and Saroual (West of Annaba city)

"Kaf Al Nisour" course, heading towards Oued Boujmaa river, and resulting consequently in a large load of sediments and congestion of the main bed river with infrastructures, land dams, and crossing works. Accordingly, the floods were constantly frequent, and from here large areas of water have emerged, including the swamps of the regions; Bosedra, Saroual, Bidari, SidiAshour, and Boukhadra (West of Annaba city). These swamps are mixed with wastewaters, which results in the deterioration of these water bodies, and the spread of unpleasant odors, mosquitoes, and rodents, in addition to distorting the beautiful appearance.

Physiochemical and bacteriological properties: The physicochemical and bacteriological properties of the urban wastewater of Annaba city, which are dumped directly in the natural waterways in the middle of the city for a period of four years (2016-2019) were estimated. The sampling and analysis techniques used in this study are summarized as they are in Table 1.

Study period and location: The study was carried out on two direct wastewater pouring points in natural waterways, selected as two sampling places considering the size of the population and the amount of discharged water. This was for the aim to obtain representative samples in the west of Annaba city ending up in the Mediterranean Sea. Further, the study lasted four years (2016 - 2019) at the same two sites and at the same time set at nine in the morning.

Sampling: The sampling process was performed regularly, twice a month, for the physicochemical characteristics, and monthly for the bacteriological characteristics. The sampling was performed exactly as described by Ort et al (2010). In brief, samples were taken very carefully using sterilized glass bottles of various volumes depending on the type of analysis to avoid any probable contamination and then were kept in a

Table 1. Sampling techniques and analysis of pollution level urban wastewater in Annaba city

Sampling techniques	Analysis of properties
• Sampling points • Method of sampling • The frequency of sampling • Transport of samples	- The daily amount of used water - Heat - pH - Electrical conductivity - Dissolved oxygen - Suspended matters - Nitrite - Nitrates - Phosphorous - Chemical Oxygen Demand (COD) - Biological Oxygen Demand (BOD) - Searching for coliforms and their counts. - Search for fecal coliforms and their counts - Search for Sulfur-reducing Bacteria and their counting

cold place until analysis. Due to the proximity of the two laboratories, the time for transporting samples did not exceed 15 minutes, and so the analyses were performed upon arrival at the laboratory directly.

Techniques for Analyzing Wastewater Properties

On-site measurements: Since some measurements such as temperature, pH, and conductivity of electricity were measured at the site of sampling because it directly interferes with other properties and is affected by the transfer, the measurements are made using a multimeter.

Physicochemical analysis: To show the level of wastewater pollution, the physicochemical properties are analyzed by standardized methods approved in the laboratory at the station level; environmental monitoring of Annaba, affiliated to the National Observatory for the Environment and Sustainable Development (NOESD).

Bacteriological analysis: To show the degree of wastewater pollution, the bacteriological characteristics are analyzed by standardized methods approved by the central laboratory of Annaba city.

Statistical analysis: The presentation of the results of each studied parameter (physicochemical and bacteriological properties) is based on the averages obtained on four independent trays. Pairwise comparisons (physical parameters *vs* threshold control values) were performed with GraphPad Prism (Prism 7, version 7.00, GraphPad Software, California, USA), using the Student's t test with a significance level of 95% as performance reduction.

RESULTS AND DISCUSSION

Temperature and pH: Temperature and acidity are extremely important factors due to their selective role in the micro-bacteria responsible for the decomposition of primary wastes. Therefore, these should be taken into consideration when trying to monitor urban sanitation, and of note, the optimum pH is 5.5-8.0 (Sundberg et al 2004, Zorpas et al 2003). Further, the excessive changes in these two properties in the receiving environment negatively alter the ecosystem as they disrupt and even halt the aquatic and land life.

The temperature of the two downstream water levels was between 11.85 and 21.45 °C and was significantly low for all seasons as compared with what is nationally applicable. This decrease affects the bacterial content growth and the wastewater bacterial activity, contributing to the self-filtering of wastewater (Fig. 5). Moreover downstream pH were between 7.1 and 8.6, indicating a match with what is recommended (Fig. 6) (Taleb et al 2004).

Electrical conductivity: The significant decrease in the conductivity in the winter season compared with the standard is because samples were taken during the days of increased levels of rain-free of mineral salts (Fig. 7). The other seasons revealed a highly significant increase in the conductivity values as explained by the mineralization of the organic matters by the microbial group, along with a slight rise in summer due to the high temperature (a determining factor). Thus, the high conductivity values are explained by the presence of a large number of mineral salts, since these values are significantly below the threshold applicable in Algeria. The specifications of treated wastewater used for irrigation purposes are estimated as 3000µs/cm (Samia 2014).

Aquatic species do not generally tolerate large differences in dissolved salts and this can be observed for example in the case of a wastewater spill (De Villers et al 2005).

Dissolved oxygen content: The dissolved oxygen content was estimated at 5 mg / l under which, the ecosystem begins to suffer, while 2 mg / l indicates that this system has entered the serious hypoxia field (Ménesguen et al 2001).

The value of dissolved oxygen is significantly inferior to

Fig. 4 Annaba city showing the sampling stations

1mg/l (very low value) (Fig. 8) but can cause a great and dangerous impact on ecosystems, leading consequently to suffocation of species organisms found in it. The significant increase in dissolved oxygen in winter compared to that of the threshold control value is because samples were taken in rainy times, and this is obvious because rainwater is rich in dissolved oxygen.

Suspended maters: During four years the urban water discharged was full of suspended matters, which were significantly increased (Fig. 9) than those of the permissible values on the national scale, which subsequently causes concern, especially in the case when the suspended matters cause the formation of sludge and drain clogging and the proliferation of anaerobic bacteria leading to the emission of bad odors and pathogens. The suspended matters are significantly higher in winter as compared to that in the other seasons and the control limit values. This is due to the mixing of wastewaters with rainwater, which cleans roads and rooftops, bringing with it dirt and dust.

Nitrite: The urban wastewater is a significant source of nitrite and that its high levels negatively affect the ecosystem (Fig. 10). The excess nutrients from wastewater dumping make their way through watercourses into surface and underground ecosystems located below the hydrographic network. The the equilibrium of aquatic ecosystems can be disrupted by altering the inherent physical, chemical, and biological properties of waterways (Chrétien et al 2017), which consequently leads to the excessive growth of algae resulting in the impoverishment of dissolved oxygen.

Nitrates: Alike to nitrite, nitrates are a source of nitrogen and thus, promoting enriching surface and ground aquatic environments. The high level of nitrates badly affects public health, especially for children (new-borns). Most scientific studies have reported an increase in algal blooms over the past 30 years. In addition, the nutrient richness of water in some French coasts (mainly N and P) via anthropogenic discharges would explain the observed increase in algal blooms, and possibly the evolution of toxic species (Chrétien et al 2017).

Phosphorous: In the phosphorus level in two contaminated wastewater sites in Annaba city increases proportionally and significantly during the four seasons of the study period as compared with the normal reference values (Fig. 12). Additionally, this increase is high in summer because of the intensified use of detergents during this hot season, and consequently, this indicator must be taken into account in the filtering of wastewaters. Phosphorus is naturally present in very small quantities in soil, water, and in the bodies of biological organisms. A high concentration of phosphates can lead to algal blooms when becomes a nutrient for plants.

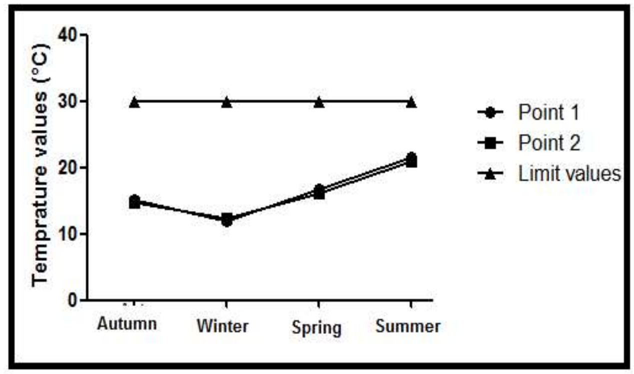

Fig. 5. Variation of temperature during the four seasons of the study period

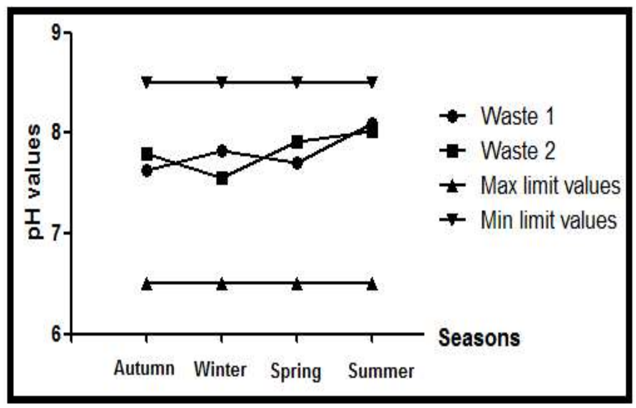

Fig. 6. Variation of pH during the four seasons

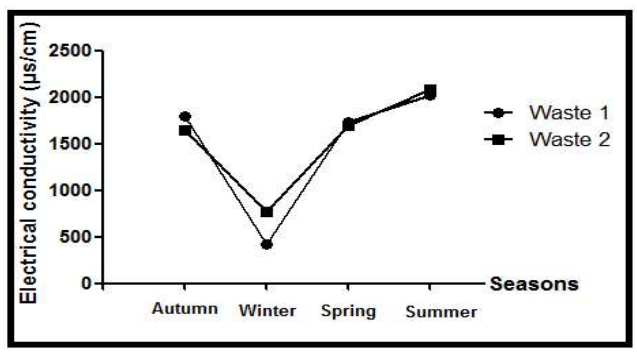

Fig. 7. Variation of electrical conductivity during the four seasons of the study period

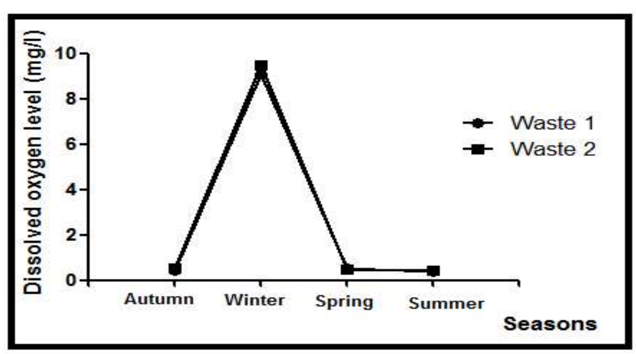

Fig. 8. Variation of dissolved oxygen content during the four seasons

Algae are responsible for the eutrophication of stagnant waters. This process is more or less important depending on the phosphate content in the wastewater. The phosphorus is the limiting factor involved effectively in reducing eutrophication (Donnert and Salecker 1999).

Biochemical oxygen demand (BOD5): The biochemical oxygen demand is an indication of the amount of biodegradable organic matter in the water and is related to the amount of oxygen consumed by the microorganisms in the demolition of dissolved and suspended organic matters. The significant increase in BOD5 values, ranging from 300 to 480 mg / l was observed (Fig. 13) and this is known as a characteristic of the urban wastewater in the natural state due to its containing a huge amount of aerobic microorganisms in addition to dissolved and suspended organic matter. This leads to a state of suffocation and rotting in the natural environment receiving a lack of dissolved oxygen consumed by aerobic microorganisms (Graham 2011).

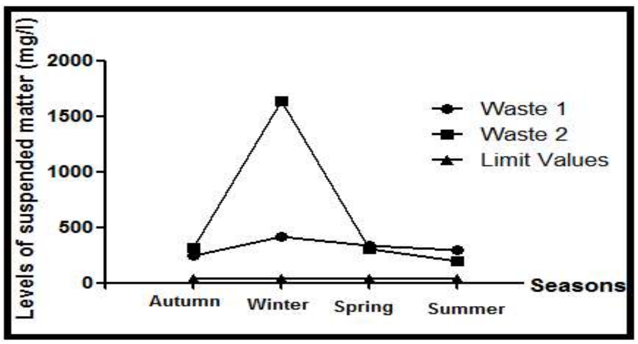

Fig. 9. Variation of suspended matter level during the four seasons

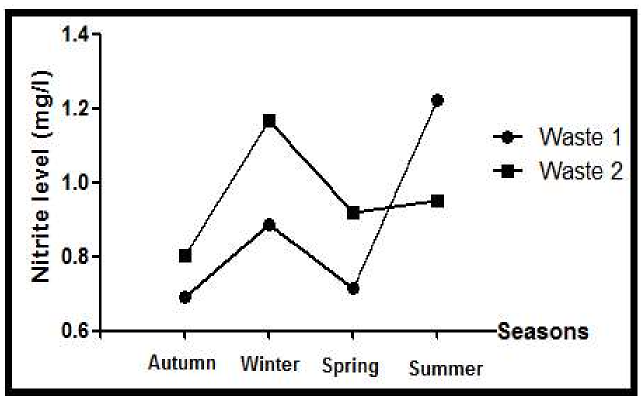

Fig. 10. Variation of nitrite level during the four seasons

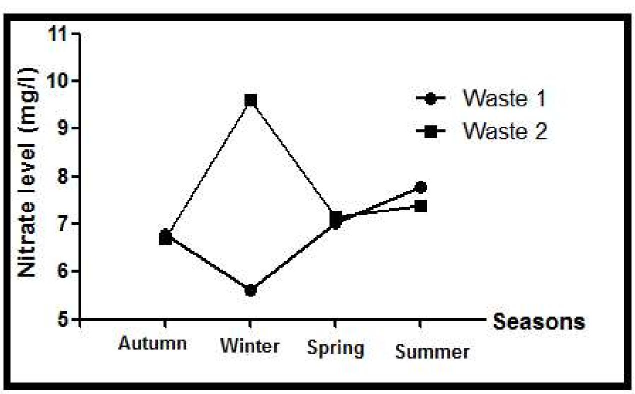

Fig. 11. Variation of nitrate level during the four seasons

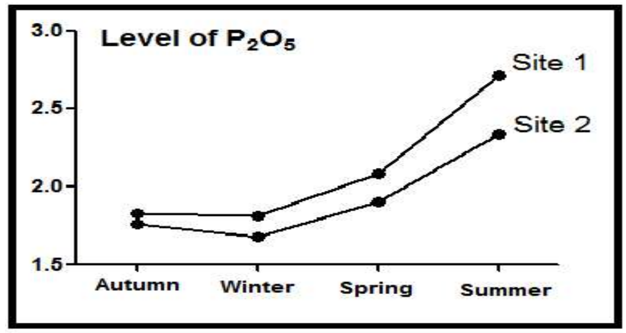

Fig. 12. Variation of phosphorous (P_2O_5) level during the four seasons

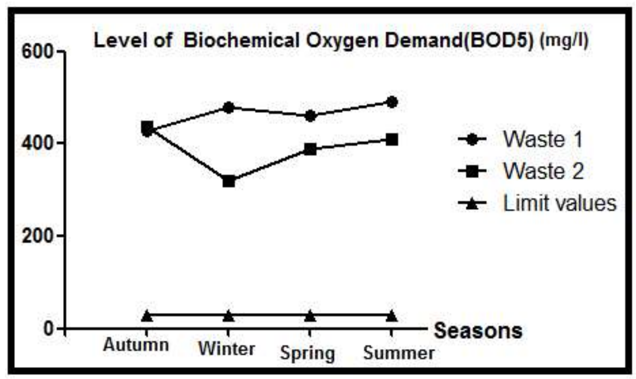

Fig. 13. Variation of levels of biochemical oxygen demand (BOD5) during the four seasons

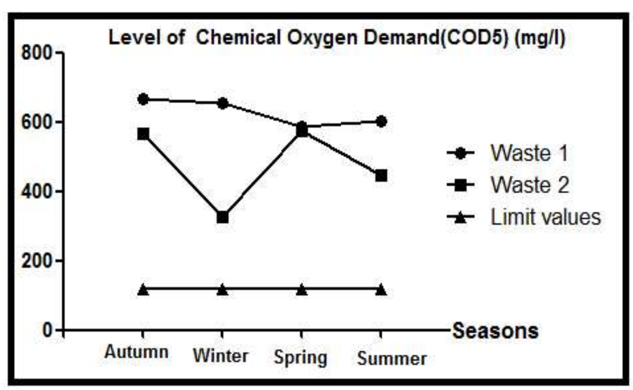

Fig. 14. Variation of levels of chemical oxygen demand (COD) during the four seasons

DCO/DBO = 1,36 Point 01 Well-degradable organic load

DCO/DBO = 1,22 Point 02

In accordance with Mougeot (1999), the rapport DCO/DBO5 indicates that the waters are perfectly biodegradable

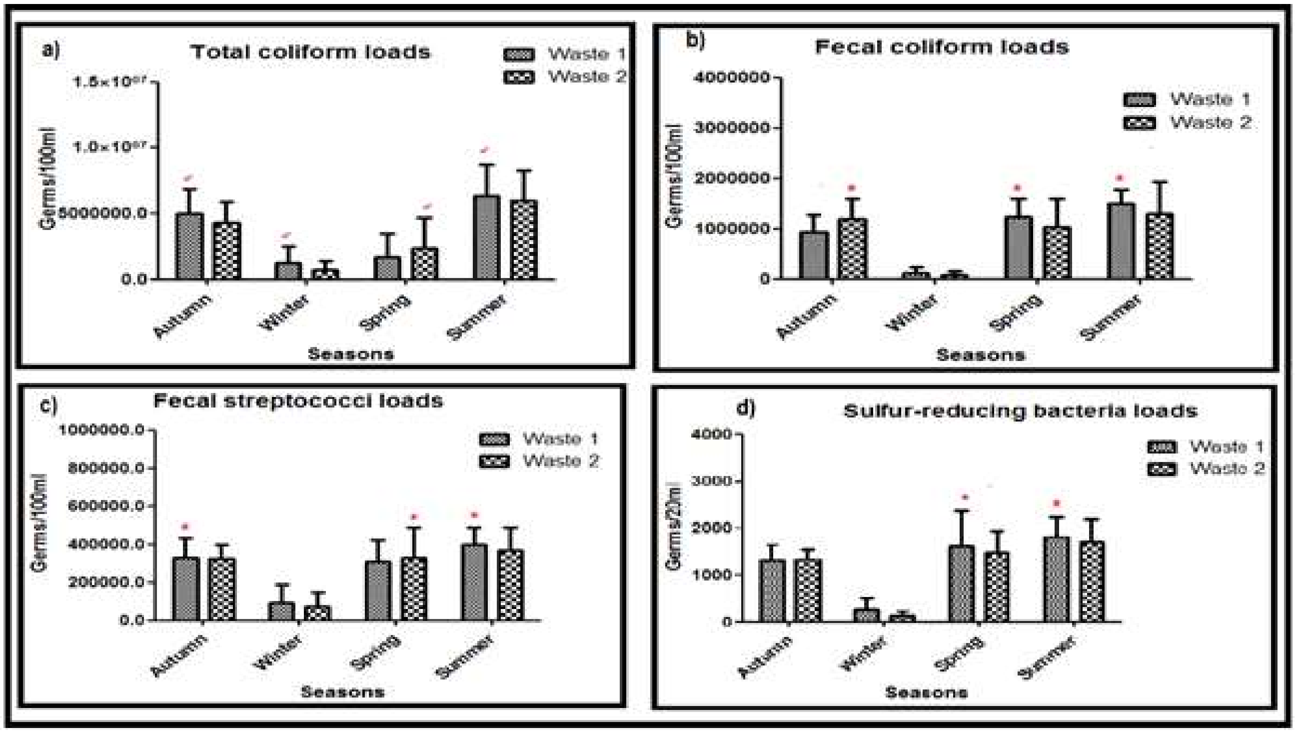

Fig. 15. Bacteriological evaluation of wastewaters of Annaba city: a) total coliform loads; b) faecal coliform loads, c) faecal streptococci loads, d) sulfur-reducing bacteria loads

Chemical oxygen demand (COD): There was significant increase in the chemical oxygen demand values is shown, ranging from 450 to 680 mg /l is due to the high content of oxidants, whether organic or mineral, in the wastewater (Fig. 14).

Bacteriological parameters: The total coliforms colonize the digestive tract of humans and animals and control the recent faecal contamination. There was significant increase in the number of coliform bacteria (up than 10^7 /100ml) (Fig. 15a) refers to the degree of risk of contamination with pathogenic bacteria**.** The enumeration of faecal coliforms revealed a relatively high rate of these microorganisms, averaging over 10^6 germs / 100 ml of sample **(**Fig. 15b**).** Furthermore, **t**he saprophytic streptococci group D, common of the nasopharyngeal and intestinal tracts of humans and animals, were chosen as indicators of older faecal pollution, due to their greater persistence in the environment**.** In addition, the counting carried out on raw water revealed a relatively low density of these bacteria compared to that of faecal coliforms and was estimated to be around 10^5 germs / 100 ml. The pathogenic organisms in wastewater can transmit diseases. Additionally, faecal Streptococci are proposed as indicators to confirm pathogen reduction efficiency, and noteworthy, faecal Streptococci are the only indicators exhibiting a significant correlation with listeria monocytogens. These would also be reliable indicators, in particular for evaluating the reduction of Salmonella (Fig. 15c). The sulphur reducing bacteria, require a strict absence of oxygen**.** The spore form can provide a good understanding of any contamination, recent or previous, although the new European directives no longer consider them as faecal pollution indicators. There was significant increase in sulfur-reducing bacteria rate responsible for the emission of foul smells than that of threshold control (Fig. 15d).

CONCLUSIONS

The large percentage of wastewaters pollution in the city evidenced by the increased levels of pH, water temperature, conductivity, suspended matter, nitrogenous and phosphorous materials. The water dissolved oxygen was decreased during seasons, except winter where the oxygen level reaches its maximum of 10mg/l. Moreover, the results showed high levels of coliform bacteria (more than 10^7 in 100 ml), streptococcus protozoan, and sulfur-reducing bacteria, which exceeded the permissible values on the national scale. This results in a negative impact on public health through the emission of disgusting odors. Therefore, there is no doubt that these dangerous results lead us to seriously think about the consequences that wastewater can leave behind, and hence to search for mechanisms and means to be taken to eliminate, or at least to reduce the harmful impact of wastewater.

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Received 21 December, 2021; Accepted 02 April, 2022

Indian Journal of Ecology (2022) 49(2): 353-357
DOI: https://doi.org/10.55362/IJE/2022/3528

Manuscript Number: 3528
NAAS Rating: 5.79

Impact of Covid-19 on Domestic Wastes after Lockdown

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***Abstract*:** To combat the spread of the COVID-19 epidemic, the Government of India implemented a lockdown plan. The study's major goal was to evaluate the impact of lockdown over household trash, focusing on mask use and handling habits. An online questionnaire survey was done on n=268 households in the Bilaspur district of Chhattisgarh, India, using the snowball sampling approach and n=34 waste collectors were interviewed offline. The population uses an average of two masks every week. Aside from that, a major per cent of participants observed an increase in the amount of medical waste in their household trash can during COVID–19 compared to prior years. The waste collectors noticed differences in the waste's physical qualities, such as a higher percentage of dry waste compared to moist waste. To reduce waste generation and overburdening at waste treatment sites, the "3R Masks Waste Reduction Model" has been proposed.

***Keywords*:** Mask, Medical wastes, Precautionary material, Pandemic, Population

Human coronaviruses (HCoVs) have been causing respiratory infections in various regions of the world since January 2020 (Atwal 2021) and it has become an outbreak in several nations. In the absence of a specific vaccination or cure for the coronavirus, some countries, including India, have decided to implement a lockdown strategy. The lockdown was intended to keep people at home for a few weeks to months. During the lockdown, there was a 70% drop in people moving to public places like parks, workplaces, and metro stations, and a 50% increase in people going to grocery and medical stores, while there was a 22% increase in people going to home areas in India (Kawoosa 2020). The members residing in a house and time of year like summer, winter, and rainy affect domestic waste generation's quantity and composition. Besides these the society, the people living inside it, their economic status, the art of living and its scale of development in the sectors of institutions, business and industries are considered major factors that affect waste (Jouhara et al 2017). During this period, two different kinds of waste are generally produced i.e., waste generated through households and waste generated through healthcare facilities which creates further challenges in the management of this solid waste (UNEP 2020). The wearing of masks in society was one of the major guidelines or suggestions provided by Health officials from various countries like the United Kingdom, Germany and Singapore (Feng et al 2020). An Infected person uses a mask to stop the spreading of infection whereas a well person uses a mask for safety when in being contact with an infected person (World Health Organization 2020). The large numbers of people were using masks resulting in harm to the environment in a new way by adding more waste in form of an infected mask (Fadare and Okoffo 2020, Patrício Silva et al 2020) and also creating problems for upcoming sustainable waste management activities (Ilyas et al 2020). Poor management of solid wastes can raise the chances of coronavirus infection, mainly in developing nations (Mol and Caldas 2020). Recently, an emerging risk to World's ecosystems is the hazardous medical waste that originated due to COVID-19 which is generally made up of plastic. (Saadat et al 2020). The study aims to analyze attitudes towards the use, disposal of masks and the amount and quality of domestic waste generated by the people of district Bilaspur situated in the Chhattisgarh state of India after the lockdown period.

MATERIAL AND METHODS

There were two targeted groups for sampling first one was the population who were using masks and the second one was the waste collectors; each person have a vehicle to collect the wastes from a particulate locality. The sample size for the first group was n= 268 and an online questionnaire were prepared to avoid contact with people during the pandemic. The self-administered questionnaire(Gupta et al 2021) containing open and close-ended types of questions and a snowball sampling method were adopted to cover the sample group. For the second group sample size was n= 34(50% of the total waste collectors). The vehicle collects the wastes from door to door in different localities of the area. To contact the second group, 4-5 people group interviews had been taken at their vehicle stand center one by one and asked questions. After four months of lockdown, the survey had been done because the life of people started again in the office, market, institutions, etc. People started to go out with precautionary materials like masks, gloves, and sanitizers. The per cent of maximum responses were taken as a reference to estimate the average number of masks and then the average number was multiplied by the population of the area for a week and month to estimate the average number of masks used by the whole population of the area. In the absence of current data, the average decadal population growth rate of the state Chhattisgarh from 1971 to 2011 was calculated 22.78% for the population estimation of 2021. The child population from 0-6 years was excluded because they had less interaction with the outside of the area. The responses were recorded in terms of percentages of the total population.

RESULTS AND DISCUSSION

People Behavior Related to Mask

Status of respondent: The respondents were students, job employees, businessmen and others such as unemployed, housewife, labour and their percentage in the total responses were 32.2, 34.5, 14.6 and 18.8%.

Consumption of average numbers of masks: The study revealed that the maximum percentage of 63.8 % of responses were used in the range of 1-3 while 23.8% used 4-6 and the very least population 12.3% were using more than 6 masks within a week. The amount of consumption of masks depends on many factors like the rate of leaving the house, the consciousness of the general public related to the use of masks and altering after use and socio-economic aspects (Ouhsine et al 2020). According to the survey, Bilaspur city consumed 4,321,808 masks every month.

Types of masks in use: There were three kinds of masks in use during the period such as i) respirator masks (N95, FFP2), ii) surgical or medical masks and iii) non-certified disposable masks (cloth masks) (Das et al 2020, Ho et al 2020). Clothing masks were used by 56.2 per cent of the population, followed by surgical masks (blue colour 3/6-layer masks), N-95 masks, and others at 24.6, 16.5, and 2.7 per cent, respectively. Figure 2 depicts the various types of masks and their respective weights.

Handling behaviour of masks: The maximum number of people (51%) was disposing of used masks in their home dustbin which mixed with other like food wastes. There was 36.8% per cent of the people put mask wastes into a separate dustbin and the rest of the people burned the wastes after using. The huge number of persons who reuse masks after washing could be the cause for the majority of respondents' lower mask consumption. Some people use a single cloth mask 2-3 times after washing and drying it, while others burn it after each use.

Medical waste even in the least amount if added to domestic waste gives results in form of hazardous waste, as a result, it can develop into a carrier for the spread of diseases like hospital waste (Ansari et al 2019). The majority of the population who wear cloth masks, as well as surgical masks, were disposing of it in their home dustbins while people who are using N-95 were concerned about infection and disposing of it in the separate dustbin. Some other methods of disposing of the masks were burning and burying them in the pit. The methods of disposing of different types of masks showing in Figure1.

Type of wastes observed in a home dustbin: The maximumper cent (47.5%) of respondents observed more amounts of medical wastes like gloves, mask sanitizer bottles, plastic materials in their dustbin compare to previous years because of the use of precautionary materials to protect from the infection followed by food wastes (37.20 %)

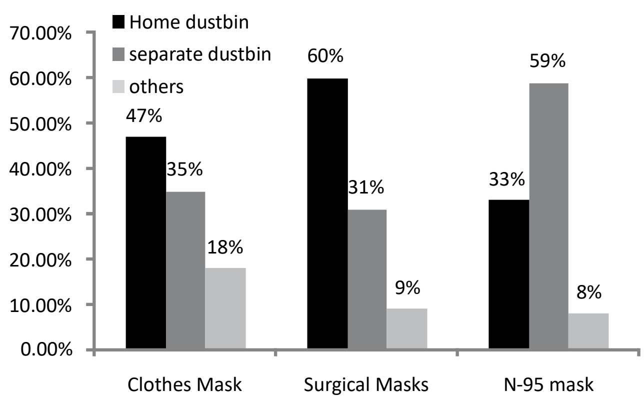

Fig. 1. Method of disposing of different types of masks by individuals (X-reflecting kinds of masks, Y-reflecting the percentage of consumers who utilize a specific disposal method)

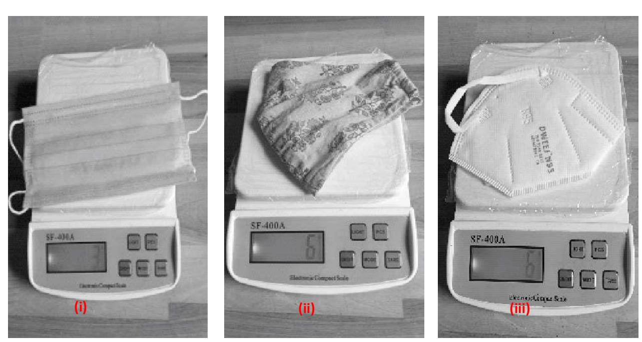

Fig. 2. Types of masks (i) Surgical mask (ii) Cloth mask (iii) N-95

may be a reason behind more hours spent in the home and the least respondents observed electric and mobile wastes (5%) may be using online methods for study, job or transaction by electronic equipment's. The wastes like infected gloves, masks and outdated medicines very simply be added to household waste which is supposed to be handled as hazardous waste and discarded alone. The proper management of home waste without any harmful effects could be problematic for the period of the COVID-19 crisis. In addition, the waste has to be collected by a specific municipal worker or waste managing operator (UN 2020). Now a day, this harmful medical waste became a great risk to Earth's ecosystems.

Responses of waste Collectors

The physical property of the wastes: The waste collectors observed changes in the types of domestic wastes. Before the pandemic percentages of wet wastes such as food wastesand dry wastes such as paper, plastic, rubber and clothes, tin etc. were 50-70 % and 30-50 % which is leading to an increase in dry wastes during a pandemic. The property of waste is leading from moist to dry. According to MoUD, the more dry wastes resulted inreducing the collection and transportation charges and also reducing the emission of carbon from the fuel of the collection vehicles.An increase in dry wastes leads to a decrease in the density of the wastes(mass per unit volume, kg/m^3).

Amount of Domestic Wastes: The 62 per cent of the waste collectors saw a decrease in the amount of domestic waste, 30% saw an increase, and 8% saw no difference in the amount of waste. Decrease in the amount of waste observed during the lockdown period as they reduce the collection time by coming once in two days and after lockdown, it was found that increases and overburden of the medical wastewereobserved.

Waste added to the municipal solid wasteper day: Disposable single used masks (especially surgical face masks) were made up of polypropylene (PP) and non-woven fabrics areadded regularly which emits 0.02 g CO2-equivalent greenhouse gas during its entire lifespan (Türkmen 2021). Table 1 shows the city's daily waste generation in the form of a mask.

3R Masks Waste Reduction Model

In May 2021, the second wave of COVID- 19 was at its peak in India with the highest number of new cases resulting in 33 per cent of the biomedical waste generated all over the country. The volume that month was huge at places. Chhattisgarh ranked second in the generation of COVID -19 waste of biomedical waste by 42 per cent after Haryana, followed by Andhra Pradesh and Delhi (downtoearth.org 2021). The "3R Masks Waste Reduction Model" has been proposed to overcome the problem of the daily accumulation of large volumes of waste, as shown in Figure 3.

The model follows the concept of three R, "Reduce-Reuse- Recycling". Reduce, the base of the model shows less consumption. For reuse, the people are less prone to be in close contact with patients. According to WHO, the general public under the age of 60 and with no prevailing health issues can use clothes masks in lieu of single-use masks by maintaining physical distancing. The last and third levels group of people who are in close contact with patients for

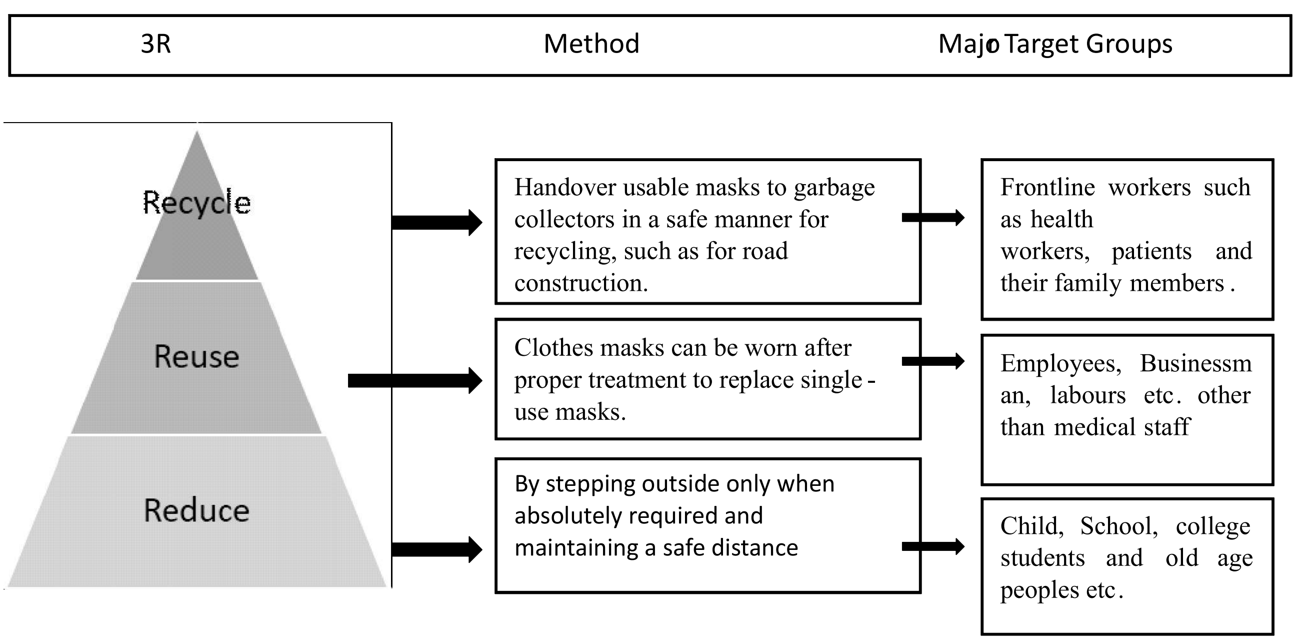

Fig. 3. 3R masks waste reduction model

Table 1. Amount of garbage added to the municipal solid waste in different forms of masks each day

Category	Number of mask generation/day	Weight of a single mask (g)	Waste addition/day (kg)
Clothes mask	80,962	6	485.77
Surgical mask	35,439	3	106.31
N-95	23,770	6	142.62
Total			734.7

many hours can keep them in separate bins for recycling. Greater Chennai Corporation (GCC) has issued guidelines for non-quarantined homes and residents. This should be discarded by either incineration or deep burial (The Union Ministry of Health and Family Welfare). According to new guidelines of CPCB (2020), masks and gloves utilized by people other than COVID-19 patients, need to be cut and put inside a paper bag for a minimum of 72 hours before disposing of it. According to Bio-Medical Waste Management Rules, 2016, bar–code bags also can be used to collect wastes (downtoearth.org 2021). For recycling, the wastes masks were used as an experiment in civil construction first time where shredded face masks were added to the recycled concrete aggregate (RCA) for the road base. This study stated that the prepared recycled material used 3 million masks in construction for one km of two-lane roads and prevented from landfill the huge volume of wastes (Mohammad et al 2021).

CONCLUSION

Despite the fact that the majority of the population is wearing clothing masks, a large volume of garbage is still being added to the waste stream, altering the properties of home waste in the form of contaminated COVID-19 preventive materials which can have a harmful effect on health and the environment in the form of life. The conversion of a large portion of household waste to medical waste has shifted our focus to developing suitable management plans for transporting medical waste safely from homes to disposal sites. The incidence of the infection may change people's lives in such a manner that they will continue to use precautionary materials even after vaccination, and the habit will be better for protecting against many infectious diseases, but it should be necessary to take environmental considerations into account. The proposed model is intended to assist in reducing trash overflow into waste treatment sites.

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Indian Journal of Ecology (2022) 49(2): 358-362
DOI: https://doi.org/10.55362/IJE/2022/3529

Manuscript Number: 3529
NAAS Rating: 5.79

Groundwater Saving in Punjab: Role of Short Duration Paddy Varieties in Agricultural Sustainability

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Abstract: There are two types of varieties of paddy grown in the state i.e. long duration and short duration. To compare the economic viability of paddy varieties, most preferred long duration variety, Pusa 44 and short duration varieties, PR121 and PR126 were chosen for the study. A random sample of sixty farmers was taken from two blocks of Ludhiana and Barnala districts. The analysis revealed that expenses on fertilizers, plant protection measures, human labour use, and expenses on diesel for irrigation was considerably higher in Pusa 44 variety vis-a-vis short duration varieties. Total variable cost incurred while growing Pusa 44 variety was Rs. 39956 per hectare whereas it was Rs. 37056 and Rs 34724, respectively in case of PR 121 and PR 126 varieties. Although gross returns and returns over variable costs (ROVC) were higher in case of Pusa 44 than short duration varieties, but it requires more number of irrigations and input usage. Pusa 44 being long duration variety, results in delayed harvesting due to late maturity of crop leading to paddy straw burning due to shortage of window between paddy harvesting and wheat sowing affecting timely sowing of the wheat crop in *rabi* season. The benefits of short duration paddy varieties in terms of saving ground water and judicious input usage should be weighed in terms of agricultural sustainability perspective for Punjab vis-à-vis higher returns from long duration paddy varieties.

Keywords: Economic analysis, Sustainability, Input use, Gross returns

India produces 107 million tonnes of rice (*Oryza sativa* L.) in an area of 44 million hectare which constitutes about 35 per cent of area and 40 per cent of food grains production in the country. About 90 per cent world's rice is grown and consumed in Asian countries. It is the major source of protein and calories for the masses (Job and Nandamohan 2004). Despite having stagnant area of rice in India during the last decade, the rice production has registered an increase of 18 per cent (Kumar et al 2018). Paddy production generates employment of about 3.5 billion man days and contributes about 10 per cent to Agricultural GDP in the country. However, paddy is considered 'water guzzler' and the unfavourable monsoon adversely affects its area, production and productivity in the country (Bouman 2009). Even it requires large quantities of inputs, particularly water, fertilizer and pesticides, contributing to high cost of cultivation (Narayanamoorthy 2013). Punjab has 1.53 per cent geographical area of India and contributed 31 per cent rice to the central pool during the year 2017-18. With the exponential increase in population, the need for increase in food grain production is becoming a great challenge. Punjab has a huge area under paddy crop though it's not staple food of the state. A sustainable production of rice in Punjab is crucial for the food security of India. Currently, out of 20 million tube wells in the country, almost 1.3 million are in Punjab, contributing to fast-paced groundwater extraction and its depletion (Satvir and Vatta 2015). The state is facing many challenges like depletion of water table, environmental issues and problem of crop diversification etc. owing to paddy cultivation. But the farmers are growing this crop due to low risk involvement and assured minimum support price and efficient marketing system in the state. To sustain paddy production, there is a need to adopt the efficient and economically viable production strategies and water saving technologies in the state (Dhillon et al 2018).

Two types of varieties of paddy are grown in the state-long duration and short duration. Under long duration varieties, Pusa 44 is sown in some districts of the state, however, this variety has not been recommended by the PAU for cultivation. Similarly, PR 121 and PR 126 are the short duration varieties sown by the farmers and recommended by PAU. These varieties are high yielding and mature nearly 20 to 37 days earlier than Pusa 44. Farmers preferred to grow short duration varieties compared to long duration in order to grow three crops in a year (Manan et al 2018). The foremost challenge to Punjab agriculture is posed by the depletion of groundwater in Central districts and its poor quality in South-Western region, requiring technological innovations besides strong policy measures. Punjab farmers deserve appreciation for adopting short duration rice varieties, which during 2017 season came to occupy about 69 per cent of parmal rice acreage. On account of short duration and low biomass, these varieties save irrigation water and lower cost incurred on pesticide usage, are suitable for transplanting after June 20, besides being amenable to residue management (Dhillon and Bains 2018). In this paper, an attempt has been made to compare the returns from long and short duration varieties of paddy grown in the state.

MATERIAL AND METHODS

Three paddy varieties namely; Pusa 44, PR 121 and PR 126 were taken under the study. Two clusters were purposely selected, one from Samrala block of Ludhiana district and another from Barnala block of Barnala district. Each cluster consisted of two to three villages and after preparing a list of farmers growing the above mentioned varieties during the year 2018-19, twenty farmers for each variety from both the clusters were randomly chosen. Hence, a total sample of 60 farmers was selected and data were collected through a well-structured schedule having details of socio-economic pattern, land holding details, input usage, cost-return structure and problems faced by farmers in raising different paddy varieties. The data were analyzed by using simple tools such as averages, percentages etc. In order to evaluate the farmer's perception with respect to constraints and advantages of different varieties, Garrett Ranking technique was used. The farmers were asked to rank the given problem according to the magnitude of the problem faced. The orders of merit given by the respondents were converted into ranks by using the following formula:

$$\text{Percentage Position} = \frac{100\,(R_{ij} - 0.5)}{N}$$

Where,

R_{ij} = Rank given for the i^{th} item by the j^{th} individual

N_j = Number of items ranked by the j^{th} individual

The percentage position of each rank thus obtained was converted into scores by referring to Garrett and Woodworth (1971). Then for each factor, the scores of individual sample farmers were added together and divided by the total respondents for whom scores were added. Thus, mean score for each problem was ranked by arranging them in the descending order.

RESULTS AND DISCUSSION

Socio-economic profile and land holding status: The socio-economic profile of the sample households is given in Table 1. Land holding pattern on sample farms (Table 2) showed that farmers growing short duration varieties have less owned land as compared to their counterparts. The operational holding on sample farms was 8.50 hectares in an overall scenario. The average operational holding size was 9.68 hectares in case of farms growing short duration

Table 1. Socio-economic profile of sample farmers growing paddy, Punjab, 2018-19

Particulars	Farmers growing paddy varieties		
	Pusa 44	PR 121	PR 126
Average age (Years)	50	44	43
Average schooling years	9	11	11
Agricultural experience (Years)	21	19	18
Family size (No.)	5.53	5.21	5.11
Family members engaged in agriculture (No.)	1.60	1.50	1.50

Relatively young farmers preferred short duration paddy varieties while having less experience in undertaking farming

Table 2. Land holding pattern on the sample farms, Punjab, 2018-19

(ha)

Particulars	Farmers growing paddy varieties		
	Long duration variety (Pusa 44)	Short duration varieties (PR 121 & PR126)	Overall
Owned land	4.30 (73.19)	3.60 (37.19)	3.82 (44.94)
Leased-in land	2.52 (42.78)	6.08 (62.81)	4.97 (58.47)
Leased-out land	0.94 (15.98)	-	0.29 (3.41)
Operational holding	5.88	9.68	8.50
Land value (Rs. lakhs ha^{-1})	59.55	62.52	61.62
Land rent (Rs. lakhs ha^{-1})	1.21	1.00	1.07

Figures in parentheses indicate the per cent share in the operational area varieties while it was 5.88 hectares for the farms growing long duration variety. The value of land for the farms growing short duration varieties was higher as compared to the farms growing long duration variety while on the other hand in case of land rent reverse was true although the average land rent was Rs 1.07 lakh per hectare on the sample farms.

Input-output coefficients: There was not much difference in seed rate for long duration variety Pusa44 and short duration varieties PR 121 and PR126. In case of fertilizer application, higher dose of urea was applied to long duration variety than short duration varieties. The extra cost of urea accounted to Rs. 452 and Rs. 492 per hectare in case of long duration variety Pusa 44 vis-a-vis short duration varieties. In case of di-ammonium phosphate (DAP) usage, more quantity was used in Pusa 44 than short duration varieties. Similar pattern was observed in the use of zinc sulphate ($ZnSO_4$) fertilizer as higher dose was applied in long duration variety in comparison to short duration varieties. Muriate of potash (MOP) was applied only in case of short duration varieties. Total expenses on fertilizer use was higher in case of Pusa 44 (Rs. 3819 ha^{-1}) than short duration varieties where it ranged between Rs. 3029 to Rs. 3292 per hectare. The expenditure incurred on plant protection measures was also higher in case of Pusa 44 than short duration varieties PR 121 and PR 126, respectively. Long duration variety require higher doses of fertilizers and plant protection measures to control pest and diseases during its period of growth in comparison to short duration varieties. Human labour requirement was also higher in long duration variety, however, use of tractor for various field operations during the crop season showed not much difference in all the varieties. Irrigation hours were considerably higher in case of Pusa 44 than short duration varieties which show its higher water requirement due to longer crop duration. Diesel usage for running diesel engine/ generator for irrigation was more than double in Pusa 44 than PR 121 while in PR 126, none of the sample farmers used diesel for irrigation purpose. The per hectare yield of paddy was 74.12 qtls for long duration variety Pusa 44 which was higher than short duration varieties PR 121 (69.87 qtls ha^{-1}) and PR 126 (67.77 qtls ha^{-1}). Thus, it can be inferred that though the productivity was comparatively lower in case of short duration varieties but these varieties require lesser quantity of inputs and saved irrigation water and time due to shorter crop period.

Number of irrigations applied to Pusa 44 variety was higher vis-à-vis PR 121 and PR 126 varieties. Consequently, farmers using submersible pump resulted in saving 16.42 and 21.50 per cent irrigation hours, respectively while irrigating PR 121 and PR 126 varieties as compared to Pusa-44 variety (Table 4). The, farmers using mono-block pumps saved 19.14 and 21.53 per cent irrigation hours in case of above cited varieties. This shows enormous saving of irrigation water while growing short duration paddy varieties and thus can play vital role in agricultural sustainability of the state.

Cost-return structure: The cost-return structure of different varieties of paddy showed that per hectare total variable cost (TVC) incurred was higher in case of Pusa 44 in comparison to PR 121and PR 126varieties (Table 5). Major components of variable cost are human labour and machine use in various

Table 3. Input-output status of different paddy varieties on sample farms, Punjab, 2018-19

(Per ha)

Particulars	Pusa 44		PR 121		PR 126	
	Quantity	Value (Rs.)	Quantity	Value (Rs.)	Quantity	Value (Rs.)
Seed (Kg)	10.97	295	12.55	375	12.42	435
Fertilizer use (Kg)						
Urea	380	2287	305	1835	300	1795
Di-ammonium phosphate (D.A.P)	35	770	25	570	30	685
Zinc Sulphate ($ZnSO_4$)	12.5	762	6.57	442	10	555
Muriate of Potash (M.O.P)	_	_	3.03	182	3.47	262
Plant protection measures (Rs.)	_	4475	_	4107	_	3902
Human labour (Hrs)	327	14880	305	14122	285	13295
Irrigation (Hrs) Value (Cost of diesel use)	359	2400	306	1180	292	_
Combine harvesting + S.M.S (Hrs)	1.27	3757	1.35	4185	1.30	4160
Tractor use (Hrs)	12.77	9450	12.97	9243	11.95	8870
Main product (Qtl)	74.12	131187	69.87	123667	67.77	119967

crop operations. These together constitute about 70 to 75 per cent of the input cost incurred on the sample farms. Similarly, fertilizer usage and plant protection measures form about 20 per cent of the total variable cost. Although electricity supply to agricultural sector is free in Punjab, the major difference in cost incurred for irrigation was diesel used for running tube wells through diesel engine/ generator set which was about 6 per cent in Pusa 44 and 3 per cent was in PR 121 variety. Gross returns (GR) as well as returns over variable costs (ROVC) were higher in case of Pusa 44 vis-à-vis short duration varieties. But, higher water usage accompanied by fertilizer and plant protection expenses for raising long duration paddy variety is an immediate threat to Punjab agriculture for agricultural sustainability in the long run.

Constraints/problems: Garret's Rank showed that short crop period was the strength of short duration varieties PR 121 and PR 126 being 120 and 136 days, respectively as compared to long duration varieties (157 days). The, short cropping period gave ease to the farmers in terms of less irrigation requirement and lower cost of cultivation, hence ranked at II and III place. Pesticide usage being lower was ranked IV by the farmers. In spite of the fact that short duration varieties require low irrigation and input usage but at the same time the yield was slightly lower than long duration varieties, hence ranked at V spot by the sampled farmers.

In case of long duration variety, the window of time for sowing wheat crop after paddy harvesting is short. So, long crop period was the major demerit reported by the farmers and hence ranked at first spot. Because of long crop period,

Table 6. Garret's rank for merits of short duration paddy varieties, Punjab, 2018-19

Merits	Short duration varieties (PR 121 & PR 126)	
	Mean score	Rank
Short crop period	6.70	I
Lower irrigation requirement	6.05	II
Low cost of cultivation	5.08	III
Lower use of pesticide	3.98	IV
Yield	3.55	V
Demerits	Long duration variety (Pusa 44)	
Long crop period	6.43	I
High cost of cultivation	6.03	II
High irrigation requirement	5.68	III
Difficult to manage paddy residue	3.78	IV
High use of pesticide/weedicide	3.18	V

Table 4. Variety-wise irrigation hours per hectare in Paddy on sample farms, Punjab, 2018-19

Particulars (Varieties & crop duration)	Submersible pump usage				Mono-block pump usage			
	No. of farmers	Average (H.P)	Irrigation (no.)	Hrs. ha^{-1}	No. of farmers	Average(H.P)	Irrigation (no.)	Hrs. ha^{-1}
Pusa-44 (157 days)	14	15	33	335	6	5	32	418
PR-121 (136 days)	11	14.5	28	280 (16.42)*	9	6	26	338 (19.14)*
PR-126 (120 days)	12	14	26	263 (21.50)*	8	6.5	25	328 (21.53)*

*Figures in brackets shows the relative difference in irrigation hours for PR-121, PR-126 vis-à-vis Pusa-44

Table 5. Cost-return structure of different varieties of paddy on sample farms, Punjab, 2018-19

(Rs. ha^{-1})

Particulars	Pusa 44	% Share in TVC	PR 121	% Share in TVC	PR 126	% Share in TVC
Human labour	14880	37.24	14122	38.11	13295	38.29
Machine use	13207	33.05	13427	36.23	13030	37.52
Cost of seed	295	0.74	375	1.01	435	1.25
Cost of fertilizer usage	3820	9.56	3030	8.18	3297	9.49
Plant protection expenses	4475	11.20	4107	11.08	3902	11.24
Irrigation charges(diesel use)	2400	6.01	1180	3.18	-	-
Interest on variable cost @ 9% p.a. for half crop season	879	2.20	815	2.20	765	2.20
Total variable cost (TVC)	39956	100.00	37056	100.00	34724	100.00
Gross returns (GR)	131187	-	123667	-	119967	-
Returns over variable cost (ROVC)	91231	-	86611	-	85243	-

cost of cultivation and irrigation requirement becomes high hence ranked II and III, respectively. Managing paddy straw is a major issue in Punjab but straw produced by long duration variety is higher in quantity and weighs heavy which cause hindrance in its proper chopping for incorporation in soil. Therefore, difficult to manage paddy straw was ranked IV by the farmers. Pesticide usage to control various pests was ranked V as major demerit of the long duration variety on the sample farms.

CONCLUSIONS

This study presents the economic returns for growing major long and short duration paddy varieties in Punjab. It was found that long duration variety was more input intensive as compared to short duration varieties. On account of short duration and low biomass, these varieties save irrigation water and cost incurred on input usage is lower. In long duration variety, irrigation need is comparatively higher, fertilizer usage, pest control measures are more. Also, the window of time for sowing wheat after harvesting paddy is short hence; crop growing period is long which are major issues vis-à-vis short duration paddy varieties. Though the returns over variable costs were slightly lower on the farms growing short duration varieties, but the savings in terms of lesser ground water extraction and lower input usage is higher. Therefore, these short duration varieties fulfil the major three requisites i.e. water saving, low input cost and short time span for crop establishment. Hence, to give paddy cultivation a sustainable pathway, the proportion of area under the short duration varieties should be increased in the state keeping in view the overall interest of Punjab in general and farming community in particular whose major share in income comes from agriculture.

Received 20 December, 2021; Accepted 02 April, 2022

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Indian Journal of Ecology (2022) 49(2): 363-371
DOI: https://doi.org/10.55362/IJE/2022/3530

Manuscript Number: 3530
NAAS Rating: 5.79

Determination of Crop Water Requirements and Irrigation Scheduling of Wheat Using Cropwat at Koga and Rib Irrigation Scheme, Ethiopia

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Abstract: Population growth, high water competition, and the effect of climate change have caused water shortage problems in the Nile basin, Ethiopia. Proper water management improves water efficiency and determining the water requirement of field crops are options for improving water productivity. In this study, the CROPWAT 8.0 model, local climate, and soil data were used to determine crop water requirement (CWR) and irrigation scheduling of wheat at Koga and Rib irrigation scheme, Nile basin. The Penman-Monteith and United States Department of Agriculture (USDA) soil conservation service methods were used to compute the reference evapotranspiration (ETo) and effective rainfall. Five levels of water depth (50%, 75%, 100%, 125%, and 150%) of the model and two irrigation intervals (14 and 21 days) were arranged in a Randomized Completely Block Design. The Koga, irrigating 75% of CROPWAT simulated water depth (9.3 , 22.9 , 44.1 and 25.8 mm at initial, development, middle and late-stage respectively) gave 3.37 t ha^{-1} wheat yield and 1.01 kg m^{-3} water productivity. The result at Rib showed that irrigating 75% of the model (9.1, 23.6, 47.2, and 34.2 mm at initial, development, middle, late-stage, respectively) gave 4.27 t ha^{-1} yield and 1.81 kg m^{-3} water productivity of wheat. The reference evapotranspiration varied from 4.86 to 3.14 mm day^{-1} at Koga and from 4.67 to 2.36 mm day^{-1} at Rib scheme. The irrigation requirement of wheat at Koga was 376.9 mm dec^{-1} while at Rib was 379.9 mm dec^{-1}. The CROPWAT model is an important tool to compute the crop water requirement of field crops in irrigated agriculture.

Keywords: Irrigation scheduling, Crop water requirement, Wheat, Koga, Rib

Water is the main production inputs in agriculture to maintain the development of irrigation agriculture and Irrigated agriculture plays an important role in food security, poverty reduction, and economic growth, thus effective management is an important issue in an irrigation system. Comprehensive irrigation water management practices are essential to improve water management and eliminate the associated problems. Agriculture is the backbone of Ethiopia but most of the cultivated land is under a rain-fed agriculture system. Even though Ethiopia has abundant water resources from precipitation, surface and subsurface source, it suffered from severe drought, high temporal and spatial variations of water resources for the last four decades. Farmers in Ethiopia produce crops under high spatial and temporal variation of rainfall which causes cop production failures. The population is growing rapidly and is expected to continue grow, which inevitably leads to increased food demand. Farmers in Ethiopia face challenges including high competition for water, unpredictable rainfall, limited financial capacity, and climate change. By realizing such challenges, the government of Ethiopia takes initiation and allocating huge investments for irrigation infrastructure development during the last two decades. Tana Beles, Megech, Koga, and Rib are some of the irrigation projects located in the Blue Nile Basin, Ethiopia. Appropriate water (crop water requirement) application in crops production can improve nutrient availability, prevent land degradation, improve crop yield and water use efficiency. Soil moisture conditions affect nutrient availability to the crops. Good irrigation management is critical for wheat productivity, a significant grain yield and tillers were observed using optimal and suboptimal crop water requirements. The proper amount and timing of irrigation water applications is a crucial decision for a farm manager to prevent yield loss and maximize the irrigation water use efficiency. Crop water requirements are the depth of water needed to meet the water loss through evapotranspiration, being disease-free, growing in large fields under non-restricting in soil, water, and fertility, and achieving full production potential under the given growing environment. Several empirical methods were developed around the world from the simplest and oldest (Blaney Criddle method) to the most recent and accurate (FAO Penman-Monteith method) to determine crop water requirement ranging. The Penman-Monteith method has been recommended as the appropriate combination method to determine reference evapotranspiration (ETo) based on climatic data. CROPWAT is a tool developed by FAO used for irrigation planning and management and is widely used to estimate reference evapotranspiration (ETo) and crop water requirement. It allows for the development of improved irrigation practices, planning of irrigation schedules, and assessment of production under rained/irrigation conditions. Irrigation agriculture is widely expanded in the Blue Nile basin like Koga and Rib irrigation schemes. Farmers can irrigate crops based on traditional know-how causing nutrient leaching, waterlogging, and severe water shortage problems in the study area. Wheat is the most dominantly cultivated cereal crop under irrigation in the Koga irrigation command area while at Rib is the newly introduced cereal crop by farmers. However, crop water requirements and irrigation schedules of wheat were not done in the study site (Koga and Rib) irrigation scheme. Therefore, the objectives of this study were to determine the crop water requirement and irrigation scheduling of wheat using the CROPWAT model for optimal resource allocation and to increase yield and water productivity.

MATERIAL AND METHODS

Study Area

Koga irrigation scheme is located in the Tana Basin under Mecha district, south of the Amhara Region, Ethiopia. It lies between 11° 20' to 11° 32' North Latitude and 37° 02' to 37° 11' East Longitude. Koga irrigation scheme is located 41 km to the West of Bahir Dar city and 543 km to the North of the capital city, Addis Ababa at 37° 7' 29.72" Easting and 11° 20' 57.85" Northing and 1953 m a.s.l. The average annual rainfall of the area is 1124 mm. The mean maximum and minimum temperatures are 26.8 °C and 9.7 °C respectively (Fig. 1). Rib irrigation scheme is located inside Tana Basin in Fogera district Northwest of Ethiopia, 60 kilometers to the East of Bahir Dar city and 648 km North of the capital city, Addis Ababa at 37°25' to 37°58' Easting and 11°44' to 12°03' Northing and an altitude of 1803 m a.s.l. It receives 1400 mm mean annual rainfall. The mean daily maximum and minimum temperature of the area is 30°C and 11.5°C.

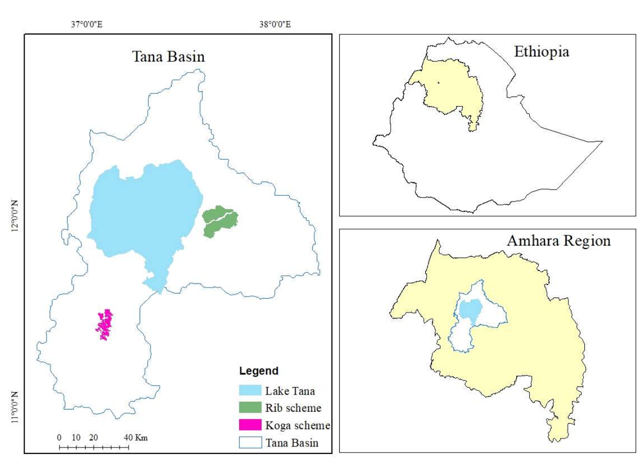

Fig. 1. Location of the study site

To verify the CROPWAT model generated water depth, field experiments were carried out for two consecutive years (2015 and 2016) at both locations. The field experiments were arranged in a randomized complete block design (RCBD) with three replications. The crop wheat variety of TAY was used and planted on 0.2 m spacing between rows with 150 kg ha^{-1} seed rate. The planting date under irrigation in the study area was started in mid-November. DAP was applied at a rate of 100 kg ha^{-1} at planting and 138 kg ha^{-1} Urea (half at planting and a half at 45 days after planting) were applied. All the agronomic practices were applied equally for all treatment as per agronomic recommendation. Local rainfall data, reference evapotranspiration (ETo), soil data, and crop data have used as an input for the CROPWAT model. Crop water requirement and irrigation water requirement were computed using the CROPWAT 8.0 model. Climate data for sixteen years (2000-2016) for the Koga irrigation scheme were taken from Koga and Bahir Dar meteorological stations while for the Rib irrigation scheme Addis Zemen meteorological station was used. The crop data for wheat (root depth, crop coefficient, critical depletion, yield response factor, and length of plant growth stage) was obtained from FAO irrigation and drainage paper 56. Information on soil properties i.e., field capacity (FC), permanent wilting point (PWP), infiltration rate, initial soil moisture depletion were done at Adet Agricultural Research Center soil laboratory using the gravimetric method. Reference evapotranspiration (ETo), the crop evapotranspiration (ETc), and irrigation water requirement (IWR) were estimated using FAO penman-Monteith method; equations 1, 2 and 3 respectively. The United States Department of Agriculture (USDA) Soil Conservation Service method was used for the estimation of effective rainfall.

$$ETo = \frac{0.408\,\Delta(Rn - G) + \gamma\,\frac{900}{T + 273}\,U2(es - ea)}{\Delta + \gamma(1 + 0.34\,U2)} \quad \text{.......... (1)}$$

Where: ETo = reference evapotranspiration [mm day-1], Rn = net radiation at the crop surface [MJ m^{-2} day^{-1}], G = soil heat flux density [MJ m^{-2} day^{-1}], T = mean daily air temperature [°C], U2 = wind speed at 2 m height [m s^{-1}], es = saturation vapour pressure [kPa], ea = actual vapour pressure [kPa], es-ea = saturation vapour pressure deficit [kPa], Δ = slope vapour pressure curve [kPa $°C^{-1}$], γ = psychrometric constant [kPa $°C^{-1}$] The crop water requirement (CWR) is the water lost from a cropped field through evapotranspiration (ET) and it is expressed as the rate of ET in mm/day. The CWR is derived from crop evapotranspiration (ETc) and estimated by the following equation. The differences in crop evapotranspiration (ETc) during the growth stages, crop coefficient (Kc) for wheat was varied over the development stage (initial development, mid-season, and late-season). Irrigation scheduling determines when and how much irrigate the specific field crop.

$$ETc = ETo \times Kc \text{ (eqn. 2)}$$

Where,

ETc = Crop Evapotranspiration (mm day^{-1}),

ETo = Reference Crop Evapotranspiration (mm day^{-1})

Kc = Crop coefficient

The irrigation requirement (IR) is the main parameter for the planning, design, and operation of irrigation and water resources systems. It is important to the optimal allocation of water resources for policy and decision-maker during the operation and management of irrigation systems. Missed management of irrigation requirements may lead to inappropriate capacities storage reservoirs, low water use efficiency, reduction of the irrigated area, and increased development costs. The irrigation requirement is therefore determined by the following equation.

$$IRn = ETc - (Pe + Ge + Ws) + LR \text{ (eqn 3)}$$

Where, IRn = Net irrigation requirement (mm), ETc = Crop evapotranspiration (mm), Pe = Effective dependable rainfall (mm), Ge = Groundwater contribution from water table (mm), Ws = Water stored in the soil at the beginning of each period (mm) and LR = Leaching requirement (mm)

Field experiment: The on-farm trial was conducted in the dry season (November to April) with ten treatments. Two fixed irrigation intervals of 14 and 21 days and five water depths 50, 75,100,125 and 150 % of CROPWAT 8.0 generated were arranged in Randomly Completed Block Design (Table 1). During crop water requirement determination 70 % application efficiency was applied at both locations.

Table 1. Treatment setup of the experiments

Treatment	Depth and interval CWR at 14 days	Treatment	Depth and interval CWR at 21 days
T1	50%	T6	50%
T2	75%	T7	75%
T3	100%	T8	100%
T4	125%	T9	125%
T5	150%	T10	150%

RESULTS AND DISCUSSION

The soil sample was taken before the planting of wheat takes place and analyzed using laboratory procedure. The particle size of the sample was determined using the hydrometer method. The result as shown the soil texture was varied in the study site (Table 2). It shown that the texture was laid under the clay soil texture class at Koga according to and the other physical characteristics were similar with . The soil analysis at Rib has shown that a light clay classification and has high alluvial deposited that comes from a mountainous area upstream of the Rib River (Table 2). Data of wheat planting and harvesting date, critical depletion level, root depth, crop growing period (Table 3) and soil characteristics of the study area (Table 2) were used to compute crop evapotranspiration.

The reference evapotranspiration (ETo) obtained using the input data at the Koga irrigation scheme was high between February and June (4.0-4.86 mm day^{-1}) due to the high temperature (Table 4). It decreases after July and the lowest value was 3.14 mm day^{-1} in August due to low temperature in the area. The average reference evapotranspiration was 3.88 mm day^{-1} (Table 4). The reference evapotranspiration value at Rib irrigation scheme shown that, a high evaporation rate was observed in March (4.67 mm day^{-1}) while the lowest evaporation (2.36 mm day^{-1}) was recorded in July (Table 5). The June, July, August, and September are the rainy seasons. The lowest rainfall and effective rainfall was during November to May (Table 6). The average rainfall of the last sixteen years (2000 – 2017) was used as input and the USDA soil conservation service was applied to estimate effective rainfall and to compute the wheat water requirement and irrigation scheduling. The average annual rainfall at Koga and Rib irrigation scheme

Table 2. Soil characteristics of the study area

Site	FC (%)	WP (%)	Sand (%)	Silt (%)	Clay (%)
Koga	30.8±1.7	18.9±1.2	20.2±4.8	22.4±2.7	57.3±4.5
Rib	59.0±1.3	21.0±1.4	24.0±2.4	36.0±3.5	40.0±5.2

Table 3. Input data for CROPWAT model in the study area

Crop	Planting and harvesting date	Root depth (m)	Depletion fraction (P)	Yield response factor (K_y)			
				Initial	Development	Middle	Late
Wheat	Mid-November	0.6 - 1.5	0.55	0.20	0.60	0.50	0.50

were 874.3 mm and 1032.0 mm while the effective rainfall was 539.2 mm 623.1 mm respectively (Table 6). The monthly reference evapotranspiration (ETO) exceeds the monthly rainfall from January to May and from November to December on both locations (Fig. 2, 3). These indicate that irrigation water is substantial during these months in the study area.

Crop water requirement: The monthly water requirement and irrigation requirement of wheat planted in mid-November shown that crop water demand in both locations was varied within the same month. The maximum crop water requirement was in February was 46.3 mm dec^{-1} at Koga and 50.2 mm dec^{-1} at Rib irrigation scheme (Table 7, 8). This variation comes from high-temperature variation between the two study sites (Table 5, 4).

Net irrigation requirement and irrigation scheduling: The farmers applied irrigation water through furrow irrigation (dominantly) and flooding irrigation (minor) systems. The application efficiency in the study area was taken as 70 % to determine irrigation requirements. The total gross and net irrigation water requirement for wheat at the Koga irrigation scheme was 529.2 mm and 370.5 mm respectively while at the Rib irrigation scheme was 635.8 mm and 445 mm respectively (Table 9).

Table 4. Climate characteristics of Koga irrigation scheme

Month	Temperature (°C)		Relative humidity (%)	Wind speed (km day^{-1})	Sunshine hours	Radiation ($MJ/m^2 day^{-1}$)	ETo (mm day^{-1})
	Min	Max					
January	8.2	27.1	48	61	9.5	20.9	3.45
February	10	29.1	43	69	9.7	22.6	4.01
March	12.7	30.1	41	86	9.2	23.3	4.56
April	14.4	30.3	42	95	9.1	23.6	4.86
May	15.2	29.7	52	86	8.5	22.3	4.62
June	14.2	27.8	66	86	6.9	19.5	4.00
July	14	24.4	76	69	4.6	16.2	3.21
August	13.9	24.8	84	69	4.6	16.4	3.14
September	13.4	25.8	73	69	6.3	18.8	3.57
October	13.7	26.8	64	69	8.7	21.4	3.96
November	11.2	26.9	57	61	9.7	21.4	3.72
December	8.5	26.8	52	61	9.7	20.6	3.41
Average	12.4	27.5	58	73	8	20.6	3.88

Table 5. Climate characteristics of Rib irrigation scheme

Month	Temperature (°C)		Relative humidity (%)	Wind speed (km day^{-1})	Sunshine hours	Radiation ($MJ/m^2 day^{-1}$)	ETo (mm day^{-1})
	Min	Max					
January	9.8	27.7	67	156	8.3	19.1	3.57
February	10.8	29.5	63	156	9.3	21.9	4.25
March	11.8	29.7	60	147	9.2	23.2	4.67
April	12.1	29.2	59	130	8.3	22.3	4.57
May	12.1	29.5	71	156	6.8	19.8	4.12
June	12.0	26.8	86	156	5.6	17.7	3.37
July	12.1	23.7	94	104	2.0	12.4	2.36
August	12.0	24.0	95	86	2.2	12.8	2.40
September	11.6	25.2	91	104	6.7	19.4	3.38
October	10.8	27.2	82	138	8.4	20.9	3.69
November	10.3	27.2	77	138	9.1	20.4	3.56
December	10.3	27.6	71	112	8.8	19.2	3.40
Average	11.3	27.3	76	132	7.1	19.1	3.61

The crop needs optimal moisture conditions to achieve maximum yield. The total available moisture (TAM) and readily available moisture (RAM) (Fig. 4, 5) are media that the plant can get from the root zone with no water stress. The crop water requirement of wheat varies in place, month, and growth stage in the study area. In general optimal irrigation application considering soil water holding capacity and crop water requirement (especially during critical stages of wheat) is essential to improve water shortage problems and to enhance yield and water productivity of the study area.

Yield and water productivity of wheat: The yield and water productivity of wheat for irrigation interval and depth has significantly affected at both locations. The optimal yield of 3.37 t ha^{-1} and 1.01 kg m^{-3} water productivity of wheat were obtained under 75 % CWR within 14-day irrigation interval at Koga (Table 11). The yield showed an increasing trend with the increase of water depth. However, a further increase in irrigation level hurt the grain yield of wheat. The production was low compared to other productive areas of northwestern Amhara this is due to the soil condition (acidic soil) of Koga command area. Besides, the soil at Koga has very low organic matter content and available phosphorus as

Table 6. Rainfall and effective characteristics of the study irrigation scheme

Month	Rainfall (mm)		Eff. Rainfall (mm)	
	Koga	Rib	Koga	Rib
January	0.0	6.0	0.0	5.9
February	0.0	2.0	0.0	2.0
March	0.1	0.0	0.1	0.0
April	0.0	11.0	0.0	10.8
May	7.3	32.0	7.2	30.4
June	122.0	110.0	98.2	90.6
July	314.8	355.0	156.5	160.5
August	274.4	319.0	152.4	156.9
September	137.9	129.0	107.5	102.4
October	17.8	51.0	17.3	46.8
November	0.0	13.0	0.0	12.7
December	0.0	4.0	0.0	4.0
Total	874.3	1032.0	539.2	623.1

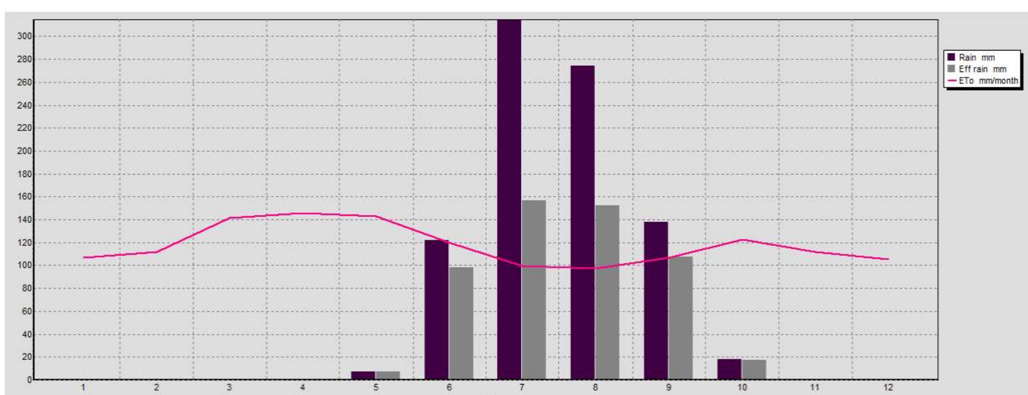

Fig. 2. Reference evapotranspiration (ETo), rainfall and effective rainfall at Koga scheme

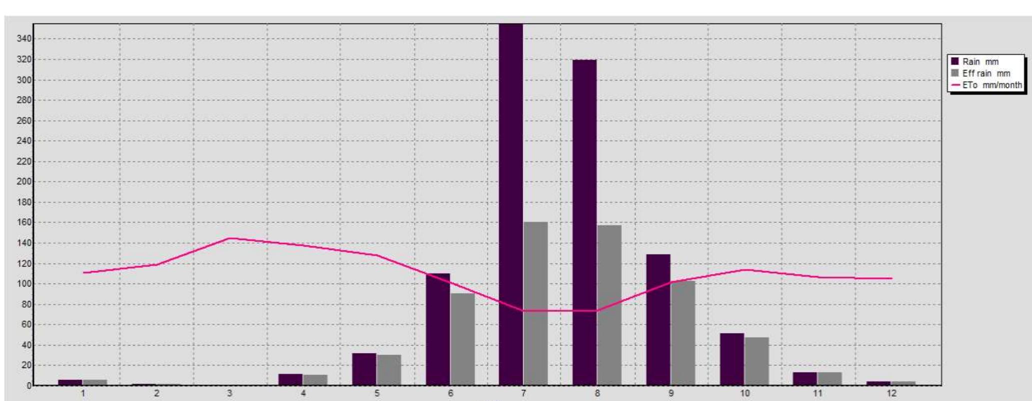

Fig. 3. Reference evapotranspiration (ETo), rainfall and effective rainfall at Rib scheme

Table 7. Crop water requirement and irrigation requirement of wheat at Koga irrigation scheme

Month	Decade	Stage	Kc (Coeff.)	ETc (mm day^{-1})	ETc (mm dec^{-1})	Eff rain (mm dec^{-1})	Irr. Req. (mm day^{-1})
November	2	Init	0.30	1.12	6.7	0	6.7
November	3	Init	0.30	1.09	10.9	0	10.9
December	1	Init	0.30	1.05	10.5	0	10.5
December	2	Dev	0.36	1.23	12.3	0	12.3
December	3	Dev	0.64	2.20	24.2	0	24.2
January	1	Dev	0.94	3.24	32.4	0	32.4
January	2	Mid	1.15	3.96	39.6	0	39.6
January	3	Mid	1.16	4.21	46.3	0	46.3
February	1	Mid	1.16	4.42	44.2	0	44.2
February	2	Mid	1.16	4.63	46.3	0	46.3
February	3	Late	1.08	4.53	36.2	0	36.2
March	1	Late	0.83	3.62	36.2	0	36.2
March	2	Late	0.54	2.47	24.7	0	24.7
March	3	Late	0.34	1.60	6.4	0	6.4
Total					377	0.1	376.9

Table 8. Crop water requirement and irrigation requirement of wheat at Rib irrigation scheme

Month	Decade	Stage	Kc (Coeff.)	ETc (mm day^{-1})	ETc (mm dec^{-1})	Eff rain (mm dec^{-1})	Irr. Req. (mm day^{-1})
November	2	Init	0.30	1.07	6.4	1.9	4.9
November	3	Init	0.30	1.05	10.5	2.5	8.0
December	1	Init	0.30	1.04	10.4	2.0	8.4
December	2	Dev	0.36	1.23	12.3	0.9	11.4
December	3	Dev	0.65	2.25	24.8	1.2	23.6
January	1	Dev	0.96	3.38	33.8	1.9	31.8
January	2	Mid	1.17	4.18	41.8	2.2	39.6
January	3	Mid	1.18	4.48	49.3	1.7	47.6
February	1	Mid	1.18	4.75	47.5	1.1	46.5
February	2	Mid	1.18	5.02	50.2	0.6	49.6
February	3	Late	1.10	4.85	38.8	0.4	38.4
March	1	Late	0.84	3.82	38.2	0.0	38.2
March	2	Late	0.55	2.57	25.7	0.0	25.7
March	3	Late	0.34	1.60	6.4	0.0	6.3
Total					396.1	16.5	379.9

Table 9. Irrigation scheduling of wheat at Koga irrigation scheme

Date	Day	Stage	Rain (mm)	Ks (fract.)	Eta (%)	Depl (%)	Net Irr (mm)	Deficit (mm)	Loss (mm)	Gr. Irr (mm)
28-December	44	Dev	0	1	100	56	58.0	0	0	82.8
18-January	65	Mid	0	1	100	56	70.7	0	0	101.0
04-February	82	Mid	0	1	100	57	71.9	0	0	102.7
20-February	98	Mid	0	1	100	58	72.8	0	0	104.0
20-March	126	End	0	1	100	77	97.1	0	0	138.7
24-March	End	End	0	1	0	4				

Table 10. Irrigation scheduling of wheat at Rib irrigation scheme

Date	Day	Stage	Rain (mm)	Ks (fract.)	Eta (%)	Depl (%)	Net Irr (mm)	Deficit (mm)	Loss (mm)	Gr. Irr (mm)
28-November	14	Init	0	0.82	92	64	45.1	0	0	64.5
12-December	28	Init	0	1	100	26	24.3	0	0	34.7
26-December	42	Dev	0	1	100	29	33.5	0	0	47.9
09-January	56	Dev	0	1	100	37	50.4	0	0	72.0
23-January	70	Mid	0.9	1	100	40	57.9	0	0	82.6
06-February	84	Mid	0	1	100	44	63.0	0	0	90.0
20-February	98	Mid	0	1	100	48	68.6	0	0	98.0
06-March	112	End	0	1	100	43	61.3	0	0	87.6
20-March	126	End	0	1	100	28	40.9	0	0	58.5
24-March	End	End	0	1	0	3				

Table 11. Result of yield and water productivity in the study area

Treatment	Yield (ton ha^{-1})		Water productivity (kg m^{-3})	
	Koga	Rib	Koga	Rib
14D x 50%	2.06	3.67	0.92	1.88
14D x 75%	3.37	4.25	1.01	1.47
14D x 100%	3.54	3.99	0.66	1.04
14D x 125%	3.61	4.54	0.64	0.95
14D x 150%	3.33	4.13	0.62	0.72
21D x 50%	2.94	3.98	1.02	2.38
21D x 75%	3.36	4.27	1.07	1.81
21D x 100%	2.87	4.14	0.68	1.34
21D x 125%	2.95	4.03	0.96	0.95
21D x 150%	2.09	3.96	0.33	0.91
CV	8.9	5.2	7.6	7.4
LSD (5%)	**	**	ns	*

Note: D = Day, * = significant, ns = no significant and ** = highly significant

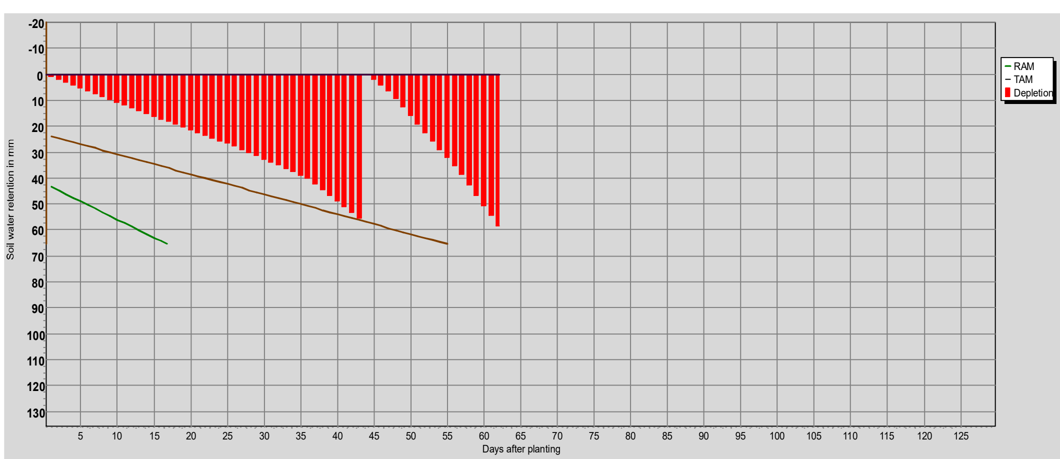

Fig. 4. Irrigation scheduling of wheat at Koga irrigation scheme

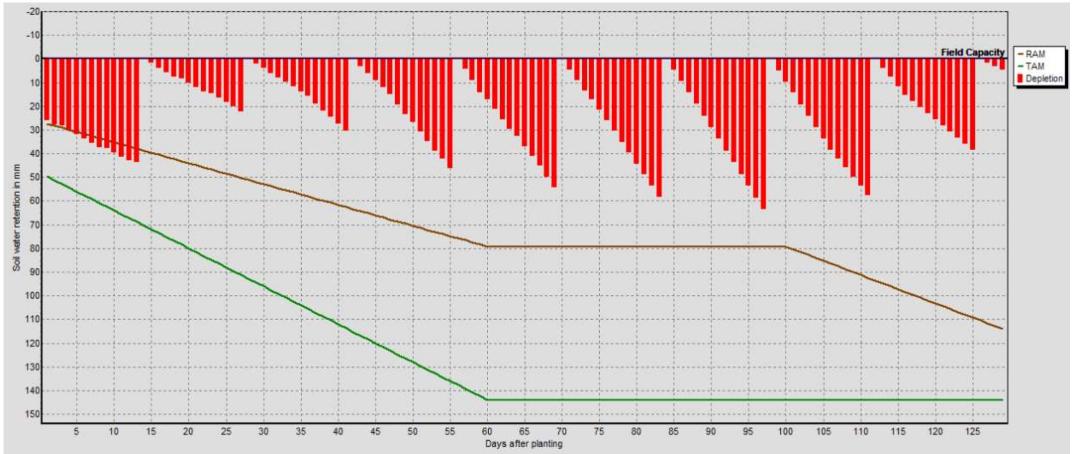

Fig. 5. Irrigation scheduling of wheat at Rib irrigation scheme

categorized by. The yield of wheat at Rib was 4.54 t ha^{-1} of wheat yield and 0.95 kg m^{-3} of water productivity was obtained at 125 % CWR within 14 days irrigation interval (Table 11). However, at Rib scheme 4.27 t ha^{-1} yield and 1.81kg m^{-3} of water productivity was achieved using 75% of CROPWAT generated depth within 21 days irrigation interval. Therefore, application of the CROPWAT generated depth of irrigation water within 21 days of irrigation interval is another option for the study area. The soil at Rib is alluvial deposited which comes from the upper catchments which has good nutrient content results the yield of wheat at Rib was higher than at Koga scheme.

CONCLUSION

Monthly crop water requirement and irrigation water requirement of wheat have high spatial and temporal variation. Simulation of crop water requirement and scheduling of wheat using the CROPWAT model was specific to the study area owing to a high seasonal and spatial variation. At Koga, irrigating 75 % CWR with 14 day interval gave optimal yield and water productivity while at Rib, irrigating 75 % CWR within 21 days irrigation interval gave better yield and water productivity. This study showed that the CROPWAT generated water depth is a good tool to determine crop water requirement of field crops. The study will help to improve the management of water resources and the productivity of wheat. CROPWAT tool can help to assess crop water requirement and irrigation scheduling of field crops in areas where water resource is limited. This study may a reference for decision-making for future planning.

Author contributions: D.T. and A.A. were responsible for Methodology, Software, Validation, Formal Analysis, Investigation, and the Original Manuscript Preparation. A.T. was responsible for Review and Editing, Discussions, Visualization, and writing the final draft. A.E. and M.W. was responsible for data collection, Editing and Discussion.

Conflicts of Interest: The authors declare there is no conflict of interest.

ACKNOWLEDGMENT

Authors recognized Ethiopian Meteorological Service Agency for providing meteorological data and Amhara agricultural research institute (ARARI) and Adet agricultural research center (AARC) for securing all expenses of the research.

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Received 20 October, 2021; Accepted 02 March, 2022

Indian Journal of Ecology (2022) 49(2): 372-377
DOI: https://doi.org/10.55362/IJE/2022/3531

Manuscript Number: 3531
NAAS Rating: 5.79

Impact of Molybdenum Application on Yield, Quality and Profitability of Cauliflower (*Brassica oleracea* var. *botrytis* L.) in an Acid Alfisol Soil

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Abstract: A field experiment was laid out to evaluate the impact of molybdenum application on the yield, quality, and profitability of cauliflower. The experiment comprised of eleven treatments i.e., T_1=NPK (control), T_2=NPK + FYM (RDF), T_3=NPK + Lime, T_4=NPK + Lime + FYM, T_5=RDF + Mo at recommended rate @ 1 kg ha^{-1} (soil), T_6=RDF + Mo at 1.5 times the recommended rate @ 1.5 kg ha^{-1} (soil), T_7=RDF + Mo at recommended rate @ 0.1% (foliar sprays), T_8=RDF + Mo at 1.5 times the recommended rate @ 0.15% (foliar sprays), T_9=RDF along with Mo @ 1 kg ha^{-1} (soil) and @ 0.1% as foliar sprays, T_{10}=RDF along with Mo @ 1 kg ha^{-1} (soil) and @ 0.15% as foliar sprays, and T_{11}=Subhash Palekar's Natural Farming (SPNF). The highest curd yield (20.7 t ha^{-1}) was recorded in T_{10}, where NPK was applied along with FYM and Mo @ 1 kg ha^{-1}(soil) + @ 0.15% (foliar) with a 29.1 per cent increase over treatment T_2. The same treatment enhanced the ascorbic acid (77.8 mg 100g^{-1}), curd solidity (46.25 g cm^{-1}), and total soluble solids (8.4° Brix) and also resulted in higher net-returns (₹ 3,10,260 ha^{-1}) and benefit-cost ratio (3.99). Mo application positively influenced the cauliflower production in an acid Alfisols. However, the conjoint application of Mo (basal and foliar) proved its superiority in enhancing the productivity and profitability of cauliflower compared to their respective sole application.

Keywords: Cauliflower, Molybdenum, SPNF, Acid soils

Cauliflower (*Brassica oleracea* var. *botrytis* L.) belongs to the Cruciferae family, is one of the major cole crop grown throughout the world (Wani et al 2016). In India, it is being cultivated in an area of 0.45 mha with a production of 8.7 million MT (Anonymous 2018). In Himachal Pradesh, it occupies an area of 5.56 thousand ha with a production of 131.01 thousand MT (Anonymous 2018). As cauliflower is a heavy feeder of nutrients, it requires a high amount of NPK and micronutrient fertilization besides other recommended package of practices for successful cultivation. Among many constraints for the low productivity of cauliflower, imbalanced nutrition is one of the major limiting factor responsible for multi nutrient deficiency, particularly of molybdenum, resulting in yield and quality deterioration.

Molybdenum (Mo) is one of the essential micronutrient affecting crop quality and productivity. Common Mo deficiency in cauliflower is generally whiptail in which leaf-blades are not fully developed and only the midrib is present which appear as a whip (Sharma 2002). It helps in biological N fixation as it is a component of the enzymes nitrogenase and the nitrate reductase and plays an important role in phosphorus utilization and protein synthesis. In India, 49 mha area is occupied by acid soils, of which 24.4 mha are considered moderately acidic (pH 4.5-5.5) and in the Himachal Pradesh, about 1.57 lakh ha area is under moderately acid soils (Maji et al 2012). Molybdenum in acid soils tends to be unavailable to plants. The Mo availability for growth of the plant is strongly dependent on the soil reaction, soil N levels, concentration of adsorbing oxides (e.g., Fe oxides), the organic matter, and the extent of water drainage (Elkhatib 2009, Rutkowska et al 2017). Molybdenum occurs in the soil as an oxy complex molybdate (MoO_4^{2-}) (Mengel et al 2001) and its soil chemistry resembles as that of phosphate or sulphate. Mo is likely to become critical in the future for sustaining high productivity in certain areas, particularly in acid soils. Keeping in view the future scenario, the present study was carried out with an objective to find out the effective method of Mo application to renumerate the Mo deficiency in the plant which greatly effects the productivity, quality, and the productivity of cauliflower in an acid Alfisol.

MATERIAL AND METHODS

A field trial was conducted during winter season of 2019-20 on cauliflower cv. Pusa Snowball K-1 at the experimental farm of Department of Soil Science, CSK HPKV, Palampur situated at 32°09' N latitude and 76°55' E longitude and at an altitude of about 1291 m above mean sea level. The study area lies in the Palam valley representing mid hills sub-humid agro-climatic conditions of Himachal Pradesh with an average rainfall of 2500 mm of which 20% is received during October to April. Taxonomically, the soils of the experimental site fall under order Alfisol (Typic Hapludalfs). The soils of the experimental site were silty clay loam in texture, strongly acidic with pH 5.29, organic carbon content of 7.11 g kg^{-1} and the content of available nitrogen, phosphorus, potassium and molybdenum were 251 kg ha^{-1}, 21.2 kg ha^{-1}, 170 kg ha^{-1} and 0.13 mg kg^{-1}, respectively.

The experiment was laid out in Randomized complete Block Design with eleven treatments, each allocated randomly and replicated thrice. The treatments comprised of T_1=NPK (control), T_2=NPK + FYM (RDF), T_3=NPK + Lime, T_4=NPK + Lime + FYM, T_5=RDF + Mo at recommended rate @ 1 kg ha^{-1} (soil), T_6=RDF + Mo at 1.5 times the recommended rate @ 1.5 kg ha^{-1} (soil), T_7=RDF + Mo at recommended rate @ 0.1% (foliar sprays), T_8=RDF + Mo at 1.5 times the recommended rate @ 0.15% (foliar sprays), T_9=RDF along with Mo @ 1 kg ha^{-1} (soil) and @ 0.1% as foliar sprays, T_{10}=RDF along with Mo @ 1 kg ha^{-1} (soil) and @ 0.15% as foliar sprays, and T_{11}=Subhash Palekar's Natural Farming (SPNF).

Basal application of molybdenum was done before transplanting and its foliar sprays were applied at 45 and 60 DAT. The cauliflower seedlings were transplanted in October, 2019 at a spacing of 60 × 45 cm. The recommended doses of N, P_2O_5, and K_2O were applied @ 115: 60: 75 kg ha^{-1} through urea, single super phosphate (SSP), and muriate of potash (MOP), respectively, except in treatment T_{11}. Half dose of urea (N), muriate of potash (K_2O) and full dose of single super phosphate (P_2O_5) were applied at the time of transplanting. The remaining half dose of urea (N) was applied further in two equal splits at 30 days after transplanting and at curd initiation whereas the remaining half dose of muriate of potash (K_2O) was applied at curd initiation. The experiment field was ploughed twice and the recommended FYM @ 20 t ha^{-1} was added to all treatments except in treatment T_1, T_3, and T_{11}. Lime application was done at the rate of 10 t ha^{-1} in the treatment T_3 and T_4. In treatment T_{11}, the cauliflower seedlings were raised by the seeds soaked overnight with beejamrit solution @ 1 l kg^{-1} before sowing. The ghanjeevamrit @ 250 kg ha^{-1} along with the FYM @ 250 kg ha^{-1} was incorporated in the treated plots before transplanting. The jeevamrit was applied at 21 days interval through foliar sprays @ 50 l ha^{-1} per spray (Mahankuda and Tiwari 2020). Irrigation and other intercultural operations were followed as per the recommended package of practices

Plant sampling and analysis: Five plants were randomly selected to record observations for various growth, yield contributing characters, yields, and quality parameters of cauliflower which consisted of curd initiation, marketable curd maturity, stalk length, number of leaves, plant height, curd depth, equatorial length, curd size index, curd diameter, curd solidity, marketable yield $plant^{-1}$, curd yield, gross weight $plant^{-1}$, gross yield, total soluble solids (TSS) and ascorbic acid. The determination of TSS and ascorbic acid were done on fresh curds by employing the refractometric (AOAC 1990) and titration method (Ranganna 1979).

Economic evaluation: Net returns and benefit-cost ratio were calculated as suggested by Zivenge et al (2013) i.e., Net returns = Gross returns – Total production cost.

$$\text{Benefit it: Cost (B:C)} = \frac{\text{Gross returns}}{\text{Total production cost}}$$

RESULTS AND DISCUSSION

Curd initiation: It was not significantly affected by different treatments (Table 1). However, a noticeable difference in days to initiation of curd among treatments was observed. The variation among the desired growth trait might be because of the temperature fluctuations recorded during the crop growing period. The same observations were also reported by Thakur (2014) in cauliflower and Thapa et al (2016) in broccoli.

Marketable curd maturity: The highest number of days to curd marketable maturity (122.3 days) were in T_{11} and lowest (101.7 days) in T_{10} as shown in Table 1. The number of days were significantly lower in T_{10} and the per cent reduction was to a tune of 11.3, 8.13, 8.4, and 6.4 per cent when compared to the treatment T_1, T_2, T_3, and T_4, respectively. Treatment T_{10} was statistically at par with the T_9 and the treatments receiving the foliar application (T_7 and T_8). The role of Mo in converting inorganic phosphorus to organic phosphorus compounds i.e., phospholipids, amino acids, ATPs, etc. within the plant (Kaiser et al 2005) might have played a significant role for causing early maturity (Sahito et al 2018). A similar effect on the number of days to marketable curd maturity resulting from the Mo application was also reported in broccoli by Thapa et al (2016).

Plant height: The plant height was significantly more in T_{10} (51.6 cm) with an increase of 33.3, 21.1, 24.3, and 19.7 per cent over the treatment T_1, T_2, T_3, and T_4, respectively, and the lowest plant height (33.3 cm) was in T_{11} as depicted in table 1. The beneficial role of FYM and lime in improving the soil health (Chander and Verma 2009) and increasing the availability of nutrient by affecting the soil pH (Santos et al 2018), might have resulted in taller plants. The treatment T_{10} was statistically at par with the treatment T_9 and T_8. Among the treatments comprising of Mo application (soil or foliar), plant height in foliar treated treatments (T_7 and T_8) were superior to the basal application (T_5 and T_6). Mo is a component of enzyme nitrogenese and nitrate reductase which are required for the nitrogen fixation and assimilation. As nitrogen is responsible for an increase in the vegetative growth of the plant (Sahito et al 2018) and Mo application might have played a significant role in enhancing the plant height. A similar increase in the plant height due to the Mo application was also reported by Kumar et al (2010b), Ningawale et al (2016) and Sani et al (2018).

Stalk length: The stalk length was superior in T_{10} (4.6 cm) over rest of the treatments. The treatments comprising of Mo application either through soil, foliar or both, behaved statistically alike as depicted in Table 1. The Mo role in nitrogen metabolism might have influenced the stalk length. Stimulative effect of Mo on stalk length has also been reported by Kumar et al (2010a,b). In treatment T_{11}, because of the sole application of organic inputs (ghanjeevamrit, beejamrit, and jeevamrit) having low nutrient contents did not prove good enough to meet the nutrient requirement of the crop. Hence, leading to shorter stalk length (3.7 cm) when compared to the control and other treatment combinations.

Number of leaves: The number of leaves plant^{-1} were significantly more in T_{10} (21.2) with an increase of 26.2, 19.8, 23.2, and 14.6 per cent higher when compared to the treatment T_1, T_2, T_3, and T_4, respectively as depicted in Table 1. However, it was statistically at par with the T_9 and the treatments receiving the foliar application of Mo (T_7 and T_8). The treatments of Mo application either through soil or foliar, behaved statistically similar to each other. Mo is responsible for the synthesis of indole-3 acetic acid (IAA) (Kaiser et al 2005) which enhances the bud formation and hence resulted in a greater number of leaves plant^{-1}. Similar stimulative effect of Mo application on the number of leaves plant^{-1} were also reported by Kumar et al (2010a,b) and Ningawale et al (2016).

All the growth parameters were significantly influenced by Mo application (Table 1). Similar enhancements in the growth parameters due to Mo application were also reported by Pandher et al (1976), Kumar et al (2010a,b, 2012), Ningawale et al (2016), and Singh et al (2017). The incremental effect of Mo on cauliflower's growth parameters may be due to the regulatory effect of Mo on enzyme systems involved in N assimilation and nitrate reduction. The enhancement in the growth parameters resulted from the foliar application of Mo when compared to the soil application was probably due to the direct application of fertilizer to the plant in the former treatment, which might have resulted in the timely availability of Mo at critical growth stages which might have enhanced the overall plant growth attributes. Also, the better plant growth observed with combined (soil and foliar) application of the molybdenum when compared to their respective sole application might be attributed to the availability of Mo throughout the crop growth and development stages i.e., in early growth stages as basal while as foliar fertilization in the latter stages.

Yield Contributing Characters

Equatorial length: The equatorial length was significantly more in T_{10} (16.7 cm) over rest of the treatments and lowest in T_{11} (11.2 cm) as depicted in Table 1. Among treatments comprising of Mo application (soil or foliar), equatorial length in foliar sprayed treatments (T_7 and T_8) were superior to the basal application (T_5 and T_6). The significant effect of Mo

Table 1. Effect of different treatments on growth and yield contributing parameters of cauliflower

Treatments	Days to curd initiation from DAT	Days to marketable curd maturity from DAT	Plant height (cm)	Stalk length (cm)	Number of leaves plant^{-1}	Equatorial length (cm)	Curd depth (cm)	Curd size index (cm^2)
T_1	91 ± 1.55	114.7 ± 1.33^{b*}	38.7 ± 0.91^{g}	4.1 ± 0.10^{c}	16.8 ± 0.15^{ef}	12.5 ± 0.44^{g}	10.1 ± 0.64^{f}	126.2 ± 11.37^{g}
T_2	90 ± 0.58	110.7 ± 2.60^{bc}	42.6 ± 1.49^{ef}	4.2 ± 0.06^{bc}	17.7 ± 1.24^{cdef}	13.9 ± 0.32^{ef}	10.5 ± 0.77^{def}	145.4 ± 13.04^{ef}
T_3	90 ± 2.33	111.0 ± 2.00^{bc}	41.5 ± 1.13^{fg}	4.1 ± 0.25^{c}	17.2 ± 0.71^{def}	13.6 ± 0.52^{f}	10.3 ± 1.04^{ef}	140.2 ± 18.21^{f}
T_4	89 ± 1.15	108.7 ± 1.45^{cd}	43.1 ± 1.18^{ef}	4.2 ± 0.15^{abc}	18.5 ± 0.45^{bcde}	14.3 ± 0.21^{def}	10.7 ± 0.58^{def}	153.0 ± 9.02^{def}
T_5	89 ± 1.20	108.3 ± 2.03^{cd}	43.5 ± 0.68^{def}	4.3 ± 0.13^{abc}	18.8 ± 0.91^{bcde}	14.6 ± 0.17^{de}	10.9 ± 0.94^{cde}	159.1 ± 14.49^{de}
T_6	88 ± 0.88	106.3 ± 0.88^{de}	45.4 ± 1.56^{cde}	4.4 ± 0.12^{abc}	18.8 ± 0.97^{bcde}	14.9 ± 0.23^{cd}	11.0 ± 0.58^{cd}	164.2 ± 11.18^{d}
T_7	87 ± 1.15	105.7 ± 1.20^{def}	46.8 ± 0.83^{bcd}	4.5 ± 0.07^{abc}	19.4 ± 0.59^{abc}	15.0 ± 0.83^{cd}	11.1 ± 0.67^{cd}	166.4 ± 9.47^{cd}
T_8	87 ± 1.45	105.0 ± 0.58^{def}	48.0 ± 1.48^{abc}	4.5 ± 0.19^{ab}	19.2 ± 0.67^{abcd}	15.6 ± 0.64^{bc}	11.4 ± 0.77^{bc}	178.5 ± 17.93^{bc}
T_9	87 ± 0.88	102.3 ± 1.45^{ef}	49.1 ± 0.66^{ab}	4.5 ± 0.08^{a}	20.6 ± 0.99^{ab}	16.0 ± 0.28^{ab}	11.9 ± 0.81^{ab}	191.1 ± 14.63^{ab}
T_{10}	85 ± 2.03	101.7 ± 2.60^{f}	51.6 ± 1.13^{a}	4.6 ± 0.12^{a}	21.2 ± 1.16^{a}	16.7 ± 0.33^{a}	12.2 ± 0.83^{a}	204.1 ± 17.38^{a}
T_{11}	93 ± 0.58	122.3 ± 1.20^{a}	33.3 ± 1.28^{h}	3.7 ± 0.10^{d}	15.8 ± 0.64^{f}	11.2 ± 0.13^{h}	8.5 ± 0.70^{g}	94.3 ± 8.29^{h}
LSD (P=0.05)	NS	4.1	3.6	0.4	2.2	0.9	0.7	13.8

*Within a column number followed by different lower cases are different at P=0.05; mean ± SEM application in increasing the equatorial length might be due to the role of Mo in nitrogen assimilation and phosphorus utilization, which leads to enhancement in the yield attributes of the plant (equatorial length).

Curd depth and curd size index: The curd depth and curd size index varied from minimum value of 8.5 cm and 94.3 cm^2, respectively in T_{11} and maximum value of 12.2 cm and 204.1 cm^2, respectively in T_{10} as depicted in Table 1. The treatment T_{10} recorded an increase of 20.8, 16.2, 18.4, and 14.0 per cent in curd depth and 61.7, 40.3, 63.9, and 33.4 per cent in curd size index when compared to treatment T_1, T_2, T_3, and T_4, respectively. However, it was statistically at par with the T_9. Also, the curd depth and curd size index in treatments comprising of Mo application either through basal or foliar, behaved statistically alike. The role of Mo in enhancing the growth parameters which might have resulted to the higher absorption and then utilization of the nutrients, might have played a significant role in enhancing the curd depth and as curd size index is a function of curd diameter and curd depth. The inferior curd depth and curd size index recorded in T_{11}, might be due to the sole application of organic inputs (ghanjeevamrit, beejamrit, and jeevamrit) with a low nutrient contents which proved to be insufficient to meet the nutrient requirement of the crop.

Yield and Quality Parameters

Curd yield: The curd yield significantly varied from lowest (6.9 t ha^{-1}) in T_{11} to highest (20.7 t ha^{-1}) in T_{10} with an increase of 57.5, 29.1, 40.6, and 22.9 per cent compared to treatment T_1, T_2, T_3, and T_4, respectively as shown in Table 2. Similar results showing an increase in curd yield due to Mo application when compared to the individual plots treated with NPK, NPK + FYM, NPK + Lime, and NPK + Lime + FYM were also reported by Reddy et al (2007) and Chowdhury and Sikdar (2017). The higher yields in these treatments might be due to the constructive role of FYM and lime in improving the soil health (Chander and Verma 2009) and increasing the availability of nutrient by affecting the soil pH (Santos et al 2018). Among treatments comprising of Mo application (soil or foliar), curd yield in foliar sprayed treatments (T_7 and T_8) were superior to the basal application (T_5 and T_6). The significant effect of Mo application in increasing the yield attributes might be due to the role of Mo in phosphorus utilisation which might have played a significant role for causing early maturity of the plant (Sahito et al 2018), which prevented the curd deformation and better marketable curds compared to control. Similar results have also been reported by Kumar et al (2010b).

Ascorbic acid and Total soluble solids (TSS): The ascorbic acid and TSS content was lowest in T_{11} (64.4 mg $100g^{-1}$ and 7.7° Brix, respectively). The maximum content (77.8 mg $100g^{-1}$ and 8.4° Brix, respectively) was in T_{10} with an increase of 12.9, 10.0, 11.5, and 8.4 per cent in ascorbic acid and 8.9, 7.3, 8.2, and 5.8 per cent in TSS content when compared to the treatment T_1, T_2, T_3, and T_4, respectively as shown in table 2. However, T_{10} was statistically at par with the treatment T_8 and T_9. Among treatments receiving the Mo application (soil or foliar), the higher ascorbic and TSS content were in foliar application (T_8 and T_9).

As ascorbic acid is greatly influenced by the better growth and development of the plant and the Mo role in enhancing the overall growth and development of the plant might have resulted to an increase in ascorbic acid content as depicted in treatments with better plant development. The significant effect of Mo application on TSS might be due to the Mo role in the nitrogen metabolism of the plant, which enhances the metabolic pools required for the synthesis of

Table 2. Effect of treatments on quality parameters and yield

Treatments	Curd yield (t ha^{-1})	Ascorbic acid (mg $100g^{-1}$)	TSS\ (°Brix)	Curd solidity (g cm^{-1})
T_1	13.1 ± 0.38^{h*}	68.9 ± 0.56^{f}	7.76 ± 0.03^{g}	35.6 ± 2.69^{c}
T_2	16.0 ± 0.19^{f}	70.7 ± 0.79^{ef}	7.87 ± 0.01^{f}	41.8 ± 3.01^{ab}
T_3	14.7 ± 0.22^{g}	69.8 ± 0.76^{ef}	7.80 ± 0.02^{fg}	39.5 ± 3.90^{bc}
T_4	16.8 ± 0.30^{ef}	71.8 ± 0.16^{de}	7.98 ± 0.01^{e}	42.7 ± 2.35^{ab}
T_5	17.2 ± 0.19^{de}	73.9 ± 0.97^{cd}	8.13 ± 0.03^{d}	43.1 ± 3.11^{ab}
T_6	17.5 ± 0.14^{de}	74.8 ± 0.46^{bc}	8.23 ± 0.05^{c}	43.2 ± 2.05^{ab}
T_7	18.1 ± 0.33^{cd}	75.0 ± 0.88^{bc}	8.32 ± 0.03^{bc}	44.3 ± 2.99^{a}
T_8	19.0 ± 0.31^{bc}	75.7 ± 0.76^{abc}	8.37 ± 0.04^{ab}	45.4 ± 3.54^{a}
T_9	19.5 ± 0.38^{b}	76.7 ± 0.76^{ab}	8.40 ± 0.06^{ab}	44.6 ± 3.59^{a}
T_{10}	20.7 ± 0.66^{a}	77.8 ± 1.04^{a}	8.44 ± 0.02^{a}	46.3 ± 4.40^{a}
T_{11}	6.9 ± 0.38^{i}	64.4 ± 0.71^{g}	7.67 ± 0.02^{h}	22.3 ± 2.06^{d}
LSD (P=0.05)	1.03	2.16	0.09	4.50

*Within a column number followed by different lower cases are different at P=0.05; mean ± SEM

Table 3. Effect of different treatments on economics of cauliflower

Treatments	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C
T_1	75984	262847	186863	3.46
T_2	96484	320686	224202	3.32
T_3	126484	294414	167930	2.33
T_4	146734	336624	189891	2.29
T_5	99145	343618	244473	3.47
T_6	100475	351004	250529	3.49
T_7	99645	361457	261812	3.63
T_8	100975	379556	278581	3.76
T_9	102306	389279	286974	3.81
T_{10}	103636	413896	310260	3.99
T_{11}	71855	138124	66269	1.92

Market price of (a) cauliflower: ₹20 kg^{-1} and (b) ammonium molybdate: ₹1386 kg^{-1}

the saccharides with direct effect on this quality parameter (Kaiser et al 2005). Similar results showing an increase in the quality parameters i.e., ascorbic acid and TSS content have also been reported by Thapa et al (2016).

Curd Solidity. The curd solidity was minimum (22.3 g cm^{-1}) in T_{11} and maximum (46.25 g cm^{-1}) in T_{10} as shown in table 2. The curd solidity in treatments with the Mo application either through soil, foliar, or conjoint behaved statistically alike. In treatment T_{11}, due to the sole application of organic inputs (ghanjeevamrit, beejamrit, and jeevamrit) with a low nutrient contents, which proved insufficient to meet out the nutrient requirement of the crop. Hence, leading to poor curd solidity when compared to other treatments. There exists a proportional relationship between curd solidity and curd weight, thereby, the change in curd weight have a direct effect on curd solidity.

Economics: Higher net returns (₹ 3,10,260 ha^{-1}) and benefit-cost ratio (3.99) were recorded in T_{10} (table 3) whereas, the lowest net returns (₹ 66,269 ha^{-1}) and benefit-cost ratio (1.92) were recorded in treatment T_{11}. The higher net returns and lower B:C recorded in treatment T_3 and T_4 when compared to the T_1, was because of the higher cost of inputs (lime and FYM). The treatment T_4 recorded the highest cost of cultivation over rest of the treatments. However, the higher B:C recorded in the treatments (T_5 to T_{10}), was because of the use of agricultural grade ammonium molybdate (₹ 1386 kg^{-1}) which resulted in lower cost of cultivation with perspective to higher gross returns. The treatment T_{10} was more feasible with higher net returns and benefit-cost ratio, and should be recommended in the Mo deficient soils.

CONCLUSIONS

Mo application played a significant role in enhancing the productivity, quality, and the profitability of cauliflower crop grown in Mo deficient soil. However, the conjoint application of Mo (soil plus foliar) @ 1.0 kg ha^{-1} as basal and @ 0.15 % as foliar feeding, respectively, along with the RDF proved to be the best Mo application method to remediate the Mo deficiency in Typic Hapludalfs soil of Himachal Pradesh.

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Received 11 November, 2021; Accepted 02 March, 2022

Indian Journal of Ecology (2022) 49(2): 378-382
DOI: https://doi.org/10.55362/IJE/2022/3532

Manuscript Number: 3532
NAAS Rating: 5.79

Effect of Seed Coating and Foliar Spray Treatments on Plant Growth, Seed Yield and Economics of Seed Production in Garden Pea (*Pisum sativum* L.)

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Abstract: A field experiment was carried out to evaluate the effect of various treatment combinations comprising of seed coating and foliar application of micro-nutrients and bio-agents on plant growth, seed yield and yield contributing parameters of pea cultivar Punjab-89 during 2018-19. It was observed that among different treatments, seed coating with *Rhizobium* @ 30 g + PSB @ 30 ml kg^{-1} seed along with two foliar sprays of $ZnSO_4$ + $FeSO_4$ @ 0.3 per cent each given at the time of 50 per cent flowering and 15 days after the first spray significantly influenced nearly all the parameters resulting in maximum field emergence (92.67 %), plant height (91.03 cm), pods $plant^{-1}$ (27.07), pod length (9.81 cm), seeds pod^{-1} (7.93), 100 seed weight (17.11 g), seed yield (13.98 g $plant^{-1}$, 1.2 kg $plot^{-1}$ and 21.33 q ha^{-1}) and maximum B: C ratio (2.00). Therefore, it was concluded from the investigation that seed coating with bio-fertilizers i.e. *Rhizobium* @ 30 g + PSB @ 30 ml kg^{-1} seed and two foliar applications of $ZnSO_4$ + $FeSO_4$ @ 0.3 per cent each is a good treatment for getting higher yield of quality seed in pea.

Keywords: Garden pea, *Pisum sativum*, *Rhizobium,* Seed coating, Foliar sprays

Pea (*Pisum sativum* L.) comes under one of the most important legume vegetable crops. It is native to Europe and West Asia, but its wild ancestor, *Pisum humile syn. syriacum*, originated in Ethiopia (Candolle 1886) and then it moved to the Mediterranean region and rest of the world. As leguminous crop, it fixes the biological nitrogen and introduce large amount of organic matter which increase and maintain the soil fertility. In India, pea is cultivated on an area of 540,000 hectares with 5422, 000 MT production and average productivity of 10 MT per hectare having a share of 21 per cent in the world production. In India, 60 per cent of the total production comes from Uttar Pradesh state only followed by Madhya Pradesh (Anonymous 2018). The edible portion of 100 g fresh pod has appreciable amount of proteins (7.2%), carbohydrates (15.9%), fat (0.1%), carotene (83 g), vitamin C (9 mg), thiamine (0.25 mg), and riboflavin (0.01 mg). Peas also have essential amino acids and minerals such as potassium, phosphorus, calcium, magnesium and iron (Choudhary 2017).

Seed coating is a quality enhancement treatment in which with the help of a special binder (carboxy methyl cellulose, gum arabic, etc), an active ingredient in the form of microbial inoculants/ chemical is applied on seed surface. Due to precise application of active ingredient, this method has been used successfully for seed inoculation in different crops (Jetiyanon et al 2008, Oliveira et al 2016, Rouphael et al 2017, Accinelli et al 2018 and Rocha et al 2018). CMC (Carboxy Methyl Cellulose) is a commonly used binder because it is easily available, inexpensive and has a low rate of application. *Rhizobium* culture increases the nitrogen fixation (about 40 to 50 kg ha^{-1}) by enhancing nodulation. It has been seen that *Rhizobium* culture increases the crop yield up to 10 to 15 per cent (Anonymous 2008). Phosphate solubilizing bacteria dissolve the insoluble and unavailable forms of different phosphates (tricalcium, iron, and aluminum phosphates) making them available to plants. Bio-fertilizers result in the production of anti-metabolites and hormones which promote the root growth. Application of bio-fertilizers to seed or soil increases the nutrient availability and enhance yield to the tune of 10 to 25 per cent without negatively affecting the soil or the environment (Anonymous 2019). Hilman (1967) reported that iron is required for initiation of flowering. Iron content has been found important for floral initiation in *Lemna paucicostata* (Gupta and Maheshwari 1970, Khurana and Maheshwari 1983 and Nishioka et al 1986). Zinc is required for plant reproductive development. Zinc deficiency influences different phases of plant reproduction, viz., flowering, flower development, anthesis, gamete formation, fertilization and resultantly seed set. Zinc is essential for nitrogen fixation and root nodule formation (Nandwall et al 1990 and Balusamy et al 1996). Considering the above facts, the present investigation was carried out to study the effect of seed coating and foliar sprays on plant development, seed yield and yield characteristics in garden pea.

MATERIAL AND METHODS

The field experiment was carried out at Research Farm of the Department of Seed Science and Technology, Dr YS Parmar UHF, Nauni, Solan (HP) during rabi 2018-19. Soil texture of the Research Farm was loam to clay loam with pH ranging between 6.85-7.05. The average maximum and minimum temperatures, relative humidity and average total rainfall during the cropping period were 19.9°C, 5.6°C, 57 per cent and 52.3 mm, respectively. The field experiment was laid out using pea cultivar Punjab-89. Seed was sown at 60×7.5 cm spacing on 15th November 2018 in Randomized Complete Block Design. The plot size was 3.0×1.5 m. There were seven treatments *viz.,* T_1 (seed coating with *Rhizobium* @ 30 g kg^{-1} seed), T_2 (Seed coating with PSB @ 30 ml kg^{-1} seed), T_3 (Seed coating with *Rhizobium* @ 30 g + PSB @ 30 ml kg^{-1} seed), T_4 (Seed coating with $FeSO_4$ @ 3 g kg^{-1} seed), T_5 (Seed coating with $ZnSO_4$ @ 3 g kg^{-1} seed), T_6 (Seed coating with carbendazim @ 2.5 g kg^{-1} seed) and T_7 (control). In addition to seed coating, two foliar sprays of $ZnSO_4$ + $FeSO_4$ @ 0.3 per cent each were also given at the time of 50 per cent flowering and 15 days after the first spray in all treatments except control.

For seed coating, 15 ml Carboxy Methyl Cellulose (2%) was mixed with 250 g seeds for each treatment in a plastic container and then coating material was added and mixed thoroughly by shaking the container manually until there was a uniform coating on seeds. Treated seeds were dried in shade overnight. The uniformly coated seeds were selected for sowing. The crop was grown following standard procedure as per the package of practices of the University. The foliar application of the nutrients were given after preparing the nutrient solutions of given concentration at given time period.

Observations on various parameters *viz.,* field emergence (%), plant height (cm), days to maturity, pods $plant^{-1}$, pod length (cm), seeds pod^{-1}, 100 seed weight (g) and seed yield (g $plant^{-1}$ and q $hectare^{-1}$) were observed as per the standard procedures. For observation of field emergence all the emerged seedlings were counted in each plot and emergence percentage was worked out on the basis of number of seeds sown as per the formula:

$$\text{Emergence (\%)} = \frac{\text{Germinated seedlings}}{\text{Total seeds sown}} \times 100$$

Plant height of the ten randomly selected plants was recorded from the soil level to the tip of the plant at the end of the crop season with the help of a scale and mean height was expressed in centimetres. Days to maturity were counted from the date of sowing to fully developed mature pods for getting seeds. The number of pods from each harvest of ten randomly selected plants were counted and averaged to work out mean number of pods $plant^{-1}$. Length of ten randomly selected healthy pods was measured from the point of attachment to the tip of pod with the help of a scale. The pods used for measuring pod length were shelled for counting the seeds and the mean value of seeds pod^{-1} was determined. In each replication, 100 seeds were counted with the help of an electronic counter from the total seed produced in each plot and were weighed on electronic balance to record the weight. For seed yield per plant, ten plants randomly selected from each replication per treatment for pod characters were harvested at complete physiological maturity stage and thus obtained seeds properly dried in shade. The seeds were cleaned properly and weighed with the help of an electronic balance and average was worked out. Seed yield per hectare was worked out on the basis of seed obtained per m^2 as per the formula:

$$\text{Seed yield ha}^{-1}\text{ (q)} = \frac{\text{Seed yield/m}^2\text{ (kg)}\times 8000}{100}$$

while calculating the seed yield per hectare, twenty per cent area was considered as depreciation for construction of channels in the field.

RESULTS AND DISCUSSION

The results of the experiment obtained w.r.t. various growth and yield parameters after statistical analysis are presented and discussed hereunder:

Growth parameters: A cursory glance at the data (Table 1) revealed that majority of the seed coating treatments significantly influenced the field emergence of seed. Amongst all the treatments, however, the maximum field emergence (92.67 %) was observed in the plots under T_3 (Seed coating with *Rhizobium* @ 30 g + PSB @ 30 ml kg^{-1} seed) followed by T_1 **(**Seed coating with *Rhizobium* @ 30 g kg^{-1} seed) with 91.67 per cent field emergence. Both the treatments were at par with each other w.r.t. this parameter. In other seed coating treatments, the emergence recorded was between 83 to 85.33 per cent. The uncoated seed (control) only showed 82.33 per cent field emergence. This enhanced emergence might be due to the action of bio-fertilizer present on seed coat. These bio-fertilizers might have enhanced the microbial activity around the seed in soil thus making essential bio molecules available to the plants during the early stages of germination. Same mechanisms have been suggested by Subba Rao (1986).

While looking the data w.r.t. plant height (Table 1), again the seed coating treatments significantly influenced the plant height as compared to untreated one. The coating treatment T_3 (Seed coating with *Rhizobium* @ 30 g + PSB @ 30 ml kg^{-1} seed), which also included two sprays of $ZnSO_4$ + $FeSO_4$ @ 0.3 per cent, provided maximum plant height up to 91.03 cm, which was at par with treatment T_1 (Seed coating with *Rhizobium* @ 30 g kg^{-1} seed) and significantly higher as compared to other treatments. *Rhizobium* enhances plant growth through atmospheric fixation of nitrogen, more growth hormone and siderophores' production that chelate iron making it available to plants besides disease suppression in early growth stages (Mabrouk et al 2018). Das (1996) noticed a direct role of phosphorus in cell division and development which positively favoured plant height. Similar results upon seed coating and foliar application of bio-agents and nutrients have been observed by various workers in field pea (Bhat et al 2013, Mishra et al 2010 and Pandey et al 2017). Foliar application of zinc enhanced the cell size and number by stimulating the production of auxins (Dashadi et al 2013). Haleema et al (2018) also noticed increased plant height in tomato after Zn application.

Iron results in activation of cell division and elongation promoting enzymes that ultimately favour plant height (Nadergoli et al 2011). This element is also known to help in chlorophyll synthesis (Das 1996), which enhanced the plant height and vegetative growth. These findings are also in line with Pal (2018) who also observed increased plant height in chickpea after seed coating and spray application with bio-agents and nutrients. Days to maturity were, however, not influenced by seed coating treatments and despite of all the treatment, the crop took on an average 147.9 days for seed maturity (Table 1).

Seed yield and yield contributing characters: The data presented in Table 2 indicated that the seed coating and nutrient spray applications significantly influenced the seed yield and yield contributing characters as compared to

Table 1. Effect of seed coating on field emergence, plant height and days to maturity in garden pea

Parameters/ Treatments**	*Field emergence (%)	Plant height (cm)	Days to maturity
T_1: Seed coating with *Rhizobium* @ 30 g kg^{-1} seed	91.67 (9.57)	90.40	148.33
T_2: Seed coating with PSB (Phosphate solubilizing bacteria) @ 30 ml kg^{-1} seed	85.33 (9.24)	88.10	147.00
T_3: Seed coating with *Rhizobium* @ 30 g + PSB @ 30 ml kg^{-1} seed	92.67 (9.63)	91.03	147.33
T_4: Seed coating with $FeSO_4$ @ 3 g kg^{-1} seed	83.67 (9.15)	86.07	147.67
T_5: Seed coating with $ZnSO_4$ @ 3 g kg^{-1} seed	83.00 (9.11)	85.47	148.00
T_6: Seed coating with Carbendazim @ 2.5 g kg^{-1} seed	84.33 (9.18)	87.77	148.33
T_7: Control	82.33 (9.07)	84.57	148.67
Mean	86.14 (9.28)	87.63	147.90
CD (p=0.05)	0.07	0.97	NS

***** Figures in the parenthesis represent square root transformed values
**Foliar application of $ZnSO_4$ + $FeSO_4$ each @ 0.3 % was given at two stages in all treatments except control

Table 2. Effect of seed coating on seed yield, yield contributing characters and economics of seed production in garden pea

Parameters/Treatments*	Number of pods $plant^{-1}$	Pod length (cm)	Number of seeds pod^{-1}	100 seed weight (g)	Seed yield (g $plant^{-1}$)	Seed yield (q ha^{-1})	Gross return (₹)	Net return (₹)	B: C ratio
T_1: Seed coating with *Rhizobium* @ 30 g kg^{-1} seed	26.20	9.57	7.82	16.88	13.25	19.56	195556	124613	1.76
T_2: Seed coating with PSB (Phosphate solubilizing bacteria) @ 30 ml kg^{-1} seed	25.10	9.11	7.70	16.63	12.55	18.67	186667	117557	1.70
T_3: Seed coating with *Rhizobium* @ 30 g + PSB @ 30 ml kg^{-1} seed	27.07	9.81	7.93	17.11	13.98	21.33	213333	142273	2.00
T_4: Seed coating with $FeSO_4$ @ 3 g kg^{-1} seed	24.90	9.06	7.53	16.30	11.93	17.33	173333	104264	1.51
T_5: Seed coating with $ZnSO_4$ @ 3 g kg^{-1} seed	24.57	9.00	7.22	16.12	11.10	16.89	168889	99799	1.44
T_6: Seed coating with Carbendazim @ 2.5 g kg^{-1} seed	23.97	8.97	7.27	16.20	11.33	17.04	170370	101231	1.46
T_7: Control	23.03	8.58	6.67	15.47	10.41	16.00	160000	94860	1.46
Mean	24.98	9.16	7.45	16.39	12.08	18.12			
CD (p=0.05)	0.90	0.34	0.63	0.75	1.11	2.63			

*Foliar application of $ZnSO_4$ + $FeSO_4$ each @ 0.3 % was given at two stages in all treatments except control

control. Amongst various treatments, highest number of pods $plant^{-1}$ (27.07), pod length (9.81 cm), seeds pod^{-1} (7.93) and 100 seed weight (17.11 g) were registered in treatment T_3 (Seed coating with *Rhizobium* @ 30 g + PSB @ 30 ml kg^{-1} seed) which was resultantly statistically at par with T_1 (Seed coating with *Rhizobium* @ 30 g kg^{-1} seed). This improvement in seed yield and its contributing characters might be the result of combined inoculation of *Rhizobium* and PSB which regulates the supply of essential plant nutrients like nitrogen and phosphorus. Nitrogen being an integral part of chlorophyll improves vegetative growth of the plant via increased rate of photosynthesis (Das 1996). Further, *Rhizobium* has a well established role in the production of growth promoting hormones and solubilization of plant nutrients which lead to enhanced vegetative growth, pod length and pods $plant^{-1}$ (Mabrouk et al 2018). Bhat et al (2013) and Sharma et al (2018) also found the same results in field pea and soybean, respectively. Microbes' action also increased the seeds pod^{-1} and 100 seed weight through enhancement of nutrient uptake, vegetative growth and photosynthesis resulting in increased plant biomass and accumulation of more food reserves in seeds. Consequently, more flow of assimilates from source to sink under current situation resulted in increased number of seeds pod^{-1} and 100 seed weight. Ganie et al (2009) and Pandey et al (2017) also obtained higher seeds pod^{-1} in pea through bio-fertilizers' inoculation of seed. Furthermore, zinc is directly involved in auxin synthesis (Das 1996), which might have enhanced the vegetative growth and yield contributing traits in pea. Foliar application of iron might have resulted in an increase in the chlorophyll content enhancing rate of photosynthates' production and accumulation in seed and pod. Bazgalia (2017) recorded more number of pods and seeds pod^{-1} in chickpea due to foliar application of iron and zinc. Sadeghi and Noorhosseini (2014) also reported similar results in lentil.

Benefit: cost (B: C) ratio: The data on the economics of garden pea seed production for various treatments is presented in Table 2. A deep insight into the data revealed maximum net returns (₹ 142273) and B: C ratio (2.00) in treatment T_3[seed coating with *Rhizobium* @ 30 g + PSB @ 30 ml kg^{-1} seed and two foliar sprays of $ZnSO_4$ (0.3 %) + $FeSO_4$ (0.3 %)]. This treatment was closely followed by treatment T_1 [seed coating with *Rhizobium* @ 30 g kg^{-1} seed and two foliar sprays of $ZnSO_4$ (0.3 %) + $FeSO_4$(0.3 %)] with second best net returns (₹ 124613) and B: C ratio (1.76). However, the lowest B: C ratio of 1.44 was obtained in treatment T_5.

CONCLUSION

From the present investigation it was concluded that treatment, seed coating with *Rhizobium* @ 30 g + PSB @ 30 ml kg^{-1} seed and two foliar sprays of $ZnSO_4$ (0.3 %) + $FeSO_4$ (0.3 %) at 50 per cent flowering and 15 days later was rated best amongst all the treatments tested for growth, yield attributes and quality seed production in garden pea under mid-hill conditions of Himachal Pradesh.

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Received 05 January, 2022; Accepted 21 March, 2022

Indian Journal of Ecology (2022) 49(2): 383-387
DOI: https://doi.org/10.55362/IJE/2022/3533

Manuscript Number: 3533
NAAS Rating: 5.79

Gravity-Fed Drip-Fertigation: An Efficient Water and Nutrient Management Tool for High Valued Crops in a Deep Tube Well Command of West Bengal

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Abstract: Drip-fertigation with proper irrigation scheduling can be an efficient and viable technology alternative to traditional irrigation and fertilizer management for enhancing crop productivity, water and nutrient use efficiency and economics. The gravity-fed drip fertigation with moderately deficit or optimum irrigation resulted in maximum yield (9.9-43.3 t ha^{-1}), water use efficiency (19.7-73.54 kg $ha^{-1}mm^{-1}$), fertilizer use efficiency (9-312 kg increase kg^{-1} NPK added), income (₹46250-₹144748 ha^{-1}) and BCR (2.05-4.41) for several high-value crops. The increase in yield, water-saving and income was 11.0-42.9%, 20.1-68.1% and 18.8-59.5%, respectively over farmers' traditional practices. Inclusion of partly pre-plant fertilization, plastic mulching for soil water conservation and vermicompost in the nitrogen management had additional influences in promoting the parameters studied.

Keywords: Drip irrigation, Fertigation, Yield, Water use efficiency, Water-saving, Income

Water is one the major environmental constraints affecting the sustainability of irrigated agriculture (Shamshiri et al 2011). Rapid population growth, increasing competitive demand from agricultural, industrial and domestic sectors, improved standard of living, decreasing water availability due to water pollution and groundwater mining and climatic variability have exacerbated the water crisis in the world (Dhiman et al 2015). The farmers' conventional surface method of irrigation is quite inefficient for input utilization and non-remunerative (Pramanik and Patra 2016). In this challenged situation in agriculture, many improved water-saving technologies have been developed and adopted around the world for efficient and economic utilization of precious irrigation water resources for maximum crop production while minimizing adverse impact on environment (Fereres and Soriano 2007, Kumari et al 2014). Deficit irrigation is a water management strategy which can cope with the risk of excessive water and nutrient leaching in one hand and simultaneously produce higher yield and input use efficiency on the other (Chai et al 2016, Filho et al 2020). However, drip irrigation is a modern and economically viable irrigation method and proves its superiority over other methods of irrigation because of its unique ability to supply precise but frequent water under low pressure in synchrony of crop evapotranspirative demand directly in the root zone of each plant (Rajurkar et al 2012, Abd El-Wahed and Ali 2013). Drip irrigation with proper scheduling is considered the best solution to save precarious water resources with increased yield and water use efficiency especially in the areas where water is either expensive or scarce or the soils are coarse textured (Deshmukh and Hardaha 2014). It is preferred for vegetable and fruit crops having high commercial value so that its high initial investment cost can be recovered with high economic return. The use of plastic mulch is an eco-friendly approach to conserve soil water, suppress weed growth, reduce disease and pest infestation, improve soil condition, moderate soil hydrothermal regime, reduce nutrient loss and increase yield and water use efficiency of crop (Bakshi et al 2015, Kader et al 2019).

Plant nutrients are also the most critical inputs for a resilient and sustainable agricultural production and quality improvement. Traditional fertilizer broadcasting across the surface of crop field is inefficient with low nutrient use efficiency and crop productivity (Rahman and Zhang 2018). Chemical farming especially the continued and indiscriminate use of nitrogen fertilizers have a hidden danger because of its adverse impacts on soil quality, human health, atmospheric and groundwater pollution as a result of nitrogen losses through leaching, ammonia volatilization and denitrification (Bishnoi 2018). Proper management of fertilizer application is thus very important to register higher fertilizer use efficiency. Adjustment of nitrogen fertilizer through balanced use of organic manure and inorganic fertilizer is an alternative for deriving higher soil and crop productivity and nutrient use efficiency (Singh et al 2014, Kumar et al 2019). Since both water and fertilizer are costly inputs, their optimum utilization is imperative for increase in yield. Drip fertigation which combines drip irrigation with soluble fertilizers as per crop requirement is the most effective and convenient way to achieve the target of higher water and fertilizer use efficiency (Sureshkumar et al 2016). In this perspective, the objective of the present paper was to evaluate the feasibility of gravity-fed drip-fertigation vis-à-vis farmers' practice on yield, water and fertilizer use efficiencies, water-saving and economics from high-value crops in a sandy loam soil.

MATERIAL AND METHODS

Experimental site: The experimental site is located between 22^{0}58'31" N latitude and 88^{0}26'20" E longitude with an altitude of 9.75 m above mean sea level in a humid sub-tropical climatic belt. Average annual rainfall was 1450 mm, of which nearly 75% being received during June through September. Intermittent rainfall showers during November-February and April-May were experienced. The weather was hot and humid during summer (May-June) and dry and cold during winter (December-January). Mean monthly temperature ranged between 9.5 to 23.7 ^{0}C in winter and 25.4 to 37.6^{0}C in summer. Mean relative humidity around the year fluctuated between 70 to 95%. Wind speed ranged from 0.2 to 3.69 kmph. Pan evaporation loss varied from 0.9 to 1.4 mm/day during December-January and 4.2 to 4.6 mm/day during April-May. Depth of watertable ranged from 5.6 to 6.8 m bgl. The soil (Typic Fluvaquept) was sandy loam in texture. Gravimetric soil water content at field capacity (-1/3 bar) and permanent wilting point (-15 bar) was 32.1 and 11.2% w/w, respectively on dry weight basis. Plant available soil water was 30.5 cm/m. The monthly rainfall and evaporation pattern of the experimental site and relevant soil properties are presented in Figure 1 and Table 1, respectively.

Data collection and methodologies adopted: A number of field experiments on gravity-fed drip-fertigation were conducted during the period 2006-07 to 2014-15 with the initiatives of AICRP-Irrigation Water Management, BCKV center, West Bengal to optimize irrigation water and fertilizer requirements for several high-value crops. The selected data for the designated crops were collected from the Annual Reports of 2009-2017. The standard methodologies for design layout, agronomic manipulations, proper irrigation scheduling as per crop water need and graded dose of N, P and K through drip-fertigation were adopted for each test crop. Some other interventions like integrated nitrogen management incorporating vermicompost as a source of nitrogen in the fertilization schedule and black polyethylene film of 80 μ thickness as mulch material were accommodated in the experimentation. All soluble N, P and K nutrients in the form of urea, acidified single super phosphate and muriate of potash at very low concentrations in multiple splits were applied by drip irrigation as per prescribed schedules. In some treatments, 50% NPK or, 100% PK or 50% N as vermicompost of the recommended dose of fertilizer (RDF) was incorporated as pre plant and the remaining dose was fertigated through drip irrigation. The amount and number of splitting for N, P and K doses for fertigation varied according to the type of crops, duration and critical growth stages. The required amount of fertilizer nutrients selected was dissolved in 10 L of water and the stock fertilizer solution was prepared. The desired amounts of nutrients were mixed in a 500 L capacity overhead tank placed at a height of 3.3 m above local ground surface to facilitate water movement on gravitational force. The irrigation water along with nutrients was applied in the drip-fertigation treatments. The evaporation data was recorded daily from a USWB Class A Pan located inside the experimental site. The reference evapotranspiration (ET_0) was determined by multiplying pan evaporation (E_p) with pan coefficient (K_p). The crop evapotranspiration (ET_c) was estimated by multiplying ET_0

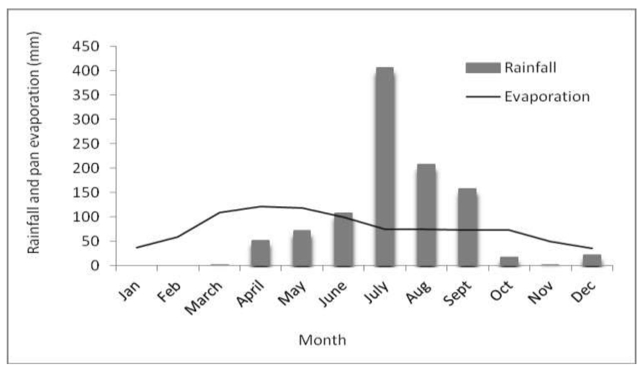

Fig. 1. Rainfall and evaporation pattern at the experimental site

Table 1. Important properties of the experimental soil

Parameter	Value
Sand (%)	69.8
Silt (%)	15.5
Clay (%)	14.7
Bulk density (Mg m^{-3})	1.49
pH (1:2.5)	6.9
EC (dS m^{-1})	0.37
CEC [cmol (p^{+}) kg^{-1}]	15.6
Organic carbon (g kg^{-1})	5.6
Available N (kg ha^{-1})	183.7
Available P (kg ha^{-1})	35.8
Available K (kg ha^{-1})	187.6

with crop coefficient (K_c) for different crop growth stages (Allen et al 1998). The amounts of irrigation and actual crop water use, marketable yield, water use efficiency (WUE), fertilizer use efficiency (FUE), water-saving and income gain from several test crops due to imposition of different adaptable drip-fertigation technique vis-à-vis farmers' traditional water and fertilizer management practice (control) were estimated. The economic assessment in terms of income and benefit-cost ratio (BCR) based on the prevailing market values of the produce and the inputs used for the experimentation were computed.

RESULTS AND DISCUSSION

Brinjal: Drip-irrigation at 100% ET_0 with 50% NPK as basal and remaining 50% NPK of RDF through fertigation recorded maximum fruit yield (14.42 t/ha), WUE (62.65 kg/ha/mm), FUE (9.0 kg increase/kg NPK) and income (₹50520/ha) with BCR as 2.05. The increase in yield, water-saving and income was 20.3, 21.43 and 26.5%, respectively over the farmer's practices (Table 2). The drip-irrigation at 100% ET_c with 100% PK as basal and 125% N of recommended dose (RD) as fertigation demonstrated highest fruit yield (16.65 t/ha), WUE (73.54 kg/ha/mm), FUE (11.52 kg increase/kg NPK) and income (₹46250/ha) with BCR as 2.64. The enhancement in yield, water-saving and income was 23.0, 28.65 and 29.6%, respectively over the conventional practices.

Guava: Imposition of drip-irrigation at 100% ET_c with 100% PK as basal and 100% N of RD through fertigation increased fruit yield by 11.0% (21.2 t/ha), WUE (19.7 kg/ha/mm), FUE (85.5 kg increase/kg NPK), water-saving by 20.1% and income by 18.8% (₹118400/ha) with BCR 3.03 over the traditional practices.

Broccoli-okra-cowpea cropping sequence: Application of moderately deficit drip-irrigation at 80% ET_c coupled with

Table 2. Effects of different irrigation scheduling and fertigation through drip system on yield, water and fertilizer use efficiencies, water-saving and income for various crops

Crop, variety and season	Drip irrigation schedule with/without mulch	Fertigation schedule	Recommended dose of fertilizer (kg ha^{-1})	Yield (t ha^{-1})	Yield increase (%)	WUE (kg ha^{-1} mm^{-1})	FUE (kg increase Kg^{-1} NPK)	Water-saving (%)	Income (₹ ha^{-1})	Income increase (%)	BCR
Brinjal cv. Muktakeshi (Rabi)	Drip irrigation at 1.0 ET_0 (irrigation 198 mm at 2-day interval and total crop water use 230 mm)	50% NPK as basal and 50% NPK as fertigation in 10 splits at 7-day interval	120:60:90	14.42	20.3	62.65	9.0	21.43	50520	26.5	2.05
Brinjal cv. Muktakeshi (Rabi)	Drip irrigation at 1.0 ET_c (irrigation 205 mm at 2-day interval and total crop water use 226 mm)	100% PK as basal and 125% N as fertigation in 10 splits at 7-day interval	120:60:90	16.65	23.0	73.54	11.52	28.65	46250	29.6	2.64
Guava cv. Khaja	Drip irrigation at 1.0 ET_c (irrigation 576 mm at 6-day interval and total crop water use 1074 mm)	100% PK as 2-splits and 100% N in 10 splits at 10-day interval as fertigation	200:160:260 g/plant	21.2	11.0	19.7	85.5	20.1	118400	18.8	3.03
Broccoli cv. Green magic-Okra cv. Pankaj –Cowpea cv. Local	Drip irrigation at 0.8 ET_c (irrigation 238 mm at 2-day interval and total crop water use 668 mm) with BPM	100% PK as basal and 100% N as fertigation in 6-7 splits in broccoli and okra and 2 splits in cowpea	Broccoli-100:60:60 Okra-90:60:40 Cowpea-20:40:40	33.4 broccoli eq.	23.34	50.0	15.96	68.1	362609	59.5	4.41
Gladiolus cv. American beauty (Rabi)	Drip irrigation at 0.8 ET_c (irrigation 115 mm at 3-day interval and total crop water use 158 mm)	100% PK and 50% N through vermicompost as basal and 50% N as fertigation in 6 splits	100:60:60	9.9 (fresh spike yield)	34.1	62.41	6.52	66.4	80000	33.4	2.78
Banana *cv.* Martaman (AAB, Silk)	Drip irrigation at 0.8 ET_0 (irrigation 318 mm at 3-day interval in summer and 5-day interval in winter and total crop water use 721 mm)	100% N in 20-splits, P in 2 splits and K in 9 splits as fertigation at 10-30 days interval	200:50:250 g/plant	43.3	42.9	60.1	312	66.9	144748	19.8	2.07

ET_0: Reference pan evaporation, ET_C: crop evapotranspiration, BPM: black polythene mulch

100% RD of PK as basal application and 100% RDN through fertigation under black polyethylene mulch condition enhanced broccoli equivalent yield by 23.34% (33.4 t/ha), WUE (50 kg/ha/mm), FUE (15.96 kg increase/kg NPK) and water-saving by 68.1% over the usual irrigation and soil fertilization without mulching. The corresponding income increase was 59.5% (₹362609/ha) with BCR 4.41 over the farmers' practice.

Gladiolus: Moderately deficit drip-irrigation scheduling of 80% ET_c with basal application of 100% RD of PK + 50% RDN through vermicompost and 50% RDN through fertigation increased the fresh spike yield by 34.1% (9.9 t/ha), WUE (62.41 kg/ha/mm), FUE (6.52 kg increase/kg NPK), water-saving by 66.4%, income by 33.4% (₹80000/ha) with BCR 2.78 over the existing surface irrigation and soil fertilization.

Banana: Moderately deficit watering through drip-irrigation at 80% ET_0 with 100% RDF through fertigation increased fruit yield by 42.9% (43.3 t/ha), WUE (60.1 kg/ha/mm), FUE (312 kg increase/kg NPK) and water-saving by 66.9.1% over the traditional practices of flood irrigation and soil fertilization. The corresponding income increase was 19.8% (₹144748/ha) with BCR 2.07.

The increase in yield of different crops and cultivars under drip-fertigation ranged between 11.0 to 42.9% as compared with conventional irrigation and soil fertilization. These results are in consistent with those of earlier researchers (Brahma et al 2010, Vijayakumar et al 2010, Deshmukh and Hardaha 2014, Kumari et al 2014, Debbarma et al 2018). The water use efficiency and fertilizer use efficiency obtained in drip-fertigation, irrespective of crop and water and nutrient scheduling adopted, varied widely ranging from 19.7 to 73.54 and 9 to 312 kg increase/kg NPK added, respectively with increase in water-saving of 20.1 to 68.1% and income of 18.8 to 59.5% over farmers' conventional practices. This improvement could be largely due to steady movement of water and nutrients both laterally and vertically as a result of precise and controlled watering at higher frequency with several splits application of fertilizers through drip-irrigation according to the growth stage specific crop requirements. The drip fertigation enabled more favorable and uniform distribution of water and nutrients in the vicinity of active root zone across the growth stages which encourages better root growth and development and more absorption of water and nutrients from soil and subsequent translocation of assimilates from source to sink resulting in higher marketable yield and input use efficiency (Sureshkumar et al 2016, Debbarma et al 2018). Drip-fertigation reduces losses of water and nutrients in deep percolation and leaching in one hand and allows efficient and appropriate use of water and nutrients by plants on the other which ensures better resource use efficiency (Chai et al 2016, Filho et al 2020). In contrarily, the soil water and nutrient distribution down the layers of the soil profile throughout the growing season was uneven and inconsistent or asymmetrical under conventional irrigation and soil fertilization, permitting excessive leaching and deep percolation losses and subsequently causing lesser availability in soil for root absorption and the plants suffer from acute soil water and nutrient stresses for a longer period which adversely affected the plant with depressed yield and poor input use efficiency (Pawar and Dingre 2013, Pramanik and Patra 2016).

CONCLUSIONS

Gravity-fed drip fertigation with moderately deficit or optimum irrigation scheduling recorded maximum yield, water and fertilizer use efficiency, water-savings and economic return as compared with farmers' conventional water and fertilizer practices. Based on the resource availability, imposition of fertilization partly as pre-plant and rest through fertigation or full drip-fertigation, integrated nitrogen management and plastic mulching as soil water conservation were found to be techno-economically feasible for the farmers of deep tube well command in West Bengal or similar agro-climatic conditions. However, the commission of the system is costlier and requires more skill and expertise for operation and maintenance.

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Received 11 September, 2021; Accepted 21 March, 2022

Indian Journal of Ecology (2022) 49(2): 388-393
DOI: https://doi.org/10.55362/IJE/2022/3534

Manuscript Number: 3534
NAAS Rating: 5.79

Long Term Effect of Fertilizers and Amendments on Macronutrients Uptake by Maize and Relationship with Soil Organic Carbon in Maize-Wheat System in Acid Alfisol of North-Western Himalayas

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Abstract: Present study was carried out during *kharif* 2018 in the ongoing long-term fertilizer experiment, initiated in 1972 at the experimental farm of the Department of Soil Science, Chaudhary Sarwan Kumar Himachal Pradesh Agriculture University, Palampur, to study the effect of chemical fertilizers, farmyard manure and lime application on yield and nutrient uptake by maize and their relationship with soil organic C in an acid Alfisol. The experiment consisted of three replications of eleven treatments in a randomized block design. The results revealed that the continuous use of NPK fertilizers along with FYM or lime increased the maize yield by 46.7 and 38.5%, whereas omission of S and K from the fertilization schedule declined the yield by 54.8 and 52.2% over the sole use of NPK fertilizers, respectively. The uptake of N, P, K, S, Ca and Mg by maize grain and stover was significantly higher in 100% NPK+FYM and 100% NPK+lime than rest of the treatments. Soil organic C recorded a positive and significant relation with uptake of macronutrients by maize, the highest being with P uptake by maize grain (r = 0.918**).

Keywords: FYM, Lime, Maize, Nutrient uptake, Soil organic carbon, Yield

Maize is the third most important cereal crop in India, after wheat and rice. It has high genetic yield potential; therefore, its nutrients requirement is also very high. The uptake of nutrients and their transport within the plant system primarily depends upon the growth stage of the plant, soil fertility, amount of fertilizers applied etc. (Bisht et al 2013). Chemical fertilizers are applied to the soil to supplement the soil nutrient supply and increase crop yields. However, inadequate and imbalanced application of fertilizers adversely affects soil health and declines crop productivity (Kalhapure et al 2014). Integration of organic and inorganic sources of plant nutrients may help to supply adequate nutrients in an optimum proportion. Organic manures supply soil organic matter and increase nutrient availability and use efficiency by regulating their supply. Soil organic matter is a reservoir of C as well as nutrients in the soil, contains almost all the nutrients essential for plant growth, therefore, is an important factor affecting the nutrient uptake by the crop (Wang et al 2015). In acid soils, high exchangeable Al, Fe and Mn and deficiency of P, Ca, Mo etc. are the most limiting factors for plant growth (Rajneesh et al 2018). Application of lime is done for remediating the soil acidity but it affects the availability and uptake of the nutrients. It is important to identify the effect of nutrient management practices involving fertilizers and amendments on crop productivity and nutrient availability to the crop over a long period. Long-term fertilizer experiments are very helpful tools in assessing the effect of the use of fertilizers and manures on crop productivity and soil health. Therefore, the present study was carried out to evaluate the effect of chemical fertilizers, FYM and lime application on yield and nutrient uptake by maize after forty-six years in maize-wheat cropping system in an acid Alfisol.

MATERIAL AND METHODS

Experimental site: Present study was carried out during *kharif* 2018 in an on-going long-term fertilizer experiment, initiated in 1972 at the experimental farm of Department of Soil Science, CSK HPKV, Palampur (31°6′ N latitude and 76°3′ E longitude, 1290 meters above mean sea level. The mean weekly temperature during the study period varied from 19.5 to 25.6 °C and the total rainfall received was 2605 mm. The soil of the study site is illitic with silty loam in texture and classified as subgroup Typic Hapludalf. At the start of the experiment, soil pH was 5.9, soil organic carbon (SOC) 7.9 g/kg, available N, P and K were 736, 12 and 194 kg/ha, respectively. The SOC ranged between 0.79 and 1.39% after the harvest of the maize crop in the present study.

Experimental layout and treatments: There were eleven treatments in three replications, experiment was laid out in a randomized block design (Table 1). Since 2011, optimal and super-optimal P doses have been reduced by 50% due to the P build-up and FYM application at the rate of 5 t/ha (dry weight basis) has been initiated in 50% NPK (T_1). The optimal dose of NPK for maize corresponds to 120, 60 and 40 kg/ha N, P_2O_5 and K_2O, respectively. Half doses of N and full doses of P and K were applied at the time of sowing and the remaining half N was top-dressed in two equal splits at the knee-high and pre-tasseling stage. Urea, single super phosphate (SSP) and muriate of potash (MOP) were sources of N, P and K in all treatments, except in NPK(-S), diammonium phosphate (DAP) was applied as a source of P. Farmyard manure (60% moisture, 1.01% N, 0.26% P and 0.40% K) was applied at the rate of 5 t/ha (dry weight basis). Till 2011, Zn was applied in T_5 as $ZnSO_4$ at the rate of 25 kg/ha every year to both crops. Lime was applied continuously in T_{10} till the soil pH was raised to 6.5 but in subsequent years, the lime application was only done when the soil pH declined to about 6.3. After ploughing with power tiller, pre-sowing irrigation was done and thereafter, the water requirement of the crop was met through rainfall. Atrazine was applied as a pre-emergence herbicide at the rate of 1.125 kg/ha in all treatments barring 100% NPK + hand weeding (T_4) in which hand weeding was done. Earthing up was done after 45 days of sowing.

Sampling and analysis: Maize grain and stover yield were recorded, the samples were collected from each plot after the harvest of the crop and dried in an electric oven at 60 °C to a constant weight. The dried grain samples were finely ground in a mixer grinder in stainless steel jar and stored in plastic bags under moisture-free conditions. The stover samples were ground in a Wiley mill and store in paper bags. The grain and stover samples were digested in conc. H_2SO_4, followed by distillation with micro-Kjeldahl method (Jackson 1973) for determination of N content. Maize grain and stover samples were digested in the di-acid mixture (HNO_3:$HClO_4$ in 9:4 ratio) and the aqueous extract was used to determine contents of P using the vanado-molybdo-phosphoric acid method (Jackson 1973), K by flame photometer method (Black 1965), S by turbidimetric method (Chesnin and Yein 1950), Ca by flame photometer method (Jackson 1973) and Mg by atomic absorption spectrophotometer method (Jackson 1973). The nutrient uptake was calculated by multiplying the percent concentration of the nutrients with grain and stover yield.

Statistical analysis: The data collected were subjected to statistical analysis using Web Agri Stat Package 2.0. The differences between the means were tested using Duncan Multiple Range Test (DMRT) ($P \leq 0.05$).

Table 1. Effect of continuous use of fertilizers and amendments on maize yield (t/ha)

Treatment	Grain yield	Stover yield
50% NPK (T_1)	3.07[c]	5.13[c]
100% NPK (T_2)	3.15[c]	5.27[c]
150% NPK (T_3)	2.75[c]	4.61[c]
100% NPK + HW (T_4)	3.66[b]	6.16[b]
100% NPK + Zn (T_5)	3.01[c]	5.03[c]
100% NP (T_6)	1.49[d]	2.53[d]
100% N (T_7)	0[f]	0[f]
100% NPK + FYM (T_8)	4.65[a]	7.7[a]
100% NPK (-S) (T_9)	1.41[d]	2.39[d]
100% NPK + lime (T_{10})	4.32[a]	7.34[a]
Control (T_{11})	0.64[e]	1.12[e]

Values with the same letters are not significantly different at $P < 0.05$.

RESULTS AND DISCUSSION

Yield: All fertilized treatments, barring T_7, recorded significantly higher maize grain and stover yield than the unfertilized control (Table 1). In T_7 treatment, continuous urea application sharply declined the soil pH that increased the Al and Fe ions in the soil to toxic levels, thus adversely affected the crop growth and the crop did not grow beyond the knee-length stage (Thakur et al 2019). The maize grain and stover yield were highest in T_8 (4.7 and 7.7 t/ha, respectively) and was at par with T_{10} (4.3 and 7.3 t/ha, respectively). This could be attributed to the balanced supply of nutrients through chemical fertilizers and additional nutrients added from FYM. In T_{10}, amelioration of soil acidity by lime application corrected the Al toxicity and increased the availability of the nutrients, especially P, Ca and Mg. Application of S and K in T_2 resulted in 55.2 and 52.6% higher grain yield than T_9 and T_6 treatments in which these were omitted, respectively, as both S and K play a key role in plant growth and metabolism.

Nitrogen uptake: The treatment 100% NPK + FYM recorded highest total N uptake (138.8 kg/ha), followed by 100% NPK + lime (119.0 kg/ha) (Table 2). These treatments recorded 74 and 49% higher total N uptake over 100% NPK, respectively. Kalhapure et al (2014), Chaudhary et al (2017) and Rajneesh et al (2017) also reported higher uptake of N by maize with the application of organic manures and attributed this to higher nutrient availability, improved metabolic functions in plants which might have been resulted in higher nutrient uptake and crop yield. The total N uptake in plots receiving of super-optimal dose of NPK (T_3) was less than optimal NPK (T_2), however the difference was non-significant. Apart from 100% N, the lowest total N uptake by maize (13.2 kg/ha) was recorded under control.

Phosphorus uptake: The highest total P uptake (29.27 kg/ha) was recorded under 100% NPK+ FYM which was significantly superior over the rest of the treatments and least in control (2.08 kg/ha) (Table 2). This could be attributed to the solubilization of native P, synchronized the release of P by mineralization of organic matter, and its uptake by crop by the addition of FYM (Sharma et al 2016). Application of 100% NP and 100% NPK (-S) treatments registered 63 and 57% reduction in total P uptake by maize in comparison to 100% NPK, respectively. Application of 100% NPK + lime recorded 61% higher total P uptake over 100% NPK alone, which could be due to increased soil pH, precipitation of Al^{3+} ions, reduced P fixation and thereby increased availability of P. In control plots, continuous cropping without any external inputs exhausted the native P reserves of soil and resulted in low P uptake.

Potassium uptake: The total K uptake by maize varied from 6.73 kg/ha in control to 85.59 kg/ha in 100% NPK + FYM (Table 2). Application of FYM or lime along with the balanced application of chemical fertilizers significantly increased the K uptake over 100% NPK by 74 and 43%, respectively. Improvement in soil properties leading to better crop growth from FYM and lime addition might have resulted in higher uptake of K in these treatments. The omission of K from fertilization schedule (T_6) for the last forty-six years, resulted in almost 66% lower K uptake than 100% NPK.

Sulphur uptake: Barring 100% N, total S uptake by maize varied from 1.68 in control to 33.57 kg/ha in 100% NPK + FYM (Table 3). Application of FYM (T_8) increased the S uptake by maize over 100% NPK by 96% which could be

Table 2. Effect of continuous use of fertilizers and amendments for forty-six years on N, P and K uptake by maize (kg/ha)

Treatment	N			P			K		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
50% NPK (T_1)	41.6^{d}	32.0^{d}	73.6^{d}	9.11^{d}	3.88^{cd}	12.99^{d}	11.18^{d}	33.25^{d}	44.44^{d}
100% NPK (T_2)	46.0^{d}	33.9^{d}	79.8^{d}	10.36^{d}	4.40^{cd}	14.76^{d}	11.85^{d}	37.48^{d}	49.33^{d}
150% NPK (T_3)	41.2^{d}	32.9^{d}	74.1^{d}	10.28^{d}	4.72^{c}	15.00^{d}	10.63^{d}	33.51^{d}	44.14^{d}
100% NPK + HW (T_4)	56.4^{c}	41.2^{c}	97.6^{c}	12.53^{c}	5.76^{b}	18.29^{c}	13.46^{c}	44.52^{c}	57.97^{c}
100% NPK + Zn (T_5)	44.5^{d}	33.2^{d}	77.7^{d}	9.30^{d}	3.61^{d}	12.91^{d}	10.91^{d}	35.07^{d}	45.98^{d}
100% NP (T_6)	19.2^{e}	15.5^{e}	34.7^{e}	4.22^{e}	1.25^{ef}	5.48^{e}	4.60^{e}	12.38^{e}	16.98^{e}
100% N (T_7)	0.0^{g}	0.0^{g}	0.0^{g}	0.00^{g}	0.00^{g}	0.00^{f}	0.00^{g}	0.00^{f}	0.00^{f}
100% NPK + FYM (T_8)	76.8^{a}	62.0^{a}	138.8^{a}	21.46^{a}	7.81^{a}	29.27^{a}	20.04^{a}	65.55^{a}	85.59^{a}
100% NPK (-S) (T_9)	18.0^{e}	14.4^{e}	32.4^{e}	4.75^{e}	1.60^{e}	6.35^{e}	4.28^{e}	14.84^{e}	19.12^{e}
100% NPK + lime (T_{10})	67.7^{b}	51.3^{b}	119.0^{b}	17.39^{b}	6.40^{b}	23.79^{b}	16.31^{b}	54.25^{b}	70.56^{b}
Control (T_{11})	7.9^{f}	5.3^{f}	13.2^{f}	1.65^{f}	0.44^{fg}	2.08^{f}	1.69^{f}	5.05^{f}	6.73^{f}

*Values with the same letters are not significantly different at $P < 0.05$

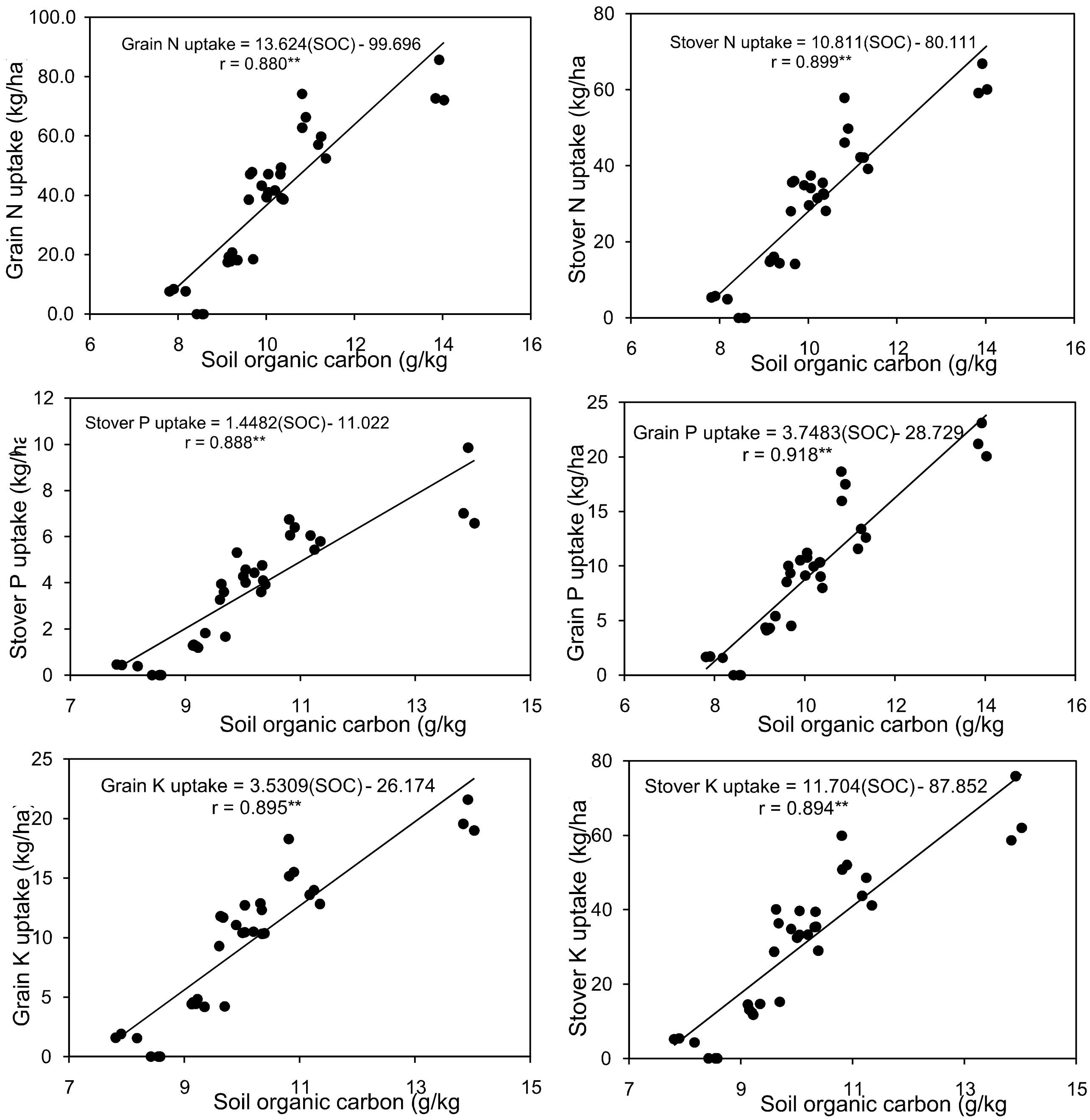
Table 3. Effect of continuous use of fertilizers and amendments for forty-six years on S, Ca and Mg uptake by maize (kg/ha)

Treatment	S			Ca			Mg		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
50% NPK (T_1)	6.75^{d}	6.17^{e}	12.92^{e}	6.02^{d}	19.98^{d}	26.00^{c}	2.66^{d}	3.78^{d}	6.44^{d}
100% NPK (T_2)	8.08^{d}	9.09^{d}	17.17^{d}	7.35^{c}	21.92^{d}	29.27^{c}	3.34^{bcd}	4.09^{d}	7.43^{d}
150% NPK (T_3)	8.26^{cd}	7.36^{de}	15.62^{de}	6.97^{cd}	21.03^{d}	28.00^{c}	3.41^{bc}	4.13^{d}	7.54^{d}
100% NPK + HW (T_4)	9.79^{c}	11.09^{c}	20.87^{c}	8.83^{b}	27.75^{c}	36.58^{b}	3.92^{b}	5.07^{c}	8.99^{c}
100% NPK + Zn (T_5)	7.51^{d}	8.37^{d}	15.88^{de}	6.86^{cd}	21.58^{d}	28.43^{c}	2.86^{cd}	3.61^{d}	6.46^{d}
100% NP (T_6)	3.59^{e}	3.70^{f}	7.29^{f}	2.75^{e}	9.01^{e}	11.76^{d}	1.24^{e}	1.49^{e}	2.72^{e}
100% N (T_7)	0.00^{g}	0.00^{h}	0.00^{h}	0.00^{f}	0.00^{f}	0.00^{e}	0.00^{f}	0.00^{f}	0.00^{f}
100% NPK + FYM (T_8)	16.30^{a}	17.27^{a}	33.57^{a}	12.23^{a}	41.56^{a}	53.79^{a}	5.99^{a}	7.80^{a}	13.79^{a}
100% NPK (-S) (T_9)	1.98^{f}	1.91^{fg}	3.89^{g}	2.44^{e}	8.24^{e}	10.69^{d}	1.19^{e}	1.62^{e}	2.80^{e}
100% NPK + lime (T_{10})	13.38^{b}	13.95^{b}	27.32^{b}	12.92^{a}	36.73^{b}	49.64^{a}	5.39^{a}	7.06^{b}	12.45^{b}
Control (T_{11})	0.86^{fg}	0.83^{gh}	1.68^{gh}	0.92^{f}	2.80^{f}	3.72^{e}	0.40^{f}	0.60^{f}	1.00^{f}

*Values with the same letters are not significantly different at $P < 0.05$

ascribed to the addition of S and other essential nutrients through FYM. Continuous addition of S-free fertilizers in 100% NPK (-S) and continuous cropping for forty-six years might have led to the depletion of soil S reserves (Kundu et al 2016), resulting in poor crop yield and thereby low S uptake which was at par with control. Das et al (2012) have also reported that lower S uptake with the continuous use of S-free fertilizers from their study at Pantnagar (India).

Calcium uptake: The highest total Ca uptake (53.79 kg/ha) was recorded in 100% NPK + FYM and the lowest was recorded in control (3.72 kg/ha), apart from 100% N (Table 3). Application of either FYM (T_8) or lime (T_{10}) along with recommended NPK improved the total Ca uptake to the extent of 84 and 70 %, respectively, over use of 100% NPK alone. The application of FYM (T_8) improved soil properties, enhanced root growth, resulting in better nutrient uptake and

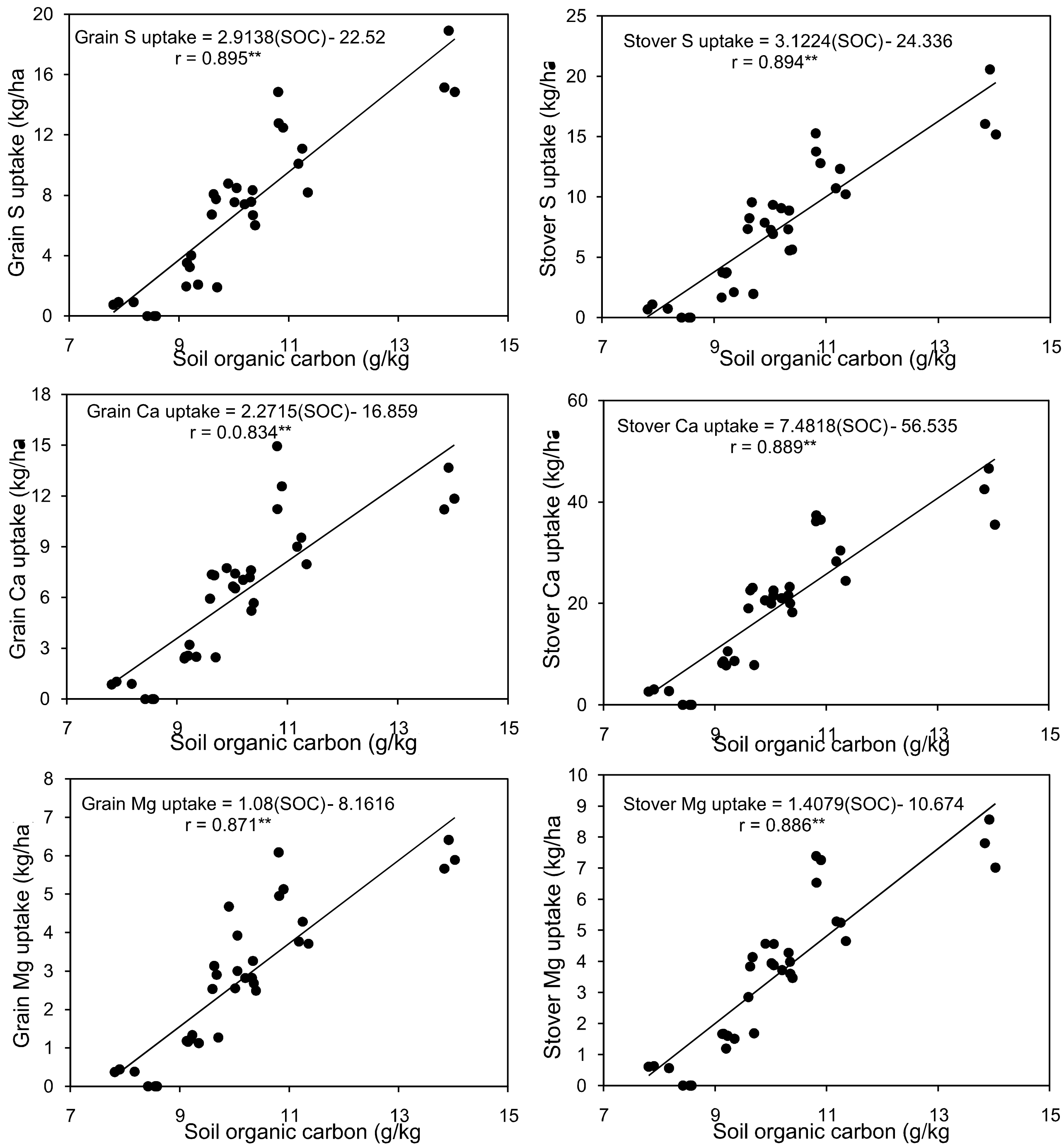


** Significant at the 1% levels of probability according to t-test (n=33)

Fig. 1. Linear regression relationship of soil organic carbon (SOC) with (a) grain N uptake, (b) stover N uptake, (c) grain P uptake, (d) stover P uptake, (e) grain K uptake and (f) stover K uptake

increased crop yield, hence recorded higher Ca uptake. The addition of lime in T_{10} increased the Ca content in soil and also neutralized the soil pH thereby increased Ca availability to the crop.

Magnesium uptake: The highest total Mg uptake was recorded under 100% NPK + FYM (5.99 kg/ha) treatment and lowest in control (0.40 kg/ha), except 100% N (Table 3). The treatment 100% NPK + lime was at par with 100% NPK + FYM. Application of FYM in T_8 increased exchangeable Mg content of soil due to the release of Mg from added FYM, improved root growth, and increased crop yield. Whereas, higher Mg uptake in T_{10} where lime was being applied might



** Significant at the 1% levels of probability according to t-test (n=33)

Fig. 2. Linear regression relationship of soil organic carbon (SOC) with (a) grain S uptake, (b) stover S uptake, (c) grain Ca uptake, (d) stover Ca uptake, (e) grain Mg uptake and (f) stover Mg uptake

be attributed to the amelioration of soil acidity, and increased biomass production (Rajneesh et al 2017).

Relationship between nutrient uptake and soil organic carbon: The relationship between nutrient uptake by maize grain and stover, and SOC was determined with nutrient uptake as the dependent variable and SOC as the independent variable (Fig. 1 and 2). It was observed that the nutrient uptake by grain and stover exhibited a strong and positive relationship with SOC for all the nutrients. It could be attributed to the addition of organic C from FYM and plant biomass, which enhanced the microbial activity in the soil, increasing the nutrient cycling and subsequently the availability of nutrients to the crop (Jadhao et al 2019). Therefore, uptake of nutrients was highest in 100% NPK + FYM treatment, in which organic C was added through FYM.

CONCLUSIONS

Integrated use of optimal NPK dose along with FYM or lime increased the maize grain and stover yield significantly over sole use of NPK fertilizers. Also, uptake of nutrients was highest when NPK fertilizers were applied in integration with FYM and lowest in unfertilized control. Soil organic C exhibited a strong and positive relationship with the macronutrient uptake by grain and stover of maize crop, thus, indicating the importance of maintaining optimum levels of organic C in soil.

ACKNOWLEDGEMENTS

The authors are highly thankful to the Indian Council of Agricultural Research (ICAR) for funding the study under the All-Indian Coordinated Research Project on Long-Term Fertilizer Experiments (AICRP-LTFE) and CSK Himachal Pradesh Agricultural University, Palampur for providing essential facilities.

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Received 23 October, 2021; Accepted 21 February, 2022

Indian Journal of Ecology (2022) 49(2): 394-398
DOI: https://doi.org/10.55362/IJE/2022/3535

Manuscript Number: 3535
NAAS Rating: 5.79

Growth, Yield and Organoleptic Characteristic of Rice (*Oryza sativa* L.) Varieties in Wet Rice Cultivation Region of Mizoram

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Abstract: The lower rice productivity has been a major concern for Mizoram rice sustainability under the rainfed wet rice cultivation (WRC). Bridging this yield gap, field experiment has been undertaken with 22 rice varieties (Gomati, NLR-1, NLR-2, NLR-3, NLR-4, NLR-5, NLR-9, PB-1121, PB-1718, RCM-9, RCM-10, Shahsarang, PNR 546, Tripura Nirogi, Tripura Sarat, Tripura Chikan, Tripura Hakuchuk, PS-5, PD-13, TRC-2015-7, TRC-2013-11 and Local cultivar) at WRC region of ICAR Kolasib research farm under RBD design for two years (2019 and 2020). The rice *cv* Gomati performed best under the humid subtropical hill region of Mizoram with 152.5% higher grain yield as compared with local cultivar. Gomati recorded high leaf area index, higher productive tillers per hill with medium duration. Apart from rice *cv* Gomati; RCM 9, RCM 10, NLR 1, NLR 9, PNR 546 and TRC 2015-7 recorded nearly double yield than that of local cultivar. However, even with high yield performance of above rice varieties, some of these varieties are not very well adopted by Mizo farmers due to taste requirements of Mizo people. Based on appearance, taste, consistency, aroma and hardness of tested rice varieties, PNR 546, RCM 9 and Tripura Chikan were confirmed at par taste with the local rice cultivar. Most of these varieties matured in about 130-150 days, with very few maturing in about 120-130 days (PNR 546, PS 5 and PD 13) and local cultivar at 159 days. Thus, with adoption of best suitable high-yielding medium duration rice varieties with their preference to taste will enhance rice productivity and narrow down the yield gaps that existed in WRC local rice cultivar of Mizoram.

Keywords: Rice, Mizoram, WRC, Yield, Taste, Crop duration

Rice (*Oryza sativa* L.) is the staple food for a major portion of the world population. In India, it occupied the major area and production with 44.2 million hectares and 116.4 million tonnes, respectively in 2018-19 (Anonymous, 2021a). This comprises 35.1% area and 40.8% production among the total food grains of India. North-East states of India are located in the easternmost part of India comprising Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura. Among them, Mizoram is one of the easternmost states situated in tropical hilly and pre-dominated by tribes called Mizo. These states have rice as a major staple crop with major source of livelihood, food and nutritional security. All these north-eastern states comprised a total rice area of 3.2 million hectares, 7.2 million tonne of production and 2213 kg/ha productivity. Mizoram having 35,210 hectare of rice area with productivity of 1704 kg/ha in 2019-20 (Anonymous 2021b). This total rice area of Mizoram includes upland rice and wet rice cultivation (WRC) area and out of which, WRC area constitutes 17,265 hectares (Mizoram Economic Survey, 2019-20). Most of the agricultural crops including rice (90% of the cultivated crop) in Mizoram are cultivated as rainfed. The area under rice decreased by 35.1% whereas, productivity decreased by 14.8% from 2000-01 to 2019-20 (Mizoram Economic Survey 2019-20). This decrease in area and productivity of rice in Mizoram is mainly due to the cultivation of lower yielded upland rice under jhum, non-availability of suitable high yielding rice varieties, least mechanization, low adoption of scientific agronomical practices, high cost of cultivation, and replacement of upland rice area with high-valuing horticultural crops, *etc*. Under the WRC system of cultivation, major rice cultivars are of local landraces and other varieties that are being preferred by Mizos due to their taste. However, these varieties are long to extra-long duration having low yield potential, susceptible to lodging during the later growth stages resulting in low yield and poor quality. Therefore, keeping this background in view an experiment has been undertaken to find the most suitable rice varieties for Mizoram having higher yield potential, medium duration with taste acceptability by Mizo people.

MATERIAL AND METHODS

Experimental site: The study was conducted at Research Farm, ICAR RC NEH Region, Mizoram Centre Kolasib, Mizoram, India during *Kharif* 2019 and *Kharif* 2020 to find out the lodging resistance high yielding rice variety suitable for the wet rice cultivation (WRC) region of Mizoram region. The field is located at 24°12'46.03"N latitude and 92°40'37.07"E longitude under the Humid Subtropical Hills agro-climatic region of Mizoram (as per NARP) and Eastern Himalayan Region (II) agro-climatic region of India (as per Planning Commission).The two-season monthly mean minimum and maximum temperatures during the cropping period were 20.8 and 29.0°C, respectively. The monthly average minimum and maximum relative humidity was 77.5 and 90.5%, respectively having a monthly average bright sunshine hour of 5.1 hrs per day. The average total rainfall during two crop seasons was 2537.8 mm with an average of 16.8 rainy days per month (Fig. 1). The soil belongs to clayey loam with slightly acidic in nature (pH 5.2). The bulk density of the soil is 1.42 Mg m^{-3} and has high organic carbon content (1.3%), low in available nitrogen (251.0 kg/ha), medium in available phosphorus (10.5 kg/ha) and medium in available potassium (289.7 kg/ha).

Experimental details: Rice (*Oryza sativa*) was sown in the experiment under randomized block design with three replications. 22 rice varieties *viz*., Gomati, NLR-1, NLR-2, NLR-3, NLR-4, NLR-5, NLR-9, PB-1121, PB-1718, RCM-9, RCM-10, Shahsarang, PNR 546, Tripura Nirogi, Tripura Sarat, Tripura Chikan, Tripura Hakuchuk, PS-5, PD-13, TRC-2015-7, TRC-2013-11 and Local cultivar were selected as varietal treatments. These varieties were collected from different north-eastern states of India based on its performance and farmers' acceptability. These varieties were raised in the nursery for 24 days during the last week of April months in both the seasons. During the nursery period, the main field was prepared by puddling with power tiller having cage wheel twice and levelled. One seedling per hill was sown at a spacing of 22.5 cm x 15 cm with a net plot size of 12 m^2. During the transplanting time, the field was maintained at the saturated condition with no standing water. All other crop management practices like fertilization, weed and pest management and irrigation was done as per recommended agronomic package of practices.

Crop growth and yield parameters: The plant height (cm) from five tagged plants from each plot was taken at the harvest stage; leaf area (cm^2) was measured from each plot at 60 and 90 DAT. Five plants were pulled out, leaves were detached and fresh leaves were placed in leaf area meter (LI-COR LI-3100C area meter) to record leaf area (cm^2) and leaf area index (LAI) was calculated by formula coined by Yoshida et al (1976).

$$\text{LAI} = \frac{\text{Leaf area per plant (cm}^2\text{)}}{\text{Spacing (cm}^2\text{)}}$$

Crop duration was recorded from date of sowing to the time of harvesting. Yield attributes like productive tillers per hill, number of grains per panicle, test weight (1000 grain weight); grain yield (kg/ha) and biological yield (kg/ha) were recorded at harvest.

Organoleptic analysis: Sixteen (16) best performing rice varieties among 22 varieties under study were evaluated for organoleptic analysis based on appearance, taste, consistency, aroma and hardness. 5.0 g of rice kept in 15 ml of water and soaked for 10 min and cooked. Based on number of variety and panellist, number of samples were cooked and served to 19 taste panellists (Anonymous 2004). Organoleptic evaluation of the samples was done using 5

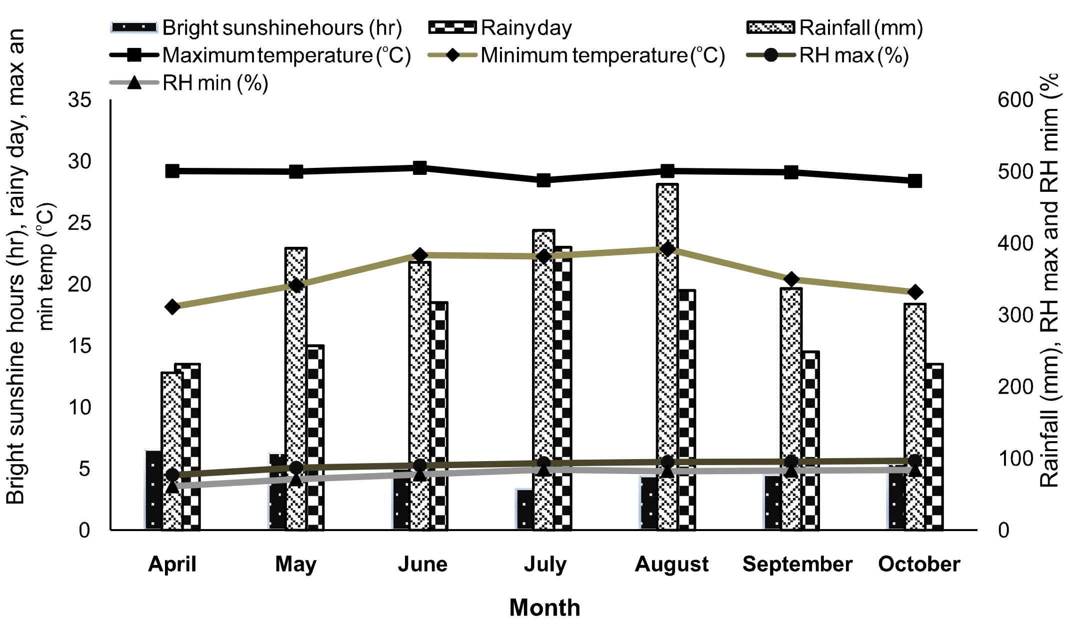

Fig. 1. Mean monthly weather condition (*Kharif* 2019 and 2020)

point hedonic scale (5 – Very good to 1 – Poor; Amerine et al 1965).

Statistical analysis: Data were analysed using OPSTAT software with the link http://14.139.232.166/opstat /default.asp. The response of treatments was similar during both the years and followed the homogeneity test.

RESULTS AND DISCUSSION

Crop growth and yield parameters: Crop growth and yield parameters of rice varieties varied under the same growing conditions. Significant variations in leaf area index (LAI) were observed at 60 and 90DAT, respectively. The significant higher LAI at 60 DAT was recorded in Gomati variety (3.06) that was at par with NLR-4,5,9, TRC-2015-7 and TRC-2013-11 whereas lowest was in PD-13 (2.03). Similarly at 90DAT, significantly higher LAI was observed under Gomati variety (4.28) at par with NLR 1,2,3,4,5,9, RCM 9, 10, local, TRC-2015-7 and TRC-2013-11. The significant lowest LAI was observed in PB-1718 (2.80) (Table 1). This might be due to genetic makeup of rice varieties having different ability to accumulate the photosynthates supplemented with conductive climatic condition. These results were also supported by finding of Kumar et al (2017). Among the 22 rice varieties evaluated for Mizoram, days to maturity varied from 124 days (PD 13) to 159 days (local rice) (Table 1). It was observed that local rice cultivar recorded significantly longest crop duration (159 days) followed by NLR 2 and Tripura Sarat whereas, significantly shortest crop duration was observed under PD 13 (124 days). Days to maturity varies with rice varieties due to genetic traits of cultivars with conductive climatic condition (Ojha 2013).

At maturity stage of rice, tallest plant was recorded in local rice cultivar (183.0 cm) followed by TRC 2013-11 while PD 13 with shortest plant height (Table 2). Number of tillers per hill is an important yield attributing parameter and significantly higher number of productive tillers per hill was recorded in Gomati (15.8 statistically at par with RCM 9 and least was observed in PS 5 (6.0). The number of grains per panicle was significantly higher in TRC 2015-7 (118.6) and was followed by Tripura Hakuchuk and significantly least in PD 13 (41.6). This might be due to varietal genetic characteristics combined with congenial environment conditions favouring healthier plant, more productive tillers per hill and higher

Table 1. Leaf area index of different rice varieties at humid sub tropical hills region of Mizoram

Variety	Leaf area index		Crop duration (days)
	60 DAT	90 DAT	
Gomati	3.06	4.28	148.7±0.7
NLR 1	2.55	3.92	142.3±2.0
NRL 2	2.49	3.84	151.0±0.6
NRL 3	2.72	3.95	145.7±3.4
NLR 4	2.89	4.17	145.7±0.9
NLR 5	2.91	4.16	149.3±0.7
NLR 9	2.97	4.07	148.7±0.3
PB 1121	2.06	2.85	149.3±0.7
PB 1718	2.21	2.80	149.3±0.7
RCM 9	2.65	3.89	148.7±0.3
RCM 10	2.50	4.21	148.7±0.7
Shahsarang	2.54	3.12	149.3±0.7
PNR 546	2.66	3.18	129.3±1.8
Tripura Nirogi	2.69	2.97	133.0±3.8
Tripura Saarat	2.25	2.91	151.0±0.6
Tripura Chikan	2.49	3.28	141.7±2.2
Tripura Hakuchuk	2.18	3.02	131.0±2.6
PS 5	2.54	3.13	125.0±0.6
PD 13	2.03	2.81	123.7±1.9
TRC 2015-7	2.98	3.68	143.3±2.2
TRC 2013-11	2.86	3.67	143.3±2.2
Local	2.66	3.89	159±0.67
LSD (p=0.05)	0.22	0.71	4.0

Fig. 2. Rice panicle of selected rice variety under study

grain per panicle and also, the differential life span of the varieties. Longer the duration of rice varieties produced better yield components than shorter duration varieties (Chaudhary et al 2008, Mandal et al 2018). The 1000 grain weight of rice varieties under study was in the range of 20.5 to 33.7 g. The significantly higher 1000 grain weight was recorded in NLR 9 (33.7 g) followed by Gomati whereas least weight was recorded in PS 5 (20.5g). The variation in 1000 grain weight between the varieties was mainly due to grains boldness, fineness and length. It is also affected by climatic conditions associated with different rice variety's duration.

Grain yield was significantly higher in Gomati (3884 kg/ha) and was statistically at par with RCM 10 and NLR 9 and significantly least grain yield was obtained in PB 1121 (1060 kg/ha) (Table 2, Fig. 2). The best performing varieties *viz*., Gomati and RCM 10 was out yielded 152.5 and 139.9%, respectively from local cultivar. The higher yield of above varieties are due to higher values of one or more yield attributes of rice *viz*., number of effective tillers per plant, number of grains per panicle and 1000 grain weight *etc*. Similar finding was reported by Kitilu et al (2019). However, the significantly higher biological yield was obtained in NLR 4 (15454 kg/ha) at par with Gomati, NLR 9, RCM 10, Shahsarang, Local and Tripura Chikan. The lowest biological yield was observed in PB 1718 (5638 kg/ha). The rice biological yield is the combined weight of rice grain yield and straw yield. However, when comparison has been made among different varieties under same ecological condition, it was found that sometime higher vegetative growth of one variety does not yielded more grain yield, this might be due to poor translocation of photosynthate from source to sink, genetic makeup and weather condition prevailing to that region. Therefore, even higher biological yield of some of rice varieties doesn't reflect higher grain yield. These results are in line with finding of Baishya et al (2015) and Mandal et al (2018). Harvest index (HI) is the depiction of ratio between grain yields to biological yield. TRC 2015-7 recorded significantly higher HI (0.39) statistically at par with PNR 546, Tripura Hakuchuk, RCM 9, NLR 1, TRC 2013-11, Tripura Nirogi, NLR 5 and PS 5 while lowest HI (0.16) were observed under NLR 4, PB 1121 and Local cultivar (Table 2). The higher HI was due to good partitioning efficiency of plants and process of translocating more photosynthates from source to sink that reflected higher HI (Kitilu et al 2019).

Organoleptic analysis: The overall mean scores for the organoleptic analysis based on appearance, taste, texture, aroma, hardness, and overall acceptability showed significant differences. Overall organoleptic mean scores of

Table 2. Yield attributes and yields of different rice varieties at humid subtropical hills region of Mizoram (Mean±SD)

Rice variety	Plant height (cm)	No of productive tillers per hill	No of grains per panicle	1000 grain weight (g)	Grain yield (kg/ha)	Biological yield (kg/ha)	Harvest index
Gomati	149.0±0.3	15.8±0.3	86.0±4.9	30.3±0.5	3884±245	14854±381	0.26±0.02
NLR 1	142.0±4.7	9.5±0.4	98.7±4.9	27.0±0.3	3143±265	10330±1110	0.31±0.02
NRL 2	154.5±3.3	8.6±0.9	58.8±0.7	26.3±0.3	2190±323	9985±2111	0.23±0.03
NRL 3	149.9±1.1	7.4±0.9	94.5±9.3	27.5±0.7	2310±136	10312±202	0.22±0.01
NLR 4	149.3±0.4	7.1±0.2	94.6±6.0	28.4±0.6	2312±279	15454±1647	0.16±0.04
NLR 5	144.4±4.3	8.7±0.4	96.1±4.7	28.5±0.3	2963±50	10521±262	0.28±0.00
NLR 9	135.4±0.7	11.6±0.9	88.2±2.5	33.7±0.6	3496±203	14087±1417	0.26±0.04
PB 1121	134.9±0.4	11.3±1.1	65.5±8.9	24.3±0.1	1060±166	6831±937	0.16±0.01
PB 1718	147.7±0.1	10.4±0.2	67.1±7.7	25.2±0.1	1119±184	5638±1452	0.21±0.03
RCM 9	132.7±2.6	13.6±0.2	65.2±1.6	25.5±0.2	3345±164	10293±526	0.33±0.03
RCM 10	156.0±8.4	12.7±0.7	87.1±3.4	26.2±0.1	3690±214	13979±130	0.26±0.01
Shahsarang	137.8±0.4	9.2±0.1	79.7±5.9	25.2±0.6	2892±107	13167±1662	0.23±0.04
PNR 546	131.3±7.6	11.1±0.1	92.0±3.8	28.6±0.5	3075±209	8390±225	0.37±0.03
Tripura Nirogi	143.5±0.2	7.2±0.1	67.2±5.1	26.0±0.0	2833±180	9863±701	0.29±0.01
Tripura Saarat	158.6±2.4	9.4±1.4	50.0±0.8	28.1±0.2	1199±161	6895±1980	0.19±0.03
Tripura Chikan	132.3±2.1	10.1±1.4	73.7±2.1	30.2±0.8	2223±240	12094±2196	0.20±0.05
Tripura Hakuchuk	147.7±0.4	7.5±0.6	110.2±4.4	24.3±0.1	2630±44	7523±375	0.35±0.01
PS 5	121.3±3.6	6.0±0.2	96.3±6.3	20.5±0.3	2665±47	9714±1150	0.28±0.03
PD 13	77.7±0.7	8.4±0.9	41.6±3.8	21.0±0.6	1451±43	6149±77	0.24±0.01
TRC 2015-7	135.3±2.5	10.2±0.1	118.6±5.1	22.4±0.2	3267±251	9014±1258	0.39±0.09
TRC 2013-11	172.9±2.9	10.6±0.7	47.1±8.2	24.9±0.4	2238±38	8834±1474	0.29±0.05
Local	183.0±4.1	7.7±0.3	67.6±4.3	23.3±0.1	1538±115	12409±3231	0.16±0.06
LSD (p=0.05)	9.1	2.9	7.8	1.2	463	4030	0.12

Table 3. Organoleptic score in hedonic scale of different rice varieties

Rice variety	Organoleptic score in 5 points hedonic scale (5-very good to 1-Poor)
Gomati	3.4±0.15
NLR 1	3.2±0.13
NLR 4	3.4±0.21
NLR 5	3.1±0.15
NLR 9	3.1±0.17
RCM 9	4.1±0.17
RCM 10	3.4±0.15
Shahsarang	3.4±0.16
PNR 546	4.4±0.14
Tripura Nirogi	4.0±0.20
Tripura Chikan	3.1±0.15
Tripura Hakuchuk	3.1±0.24
PS 5	3.6±0.15
TRC 2015-7	2.9±0.23
TRC 2013-11	3.3±0.15
Local	4.1±0.12
LSD (p=0.05)	0.4

range 2.9-4.4 (Table 3). The significant highest rating of overall organoleptic characters was seen in rice *cv* PNR 546 (4.4) followed by local cultivar, RCM 9 and Tripura Chikan. Whereas, least rating was given to TRC 2015-7 (2.9) at par with NLR1, 5, 9, Tripura Chikan, Tripura Hakuchuk. The highest organoleptic score of PNR 546 was due to its promising aromatic rice quality, attractive long and its fine grains (Singh et al 2000).

CONCLUSION

Among all 22 varieties under study, significant difference was observed among all the parameters in a WRC region of Mizoram. There is enough scope for improving rice productivity by introduction of high yielding medium-duration rice varieties like Gomati, RCM 10 and NLR 9 suitable for the WRC region of Mizoram India. Out of 22 varieties studied, except PD 13, Tripura Saarat, PB 1718 and PB 1121; all other 17 rice varieties out-yielded by 42.3 to 152.5% when compared with local cultivar. PNR 546 and RCM 9 scored organoleptically equal with local cultivar with 99.8 and 117.4% higher grain yield, respectively than local cultivar. However, more varieties from different regions should be tested to identify short to medium duration, high yielding verities suitable for the region with local taste preference so that rice fallow period can be used for growing *Rabi* crop under residual moisture.

ACKNOWLEDGMENTS

This work was supported by the ICAR RC NEH Region Umiam under the program Regional Complex Research Trial (RCRT).

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Received 03 January, 2022; Accepted 02 April, 2022

Indian Journal of Ecology (2022) 49(2): 399-404
DOI: https://doi.org/10.55362/IJE/2022/3536

Manuscript Number: 3536
NAAS Rating: 5.79

Response of Micronutrients to Seed Quality in *Coriandrum sativum* L.

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Abstract: The present investigation was carried out at CCS Haryana Agricultural University, Hisar, Haryana during 2017-18 and 2018-19 to access the effect of micronutrients on seed quality in coriander. The experiment consisted of soil and foliar application of micronutrients i.e., recommended dose of fertilizers as control, and recommended dose of fertilizers was used in combination with ferrous sulphate (5, 7.5 and 10 Kg/ha), zinc sulphate (3, 4 and 5 Kg/ha), boric acid (2, 3 and 4 Kg/ha), water spray as soli application. The foliar application of ferrous sulphate (0.4, 0.5 and 0.6 %), zinc sulphate (0.4, 0.5 and 0.6 %) and boric acid (0.2, 0.3 and 0.4 were done at 45 and 90 DAS. The soil application of micronutrients with 5 kg zinc sulphate/ha with recommended dose of fertilizers recorded significantly maximum standard germination (92%), seedling length (24.86 cm), seedling dry weight (3.45 mg), vigour index – I & II (2286.56 & 317.37), catalase (0.490 mg protein^{-1} min^{-1}), peroxidase (0.547 mg protein^{-1} min^{-1}), dehydrogenase (0.075 OD g^{-1} ml^{-1}), superoxidase dismutase (0.925 mg protein^{-1} min^{-1}), speed of germination (7.54), seedling establishment percentage (85.75%) and mean emergence time in days (11.37).

Keywords: Coriander, Micronutrients, Enzyme activity, Germination, Seed quality

Coriander (*Coriandrum sativum* L.), belongs to the family Apiaceae and possessing chromosome number 22 with cross pollination mode of reproduction, is an important and remunerative spice crop. It is native to Mediterranean region and is grown throughout the country in *Rabi* season. India is the largest producer of coriander with a production share of more than 70 per cent of the total world production. The total area under coriander crop is 583000 hectares with annual production of 784000 MT (NHB 2018-19). In Haryana, the crop is grown during *Rabi* season occupying an area of 2.41 thousand hectares with the production of 4.4 thousand MT during 2016-17 (Anonymous 2017). Seed is an important component of agricultural production. The quality seed plays important role in the agricultural production as well as in national economy. Among the seed spices, coriander is very susceptible to loss in quality in terms of seed viability and vigour during seed storage. Retention of seed viability during storage has always been of utmost concern to seed merchants and farmers. The role of micronutrients in photosynthesis, N-fixation, respiration and other metabolic processes of the plant is well documented (Naga et al 2013). Micronutrients such as iron, zinc, manganese, copper and boron are the important elements with specific and essential physiological functions in plants. They are required in small quantity for normal growth and development of plants. Zinc is an essential component of a number of enzymes, i.e., dehydrogenase, aldolase, isomerases, proteinase, peptidase and phosphohydrolase (Mousavi 2011). It is directly involved in the synthesis of indole acetic acid (IAA) and proteins. Boron helps in the absorption of water and carbohydrates metabolism (Haque et al 2011), translocation of carbohydrates in plants, DNA synthesis in meristems, cell division and elongation, active salt absorption, fertilizer, water relation, photosynthesis and involved indirectly in metabolism of nitrogen, phosphorus, fat and hormones. Boron also plays an important role in flowering and fruit formation. Keeping in view the aforesaid facts, the present study entitled "Response of micronutrients to seed quality in *Coriandrum sativum* L" was performed.

MATERIAL AND METHODS

The present investigation was carried out at CCS Haryana Agricultural University, Hisar, Haryana during 2017-18 and 2018-19. Hisar is situated between 29°10' North latitude and 75°46' East longitudes and 215.2 m above mean sea level. This tract is characterized by semi-arid climate. Hot and dry winds during summer and dry severe cold in winter are the common features of the region. The field selected for conducting the experiment was uniform in fertility gradient. The soil of the experimental field was sandy loam in texture, non-saline, medium in organic carbon, low in available nitrogen and high in available phosphorus and potassium.

A newly developed variety of coriander "Hisar Bhoomit" (DH-228) was used as a planting material with 20 treatments of micronutrient along with recommended dose of FYM 20 tonne, nitrogen 62.5 kg and phosphorus 50 kg per hectare (Table 1).

The seed was sown in the field with recommended practices and treatments were given in the plots. The foliar application of nutrients was done at 45 and 90 DAS. The crop was harvested separately according to different treatments. The seed obtained from various treatment combinations were utilized for assessing the seed vigour potential on the basis of the following parameters.

Observations: One thousand seeds replicated four times in each treatment were counted, weighed and average seed weight of each treatment was calculated. Hundred seeds of each treatment from each replication were placed between the germination papers at a temperature of 25±1ºC and 90-95 per cent relative humidity for estimation of germination (ISTA, 2011). The first count was taken on 7^{th} day and final count on 21^{st} day. The total root and shoot length of five randomly selected seedlings from each treatment in each replication was measured in cm at the time of termination of germination test and averaged. Seedling dry weight was assessed after the final count in the standard germination test (21 days). The five seedlings of each treatment replicated four times were taken. Seedlings were dried in a hot air oven for 48 h at 80±1°C. The dried seedlings of each replication were weighed and average seedling dry weight of each treatment was calculated. Seedling vigour indices (I & II) were calculated according to the method suggested by Abdul-Baki and Anderson (1973). For accelerated ageing sufficient number of seeds in a single layer from each treatment was taken on wire mesh tray fitted in plastic boxes having 40 ml of distilled water. The boxes were placed in ageing chamber after closing their lids. The seeds were placed at 40±1°C temperature and about 100 per cent relative humidity for 120 h and tested for germination in four replications of 100 seeds for each treatment. Then, the seeds were evaluated in terms of standard germination only. Electrical conductivity ($\mu S\ cm^{-1}\ g^{-1}$) was recorded as per method suggested by ISTA (1999).

The catalase activity was assessed by using the method described by Aebi (1983), which was based on the reduction of potassium dichromate to chromic acetate by hydrogen peroxide. POD activity was determined by the method of Shannon et al (1966) following the oxidation of O-dianisidine in the presence of hydrogen peroxide (H_2O_2). Dehydrogenase activity was measured by method suggested by Kittock and Law (1968) while in case the SOD activity was examined by the method of Giannopolitis and Ries (1977).

Field observations: One hundred seeds in four replications of each treatment combination stored under ambient conditions were sown in a randomized block design during *Rabi* season of 2017-18 and 2018-19 at Department of Seed Science and Technology, CCS Haryana Agricultural University, Hisar. The following observations were recorded in the field.

Speed of germination: The number of seedlings emerged were counted on each day from 1^{st} day to 30^{th} day and the field emergence index (speed of emergence) was calculated as described by Maguire (1962).

Field emergence index = + …… + Mean emergence time (days)

The mean emergence time was calculated for each treatment combination using the formula cited by Ellis and Robert (1980).

Mean Emergence Time = $\sum nt / \sum n$

Where, n = number of seeds newly germinated at time't'

t = days from sowing $\sum n$ = final emergence of seedlings

Seedling establishment (%)

The seedling establishment was determined by counting the total number of seedlings when the emergence was completed or when there was no further addition in the total emergence, i.e., on 30^{th} day.

Statistical analysis: The data obtained from the experiment

Table 1. Detail of different treatment combinations of micronutrients

T_1	: Control		(RDF)	T_{11}	: Water spray		
T_2	: $FeSO_4$	5 kg/ha	(Soil application)	T_{12}	: $FeSO_4$	0.4 %	(Foliar spray)
T_3	: $FeSO_4$	7.5 kg/ha	(Soil application)	T_{13}	: $FeSO_4$	0.5 %	(Foliar spray)
T_4	: $FeSO_4$	10 kg/ha	(Soil application)	T_{14}	: $FeSO_4$	0.6 %	(Foliar spray)
T_5	: $ZnSO_4$	3 kg/ha	(Soil application)	T_{15}	: $ZnSO_4$	0.4 %	(Foliar spray)
T_6	: $ZnSO_4$	4 kg/ha	(Soil application)	T_{16}	: $ZnSO_4$	0.5 %	(Foliar spray)
T_7	: $ZnSO_4$	5 kg/ha	(Soil application)	T_{17}	: $ZnSO_4$	0.6 %	(Foliar spray)
T_8	: H_3BO_3	2 kg/ha	(Soil application)	T_{18}	: H_3BO_3	0.2 %	(Foliar spray)
T_9	: H_3BO_3	3 kg/ha	(Soil application)	T_{19}	: H_3BO_3	0.3 %	(Foliar spray)
T_{10}	: H_3BO_3	4 kg/ha	(Soil application)	T_{20}	: H_3BO_3	0.4 %	(Foliar spray)

was analyzed using the online statistical tool (OPSTAT) developed by Sheoran (2010).

RESULTS AND DISCUSSION

All the treatments showed significant variation for germination percentage (Table 2). Pooled data indicated that maximum germination (92%) was in T7 treatment which was at par with T6, T4, T3, T2 and T5 treatments. Minimum germination (84.63%) was in control. The higher germination percentage also might be due to the bolder seeds that contain greater metabolites for resumption of embryonic growth during germination and better accumulation of food reserves like protein and carbohydrates as reported by Anitha et al (2015) in fenugreek. The results are in accordance with the findings of Lal et al (2015) in fenugreek and Deepika and Anitha (2016) in radish.

A significant variation was observed in seedling length. Higher seedling length (24.86 cm) was with T7 treatment which was at par with T6, T4 and T3 treatments while the lowest seedling length was (21.23cm) observed in control (Table 2). This might be due to release of certain enzymes by metabolites which are responsible for the conversion of macromolecules into micro molecules within the seed and increase in mobilization efficiency led to the increase in seedling length as reported by Santosh (2012) in tomato and Chanchan et al (2013) in garlic. The maximum seedling dry weight (3.45 mg) was in T7 and minimum (2.95 mg) in control. Accumulation of higher quantities of seed constituents like carbohydrates in the seed is due to the participation of micronutrients (Zn, Fe, B) in catalytic activity and breakdown of complex substances into simple form (glucose, amino acids and fatty acids etc.). These in turn reflected on enhancing the germination, elongation of root and shoot in brinjal seedling (Yogannand 2001) and higher seedling length there by increased the seedling dry weight. Similar results were reported earlier in bitter gourd by Arvind Kumar et al (2012).

Higher vigour index-I (2286.56) and vigour index-II (317.37) were in the seeds which was in T7 and was at par with T6 and lower vigour index-I (1796.94) and vigour index-II (249.27) was observed in control. These results are in agreement with the findings of Yogannand (2001) in bell pepper. Coriander seeds lost their germination up to 50% after the accelerated ageing for 120 h at 40±1ºC with 100% relative humidity. The decline in germination during accelerated ageing is related to the degree of deterioration of

Table 2. Effect of micronutrients on test weight, standard germination, seedling length, seedling dry weight of coriander cv. Hisar Bhoomit

Treatments		Test weight (g)	Standard germination (%)	Seedling length (cm)	Seedling dry weight (mg)
T_1	Control (RDF)	8.80	84.63	21.23	2.95
T_2	$FeSO_4$ 5 kg/ha (Soil application)	9.15	90.63	24.29	3.36
T_3	$FeSO_4$ 7.5 kg/ha (Soil application)	9.16	90.88	24.51	3.41
T_4	$FeSO_4$ 10 kg/ha (Soil application)	9.18	90.88	24.67	3.41
T_5	$ZnSO_4$ 3 kg/ha (Soil application)	9.12	90.38	24.19	3.34
T_6	$ZnSO_4$ 4 kg/ha (Soil application)	9.21	91.63	24.77	3.42
T_7	$ZnSO_4$ 5 kg/ha (Soil application)	9.23	92.00	24.86	3.45
T_8	H_3BO_3 2 kg/ha (Soil application)	9.04	89.00	23.69	3.31
T_9	H_3BO_3 3 kg/ha (Soil application)	9.06	89.38	23.97	3.33
T_{10}	H_3BO_3 4 kg/ha (Soil application)	9.09	89.38	24.11	3.33
T_{11}	Water spray	8.81	84.75	21.35	2.98
T_{12}	$FeSO_4$ 0.4 % (Foliar spray)	8.86	86.75	22.57	3.16
T_{13}	$FeSO_4$ 0.5 % (Foliar spray)	8.89	86.88	22.72	3.21
T_{14}	$FeSO_4$ 0.6 % (Foliar spray)	8.92	87.00	22.96	3.22
T_{15}	$ZnSO_4$ 0.4 % (Foliar spray)	8.96	87.25	23.10	3.25
T_{16}	$ZnSO_4$ 0.5 % (Foliar spray)	9.00	87.50	23.25	3.29
T_{17}	$ZnSO_4$ 0.6 % (Foliar spray)	9.02	87.63	23.49	3.29
T_{18}	H_3BO_3 0.2 % (Foliar spray)	8.82	85.25	21.77	3.02
T_{19}	H_3BO_3 0.3 % (Foliar spray)	8.85	85.38	22.32	3.08
T_{20}	H_3BO_3 0.4 % (Foliar spray)	8.85	85.63	22.43	3.13
C.D. (p=0.05)		0.29	1.90	0.46	0.07

the seed. Higher standard germination (53.00%) after accelerated ageing was observed with T7 and was closely related with T6. Similar results were reported earlier by Iqbal et al (2002) in cotton and Rithichai et al (2009) in coriander.

Significant variation in electrical conductivity of seed leachates was observed in response to different micronutrient treatments (Table 3). Lower seed leachates (114.63 µS $cm^{-1}g^{-1}$) were produced by seed produced under T7 whereas maximum (182.05 µS $cm^{-1}g^{-1}$) was observed in control. The soil application of zinc sulphate increased the cell membrane stability and decreased the leakage of solutes from the seeds. Similar results have been reported earlier by Raissi et al (2012) in isabgol.

The present investigation showed differences in enzyme activities among different micronutrient treatments. The activities of all the antioxidant enzymes showed varied differences among all the treatments (Table 4). More activities of catalase (0.490 mg $protein^{-1}$ min^{-1}), peroxidase (0.547 mg $protein^{-1}$ min^{-1}), dehydrogenase (0.075 OD g^{-1} ml^{-1}) and superoxidase dismutase (0.925 mg $protein^{-1}$ min^{-1}) enzymes were observed in treatment T7 whereas less activities of all the above-mentioned enzymes were low in control (0.331 mg $protein^{-1}$ min^{-1}, 0.379 mg $protein^{-1}$ min^{-1}, 0.048 OD g^{-1} ml^{-1} and 0.610 mg $protein^{-1}$ min^{-1} respectively). The increased activities of these enzymes helped in the removal of free radicals like H_2O_2 and O_2 available in normal or abnormal conditions and maintained the ascorbate pool which in turn led to better growth and tolerance in the plant. Similar findings have been reported Abd El- Ghany, (2007) in wheat and Siavoshi et al (2013) in rice.

Results pertaining to speed of germination and seedling establishment (%) revealed significant differences among the different micronutrient treatments (Table 5). Higher speed of germination (7.54), seedling establishment percentage (85.75 %) and significantly lower mean emergence time (11.37 days) was recorded with the treatment T7 which was at par treatments T6, T4 and T3 whereas, minimum was observed in control. Higher speed of germination might be due to bolder seeds that contain greater metabolites for consumption of embryonic growth during germination as reported by Kumar and Uppar (2007) in moth bean. The results are in close conformity with the

Table 3. Effect of micronutrients on vigour index-I & II, germination after accelerated ageing test and electrical conductivity of coriander cv. Hisar Bhoomit

Treatments	Vigour index-I	Vigour index-II	Germination (%) after AA test	Electrical conductivity (µ S cm^{-1} g^{-1})
T_1	1796.94	249.27	34.88	182.05
T_2	2202.03	304.54	48.88	129.46
T_3	2227.81	309.47	49.38	125.89
T_4	2242.66	309.54	50.63	122.61
T_5	2185.49	301.86	47.50	132.71
T_6	2269.90	313.62	51.63	118.34
T_7	2286.56	317.37	53.00	114.63
T_8	2108.60	294.18	44.75	142.57
T_9	2142.68	297.44	46.38	139.37
T_{10}	2155.10	297.61	46.88	135.90
T_{11}	1809.67	252.13	35.50	178.49
T_{12}	1958.42	273.95	39.25	163.04
T_{13}	1974.01	278.51	40.13	159.70
T_{14}	1997.96	280.07	40.50	156.52
T_{15}	2015.42	283.62	41.88	153.07
T_{16}	2034.43	288.20	42.75	149.68
T_{17}	2058.68	288.58	43.63	146.15
T_{18}	1856.45	257.48	36.50	174.98
T_{19}	1905.58	262.57	37.13	171.32
T_{20}	1920.66	268.00	38.63	167.18
C.D. (p=0.05)	63.02	7.66	1.18	2.54

See Table 1 for details

Table 4. Effect of micronutrients on enzymatic activity of coriander cv. Hisar Bhoomit

Treatments	Catalase (mg protein^{-1} min^{-1})	Peroxidase (mg protein^{-1} min^{-1})	Dehydrogenase (OD g^{-1} ml^{-1})	Superoxidase dismustase (mg protein^{-1} min^{-1})
T_1	0.331	0.379	0.048	0.610
T_2	0.464	0.495	0.070	0.795
T_3	0.470	0.510	0.072	0.815
T_4	0.477	0.520	0.073	0.890
T_5	0.454	0.485	0.065	0.780
T_6	0.484	0.525	0.075	0.895
T_7	0.490	0.547	0.075	0.925
T_8	0.427	0.441	0.061	0.745
T_9	0.438	0.455	0.062	0.755
T_{10}	0.444	0.467	0.064	0.765
T_{11}	0.341	0.385	0.048	0.625
T_{12}	0.370	0.395	0.052	0.685
T_{13}	0.379	0.403	0.053	0.670
T_{14}	0.391	0.411	0.054	0.705
T_{15}	0.399	0.419	0.056	0.700
T_{16}	0.407	0.424	0.058	0.715
T_{17}	0.417	0.429	0.058	0.730
T_{18}	0.347	0.389	0.049	0.630
T_{19}	0.357	0.391	0.050	0.655
T_{20}	0.363	0.392	0.051	0.685
C.D. (p=0.05)	0.009	0.008	0.001	0.017

See Table 1 for details

Table 5. Effect of micronutrients on speed of germination, seedling establishment (%) and mean emergence time in coriander

Treatments	Speed of germination	Seedling establishment (%)	Mean emergence time days
T_1	5.89	77.38	13.29
T_2	7.25	84.38	11.99
T_3	7.33	84.50	11.88
T_4	7.40	85.25	11.72
T_5	7.19	84.00	11.99
T_6	7.46	85.38	11.48
T_7	7.54	85.75	11.37
T_8	6.99	82.75	12.23
T_9	7.05	83.38	12.13
T_{10}	7.10	83.75	12.13
T_{11}	6.01	77.88	13.20
T_{12}	6.45	80.75	12.73
T_{13}	6.55	81.50	12.68
T_{14}	6.63	81.75	12.62
T_{15}	6.70	82.13	12.61
T_{16}	6.79	82.25	12.42
T_{17}	6.94	82.50	12.34
T_{18}	6.07	78.13	13.15
T_{19}	6.24	79.25	13.01
T_{20}	6.34	80.00	12.97
C.D. (p=0.05)	0.14	2.09	0.26

See Table 1 for detail

findings of Anitha et al (2015) in fenugreek and Maruthi and Paramesh et al (2016) in soybean.

CONCLUSION

Seed quality attributes of coriander seeds were significantly influenced by soil and foliar application of micronutrients. The treatment with soil application of 5 kg zinc sulphate/ha with recommended dose of fertilizers recorded maximum which were closely followed by soil application of 4 kg zinc sulphate/ha and soil application of 10 kg iron sulphate/ha. This study also revealed that soil application of micronutrients proved better as compared to foliar spray.

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Received 15 December, 2021; Accepted 02 April, 2022

Indian Journal of Ecology (2022) 49(2): 405-409
DOI: https://doi.org/10.55362/IJE/2022/3537

Manuscript Number: 3537
NAAS Rating: 5.79

Development of Tractor Mounted FYM Spreader

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Abstract: The application of FYM in the field is carried out traditionally lead to uneven distribution, increases cost and labour requirements. The developed machine consists of the manure tub, FYM conveyor unit, manure discharging gate, shredding and spreading unit. The conveyor unit passes FYM from manure tub in to the shredder unit with the help of belt conveyor through the manure discharge gate and manure discharge gate provided to change levels of opening from the bottom of conveyor belt. The shredding unit is mounted on the mainframe. Flexible chains are used as beating elements. The shredder collects FYM material from top surface further it directs to the openings designed in such way that the material is evenly spread on the field. The developed machine was evaluated for field performance with the optimized variables derived from the experimental trials is the conveyor speed, bulk density and clod size distribution. The optimized parameters were conveyor speed is 48 RPM, beating roller speed 255 rpm, bulk density and clod size distribution were observed as 0.503 g cm^{-3} and 57.66 % at 100 mm discharge gate opening with 4 chain links respectively. The discharge rate was 4.9 t/h at 100 mm manure discharge gate opening belt speed at 48 rpm.

Keywords: FYM, Belt conveyor, Manure control gate, FYM Shredder, Distribution unit, Bulk density, Sieve analysis

India precision farming includes specific nutrient management. The organic farming in country approximately covers 78 million hectares. Organic manure such as green manure, farm yard manure etc. In India production and accessibility of FYM is about 2850.503 lakh tonnes which is more as compared to other manure production (SOFI 2021). The FYM consists almost all the essential nutrients required for soil, help them maintain C: N proportion in the soil, increases the fertility and soil's physical and biological characteristics. Nutrient contents of FYM are 0.5% of nitrogen, 0.2% of phosphorus, 0.5% of potash and moderate micronutrients. The utilization of manure has been able to be mechanized in other nations like other field activities but in India, the innate strategies are still taken after, i.e., stacked trolley or bullock truck is moved inside the field and stopped at regular interval where a man other than the driver empties small amount of manure and drops it in the form of a pile. Present method of leaving manure in small piles scattered with in the area prior to the field application for a very long period lead to loss of nutrients. These losses can be reduced by spreading the manure. The problem faced in the application of manure with the domestic method is the non-uniform application rate and non-disintegration of large manure clumps. The objective of the study to develop tractor mounted farm yard manure shredder cum spreader and performance evaluation of the developed unit.

MATERIAL AND METHODS

Conceptual design of proposed FYM spreader: See Fig 1

Design and construction of components of FYM spreader: FYM spreader attachment to the existing tractor trailer of RARS, Tirupati consists of

a) Two-wheel tractor-trailer b) Manure tub c) Conveyor unit d) Discharge control gate e) Shredder unit f) Power transmission unit g) Housing The details and specifications of the components were as follows.

Two- wheeled trailer and manure tub: The trailer was provided with two pneumatic tyres of size 10 × 20 16 PR to support the loaded trailer the hitch of the trailer was provided with central members. At bottom of the trailer belt conveyor system is fixed with both the two end rollers, there rollers are powered through chain drive The FYM shredder unit and spreader unit assembly of the mounted at the front portion of the trailer. The entire arrangement was fitted with bolts and nuts to the trailer frame which can be dismantled. This is done to enable to use as trailer, when not in use as FYM spreader.

FYM Conveyor unit

Conveying of FYM from manure tub in to the shredder unit by the help of belt conveyor through the discharge gate. Compared to other types of horizontal conveying system, the initial cost of belt conveying system is competitive or low, lighter in weight, and consumes less power and operate without noise, give a continuous discharge. Hence reasons belt conveyors were used to carry the FYM from tub to shredder unit. The belt was made with canvas unit cloth and driven by rollers (both front and rear). The belt conveyor unit consists of a belt, drive mechanism, and end rollers, spacers and control system.

Manure discharge control gate: Discharge control gate is mounted on the front side of the manure tub. Flow control gates are designed to provide controlled discharge of bulk amount of FYM from manure tub. Discharge control gate was used for regulating and metering the flow on conveyor belt and gate was designed in front side of the manure tub and useful in metering the flow of material on belt. It consists of two sections i) Gate section and ii) Channel section Gate section is fixed to the channel with latches provided on gate and these gates slide over the lower section the channel. Restriction of gate movement was made not to lower beyond 50 mm so as to protect the conveyor arrangement. The gate opening height was calibrated for accurate application of manure.

Shredder unit: The shredder unit mainly consists of a main frame, baffle plate, beating rollers and spreading mechanism. Main frame the basic structure on which whole shredder unit was mounted and was fabricated in rectangular shape with 63 mm iron L-angles of 1800 mm × 470 mm. Four vertical L angles risers with 63 mm and 300 mm height arranged at each corner of the main frame for the purpose of creating resting point to the beating roller shaft. The baffle plate was designed in between conveyer belt and beating roller to direct the feed (FYM) from the conveyor belt to beating unit will not only delays dropping time for improving shredding and also gives double effect on pulverization. The beating roller consisted of 22 mild steel flanges arranged in four rows with equal spacing around roller and apart from each row. Provision was made to fix 22 numbers of beating elements flexible chains with each link length 25 mm flanges by using fasteners. The speed optimization is necessary for the better performance of shredder unit. Energy transmission through shredder element makes FYM lumps in to small pieces and further shredding was enhanced by hitting to shrouding sheets of the unit.

Spreading unit: The shredder FYM material collected at bottom was further directed to the bottom and openings are designed in such way that the material is evenly spread on the field.

Housing: All the components of FYM spreader system except conveyor assembly were mounted on a rectangular housing and made to rest on the trailer connecting shank including gear box and related power transmission assembly.

Power transmission to beating roller and conveyor system: Power transmission was designed to transmit the power from prime mover i.e. PTO shaft and to the gear box of the developed mechanism. The chain drive system was used for this purpose. In this power train first stage of transmission from prime mover i.e. PTO shaft to gear box to shredder unit (initially the belt drive was designed and off late changed to chain drive). In second stage power transmission, power was further connected from shredding unit shaft to conveyor roller shaft. The speed was reduced from half shaft of gear box to 255 rpm on the shredder unit. The number of teeth on driving sprocket wheel having 18 cm diameter (36 teethes). The drive from the shredder unit transmitted to belt conveyor further decreases from 255 shredder to 48rpm available at the belt conveyor unit shaft. All the speeds of the rotating components were ascertained by tachometer.

Optimization of operational parameters: It is desirable to study the effect of operations designed on FYM conveying, shredding and spreading. Certain tests were conducted to obtain optimum operational parameters conveyor speed, peripheral speed shredder, shredding element length per flange of beating roller and discharge opening positions on the clod size distribution and application rate.

The bulk density and sieve analysis were considered as an index of FYM pulverization and it measured after each experiment. The size of sieves was range 50, 40, 30 20 mm and less than 10 mm. The samples were placed on the top screen and shaken for 90 seconds. FYM retained on each screen was weighed on a laboratory scale. The weight of the FYM retained on each sieve was observed and tabulated. The same procedure was repeated for all the treatments by operating at desired levels. In order to ascertain the partial size of FYM when it was spread with developed machine.

Development of prototype FYM pulverizer cum spreader: A prototype tractor mounted FYM shredder cum spreader was developed. The optimized values of machine and operational parameters obtained from the tested levels of variables were incorporated for required out come and fabricated the FYM spreader.

RESULTS AND DISCUSSION

Effect of conveyor speed on the discharge rate: The experimental results among the treatment combinations of manure discharge gate opening at 100 mm and at 48 RPM speed of conveyor speed yielded discharge rate 4.9 t h-were are used in confirmation with the requirement of the yield expressed by Singh et al (2013 and Kothari Kunal et al (2018).

Effect of beating rollers and operational parameters on clod size distribution beating roller speed at 180 RPM: The shredder 180 RPM and number of chain links increased the percentage of minimum clod size distribution ranging from less than 10 mm (Fig. 11). The highest percentage of 16

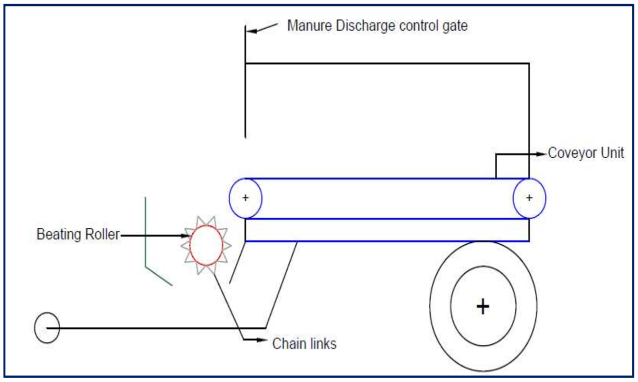

Fig. 1. Conceptual diagram of FYM spreader

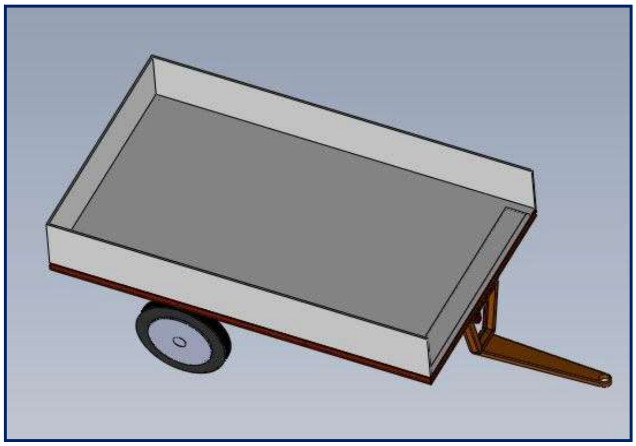

Fig. 2. Two- wheeled trailer and manure tub CAD view

Fig. 3. FYM conveyor unit

Fig. 4. FYM flow control gate

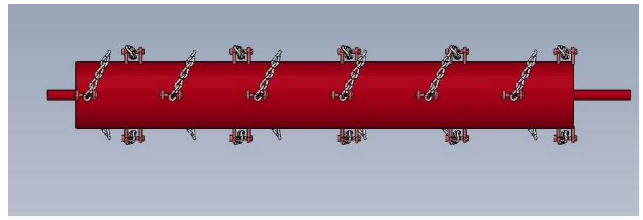

Fig. 5. Beating roller and beating elements CAD view

Fig. 6. Housing

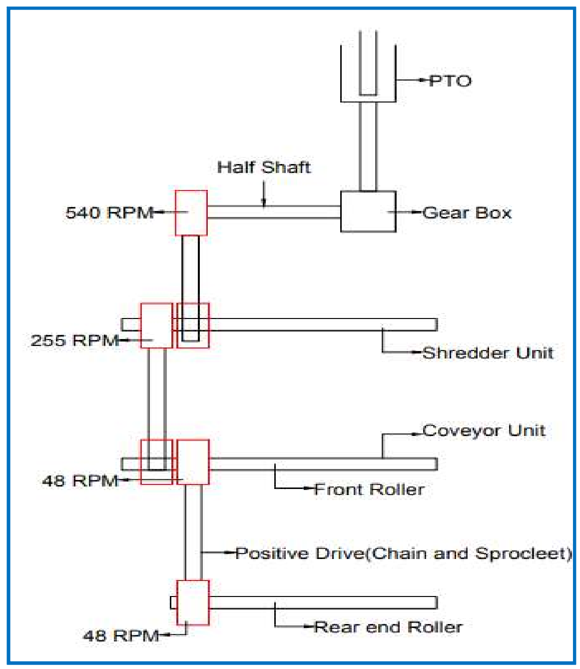

Fig. 7. Power transmission system

Fig. 8. Proto type tractor mounted FYM spreader fabricated under study

% of minimum clod size distribution in the range of less than 10 mm was obtained at 100 mm discharge gate opening and 4 link elements. Smaller manure particles have more surface area resulting in easily availability of nutrients to the microorganisms (Khaffaf 2008, Sahu 2020). This is mainly due to throwing action of the chain links. The bulk density decreased with number of chain links. The lowest bulk density of 0.512 g cm^{-3} was obtained at 75 mm discharge gate opening and 6 no of chain links.

Effect of beating rollers speed of 255 RPM on clod size distribution: The increase shredder 255 RPM and number of chain links, increased the percentage of minimum clod size distribution ranging from less than 10 mm (Fig. 12). The highest percentage of 57.66 % of minimum clod size distribution in the range of less than 10 mm was obtained 4 link elements. Smaller manure particles have more surface area resulting in easily availability of nutrients to the microorganisms (Khaffaf 2008, Sahu 2020). This is mainly due to throwing action of the chain links. The bulk density decreased number of chain links and increased shredder speed. The lowest bulk density of 0.503 g cm^{-3} was obtained at 100 mm discharge gate opening and 4 no of chain links.

Optimized beating rollers speed and beating element length percentage of 0 to 10 mm clod size distribution:

Table 1. Different variables considered for optimization of shredding cum spreader

Treatment	No levels	Particulars
Conveyor speed (RPM)	2	48 and 66
Discharge opening	3	75, 100 and 150 mm clearance
Shredder speed (RPM)	2	180 and 255
Shredder chain length	3	2, 4 and 6 chain links
No of replications		3
Total no of experiments		2×3×2×3×3=108

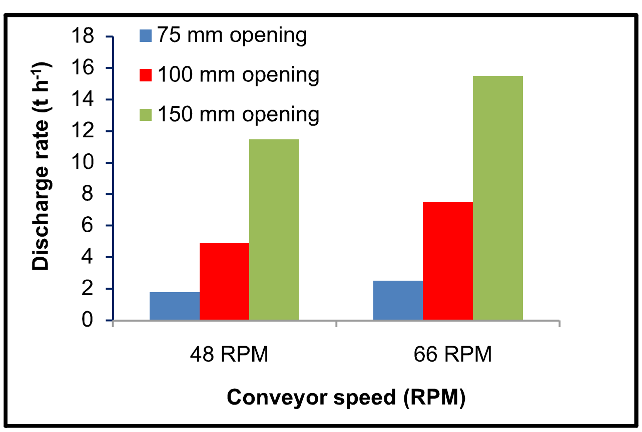

Fig. 9. Averaged is charge rate at different conveyor speed

The shredder speeds 180 RPM and 255 RPM the maximum percentage of small particles found in 255 RPM. This may be due to the high impact force developed due to peripheral velocity (2 m/sec). The data that among the lengths of beating elements 4 links lengths created more percentage of smaller pieces, whereas the 2 links length than 6 link lengths

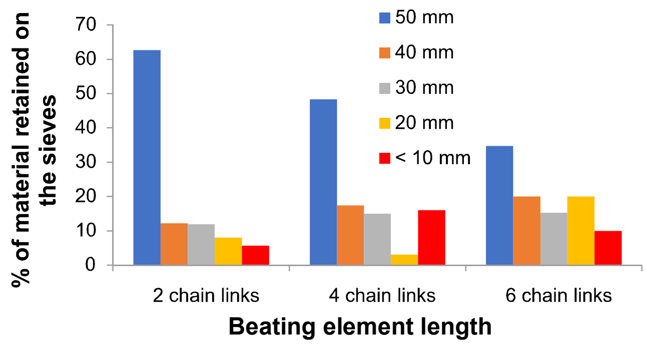

Fig. 10. Clod size distribution at beating roller speed 180 RPM

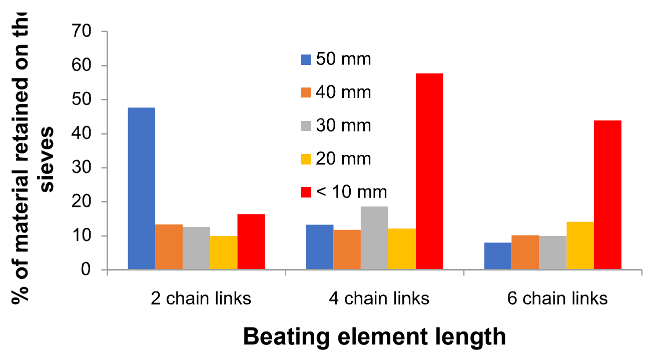

Fig. 11. Clod size distribution at beating roller speed 255 RPM

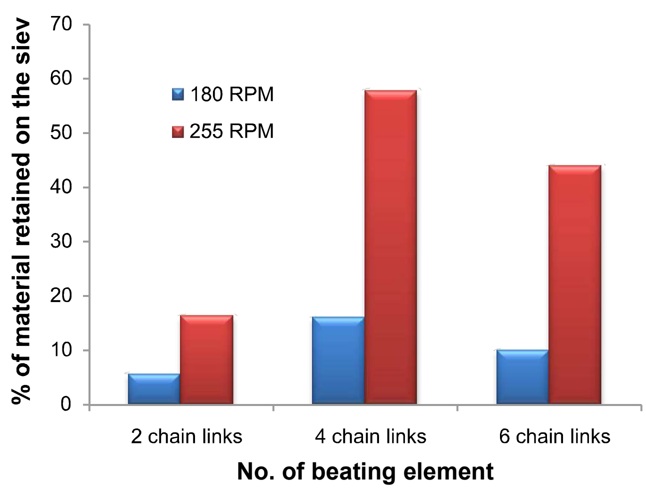

Fig. 12. Best combination for minimum percentage of clod size distribution

larger lumps are retained.

Assessment of width wise uniformity distribution: To determine the width wise uniformity, five small boxes are arranged (open area of 0.019 m^2) along the width line 1800 mm with equal spacing. FYM spreader was run at the conveyor speed of 48 RPM, beating roller speed of 255 RPM with 100 mm discharge gate opening and 4 no chain links of beating elements the shredded and spreader FYM was collected in the boxes. The weight of collected FYM was recorded and experiment was repeated three times. The average weight obtained from each box at 137 grams and 90 grams at bottom of the trailer shank.

CONCLUSION

The developed FYM shredder cum spreading unit was evaluated for optimizing operational parameters and results indicated that Bulk density decreased with increase in beating roller speed from 180 rpm to 255 rpm at FYM conveyor speed 48 RPM and the effect of beating element length also influenced the bulk density and highest percentage 57.66 of clod size distribution ranging from more than 10mm to less than 40mm sieve size of the FYM shredded. The flexibility is provided based on the soil and crop requirement the manure discharge gate will be altered from bottom of conveyor belt.

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Received 21 November, 2021; Accepted 21 January, 2022

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Indian Journal of Ecology (2022) 49(2): 410-416
DOI: https://doi.org/10.55362/IJE/2022/3538

Manuscript Number: 3538
NAAS Rating: 5.79

Seed Yield and Economics of Prickly Sesban under Spatio-Temporal Variation in Sowing in Coastal Odisha

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***Abstract*:** Field experiment was conducted at Bhubaneswar, Odisha during *kharif* 2019 to study the response of prickly sesban to spatio-temporal variation in planting. The treatments of the study comprised five dates of planting. First sowing was done with onset of monsoon on June 13 and rest four at weekly intervals. *on* 20 and 27 June, 4 and 11 July with three row spacings *viz*. 80, 120 and 160 cm. Planting on 13 June at row spacing of 80 cm recorded the maximum seed yield of 1.271 t/ha while planting on 13 June at row spacing of 120 cm and planting on 20 June at row spacing of 80 and 120 cm recorded statistically similar seed yields. All other combinations of date of planting and row spacing were inferior to the combination of 13 June planting with row spacing of 80 cm. The earliest date of planting at the closest row spacing recorded the maximum net return of Rs 96.17 x10^3/ha and return per rupee investment of Rs 2.27.

Keywords: *Dhaincha*, Phenology, Productivity, Profitability, Seed yield

Green manuring crops can meet a substantial portion of the nitrogen requirement of rice and provide organic matter to the soil to maintain soil fertility (Mondal and Goswami 2019).Among the green manuring crops, prickly sesban or *dhaincha* [*Sesbania cannabina* (Synonym: *S. aculeata*)] is the most important *in-situ* green manuring crop in rice ecosystem as it best fits into the pre-rice fallow period of 45-60 days (Sakthirama and Sivakumar 2017). Its vigorous root system utilizes a significant amount of sub-soil phosphorus and transfers it to the surface soil when incorporated. Despite this, farmers are averse to continue the practice of *dhaincha* green manuring owing to various constraints. Of the various factors influencing seed production of *dhaincha*, optimum time of sowing is the most important aspect for obtaining higher yields, as it provides optimum growing conditions for the crop. Early sown *dhaincha* during *kharif* is subjected to viviparous germination if pod ripening coincides with rainfall events. In contrary, seed filling is affected in late planted crops due to moisture stress. Sometimes seed drying becomes a problem due to humid weather leading to loss in seed viability. In this context, there is a need for deciding optimum sowing window for *dhaincha* as seed crop. Row spacing is one of the important factors in achieving optimum level of plant density. Optimum plant population utilizes available moisture and nutrients from the soil more effectively and leads to better dry matter production and accumulation which is manifested as good seed yield. Higher plant population leads to overcrowding and mutual shading of plants. Lower plant density results in sub optimal utilization of the available resources, particularly, sunlight. In both cases, seed yield per unit area decreases. Kumar et al (2006) reported the maximum seed yield of *dhaincha* with row spacing of 60 cm on sandy loam soils at Hissar, Haryana. Sangeetha et al (2011) have reported higher seed yield with plant density of 74,000 plants/ha in sandy clay loam soils at Rajendranagar. Better yield attributes and higher seed yield were reported by Rajesh et al (2017) at spacing of 120 cm x 30 cm compared to 120 cm x 30 cm and 90 cm x 30 cm at Killikulam, Tamil Nadu. Information on agro-techniques like optimum time of sowing and row spacing for seed *dhaincha* under sub humid condition are meager. It needs immediate attention of the researchers to self-sustain and strengthen the *dhaincha* seed production and supply chain in Odisha and adjoining states. With this backdrop, a field experiment was conducted during *kharif* season of 2019 to study the response of seed-*dhaincha to* spatio-temporal variation in sowing.

MATERIAL AND METHODS

The field experiment was conducted in the Agronomy Main Research Farm, Department of Agronomy, Odisha University of Agriculture and Technology, Bhubaneswar (20^0 15'N, 85^0 52'E and 25.9 m above the MSL), Odisha, India. The soil (0-15 cm) of the experimental site was characterized by sandy loam texture, acidic (pH: 5.5), normal electrical conductivity (0.032 dS/m), low organic carbon (0.427%), low available N (193.75 kg/ha), high available P (28.84 kg/ha) and medium available K (124.59 kg/ha).

The treatments comprised five dates of planting of *dhaincha* at weekly interval *viz.* D_1-onset of monsoon; D_2-one week after; D_3-two weeks after; D_4-three weeks after and D_5-four weeks after were allocated to main-plots; and three row spacings *viz.* S_1-80 cm, S_2-120 cm and S_3-160 cm were allocated to the sub-plots. These were in split-plot design with three replications having individual unit plot size of 4.8 m x 3 m. The crop was fertilized with 20-40-20 kg/ha of N-P_2O_5-K_2O. Sowing was done first on 13 June 2019 after onset of monsoon and the subsequent sowings were done at weekly intervals i.e. on 20 June, 27 June, 4 July and 11 July 2019 at row to row spacing as per the treatment specifications. Thinning of excess seedlings was carried out at 15 days after planting (DAP) to maintain intra-row spacing of 30 cm. Fully matured pods were harvested from net plot area in 2-3 phases to avoid shattering losses and the pods were threshed after sun drying.

RESULTS AND DISCUSSION

Phenology: On an average, *dhaincha* took 53.3 and 110.8 days for attainment of phenophases, 50% flowering and 1st picking of matured pods (Table 1). Between two factors under study, only date of planting influenced days to attainment of phenophases significantly. Among different stages, 13 June planting took the maximum number of days for attainment of these two developmental stages, being at par with 20 June planting. Further delay in planting reduced the number of days for attainment of these two phenophases. Better vegetative growth associated with earlier planting delayed the process of switch over from the vegetative to reproductive phase and hence, more number of days was required for attainment of the phenophases. The findings are in agreement with the findings of Triveni and Martinluther (2011) in *dhaincha*, and Sandya and Singh (2018) and Kumar et al (2019) in *kharif* pigeon pea.

Growth parameters: Both date of planting and row spacing exerted significant influence on plant height (Table 2). Plant height decreased with delay in planting while early planting facilitated better crop establishment at seedling stage that facilitated better tolerance to water logging at later stages. However, the emergence and growth of late sown *dhaincha* were affected. Taller plants with earlier sowing were also reported by Kumar et al (2006) in *dhaincha.* Among the row spacings, the closest spacing (80 cm) recorded the maximum plant height due to the keenest competition among plants for light. Competition for light became apparent, when canopy of adjacent plant came closer. Furthermore, competition for light is severe in *kharif* season. Taller plants at closer spacings were reported by Parlawar et al (2001) and Yaragoppa et al (2003) in *dhaincha* and Lamani et al (2004) in sun hemp. Both factors exerted significant influence on branch number (Table 2). Branches/plant decreased with

Table 1. Effect of date of planting and row spacing on days to attainment of phenophases (2019)

Particulars	Row spacing (cm)			Mean
	80	120	160	
Date of planting				
Days to 50% flowering				
D_1: 13 June	55.0	56.0	56.7	55.9
D_2: 20 June	55.7	55.0	55.0	55.2
D_3: 27 June	53.0	54.0	53.0	53.3
D_4: 04 July	51.7	51.0	52.0	51.6
D_5: 11 July	50.7	51.0	49.3	50.3
Mean	53.2	53.4	53.2	53.3
CD (p=0.05)	D = 1.6, S = NS, D x S = NS, S x D = NS			
Days to 1st picking of matured pods				
D_1: 13 June	115.3	115.0	114.7	115.0
D_2: 20 June	113.0	114.7	113.7	113.8
D_3: 27 June	111.0	112.0	112.0	111.7
D_4: 04 July	106.3	109.0	106.7	107.3
D_5: 11 July	106.7	104.0	107.3	106.0
Mean	110.5	110.9	110.9	110.8
CD (p=0.05)	D = 1.6, S = NS, D x S = NS, S x D = NS			

D = Date of planting, S = Row spacing, D x S= Date at same or different row spacing, S x D = Row spacing at date delay in planting. More number of branches/plant was reported with earlier planting of *dhaincha* (Kumar et al 2006). The widest row spacing recorded the maximum number of branches/plant and the values decreased with decrease in row spacing. This corroborated the findings of Parlawar et al (2001) and Sangeetha et al (2011) in *dhaincha.* Interaction effects of both factors on branches/plant were found significant. Early sowing and wider row spacing acted synergistically to increase branches/plant. Both factors exerted significant influence on horizontal spread (Table 2). More horizontal spread was recorded with earlier planting and wider row spacing. The mean horizontal spread was 119.5 cm. The row spacings of 80,120 and 160 cm recorded the horizontal spread of 115, 120.2 and 123.3 cm indicating overcrowding at 80 cm row spacing, optimum canopy growth at 120 cm row spacing and underutilization of row spacing at 160 cm row spacing. The mean dry matter production was 7.415 t/ha. These factors influenced dry matter production significantly. Higher dry matter production was associated with earlier planting and close spacing. Early planting provided congenial weather conditions for crop emergence, establishment and growth. Although, the widest row spacing

Table 2. Effect of date of planting and row spacing on growth parameters of seed *dhaincha* at harvest (2019)

Date of planting	Row spacing (cm)			Mean
	80	120	160	
Plant height (cm)				
D_1: 13 June	266.3	259.3	233.1	252.9
D_2: 20 June	261.6	246.1	241.6	249.8
D_3: 27 June	257.9	246.7	245.8	250.1
D_4: 04 July	256.0	248.1	239.4	247.8
D_5: 11 July	255.5	245.8	236.3	245.9
Mean	259.5	249.2	239.2	249.3
CD (p=0.05)	D = NS, S = 5.7, D x S = NS, S x D = NS			
Branches/plant				
D_1: 13 June	20.0	20.6	23.1	21.2
D_2: 20 June	19.8	20.7	21.8	20.7
D_3: 27 June	13.5	15.7	17.0	15.4
D_4: 04 July	12.7	16.2	16.8	15.2
D_5: 11 July	13.5	14.9	16.8	15.1
Mean	15.9	17.6	19.1	17.5
CD (p=0.05)	D = 1.3, S = 0.9, D x S = 6.1, S x D = 1.9			
Horizontal spread (cm)				
D_1: 13 June	132.8	135.8	137.5	135.3
D_2: 20 June	121.1	128.6	126.0	125.2
D_3: 27 June	108.4	108.6	129.5	115.5
D_4: 04 July	106.7	117.1	115.4	113.0
D_5: 11 July	105.9	110.8	108.3	108.3
Mean	115.0	120.2	123.3	119.5
CD (p=0.05)	D = 18.4, S = 5.7, D x S = NS, S x D = NS			
Dry matter production (t/ha)				
D_1: 13 June	10.014	9.514	8.784	9.437
D_2: 20 June	9.872	9.194	8.585	9.217
D_3: 27 June	8.343	7.084	7.895	7.774
D_4: 04 July	7.225	5.665	3.243	5.378
D_5: 11 July	5.500	5.339	4.967	5.269
Mean	8.191	7.359	6.695	7.415
CD (p=0.05)	D = 0.905, S = 0.605, D x S = 4.277, S x D = 1.352			

recorded the maximum branches/plant and horizontal spread, the closest row spacing recorded the maximum dry matter production due to the maximum plant density. Sangeetha et al (2011) have also reported higher dry matter production in *dhaincha* with closer spacing.

Yield attributes: Planting on 13 June recorded the maximum length of pod. Pod length decreased due to delay in planting. However, row spacing did not exert significant influence on pod length (Table 3). Both factors influenced pods/plant significantly. Planting on 13 June resulted in the maximum of 64.5 pods/plant (Table 3). The second date of planting recorded statistically similar pod count while further delay in planting decreased pods/plant significantly. More branches/plant, better vertical growth and higher biomass production under early planting resulted in production of more pods/plant. Higher pods/plant with early planting was reported earlier by Ulemale et al (2002) in sunnhemp, Yadav (2003) in cow pea and Kumar et al (2006) in *dhaincha.*

Table 3. Effect of date of planting and row spacing on yield attributes of seed *dhaincha*

Date of planting	Row spacing (cm)			Mean
	80	120	160	
Date of planting				
Pod length (cm)				
D_1: 13 June	18.6	18.7	18.8	18.7
D_2: 20 June	19.0	18.5	18.4	18.6
D_3: 27 June	17.7	16.5	17.7	17.3
D_4: 04 July	16.5	16.2	16.5	16.4
D_5: 11 July	17.1	15.2	16.6	16.3
Mean	17.8	17.0	17.6	17.5
CD (p=0.05)	D = 1.2, S = NS, D x S= NS, S x D = NS			
Pods/plant				
D_1: 13 June	63.2	63.5	66.7	64.5
D_2: 20 June	62.3	64.5	64.2	63.7
D_3: 27 June	60.1	58.3	64.7	61.0
D_4: 04 July	51.0	54.2	53.6	52.9
D_5: 11 July	46.4	51.6	53.5	50.5
Mean	56.6	58.4	60.6	58.5
CD (p=0.05)	D = 3.4, S = 1.3, D x S = 12.5, S x D = 3.0			
Seeds/pod				
D_1: 13 June	33.1	30.8	32.8	32.3
D_2: 20 June	31.1	29.3	33.3	31.2
D_3: 27 June	28.1	29.4	31.5	29.7
D_4: 04 July	27.4	29.6	30.7	29.2
D_5: 11 July	28.1	28.4	31.0	29.2
Mean	29.6	29.5	31.9	30.3
CD (p=0.05)	D = 1.2, S = 1.7, D x S = NS, S x D = NS			
1,000 seed weight (g)				
D_1: 13 June	17.54	17.78	17.72	17.68
D_2: 20 June	17.23	17.40	17.83	17.49
D_3: 27 June	17.50	17.61	16.81	17.31
D_4: 04 July	15.17	15.03	15.81	15.34
D_5: 11 July	14.02	14.10	15.18	14.44
Mean	16.29	16.38	16.67	16.45
CD (p=0.05)	D = 0.28, S = NS, D x S = NS, S x D = NS			

Among three row spacings, the widest row spacing recorded the maximum pods/plant and the values decreased with decrease in row spacing. More intense competition at closer spacing among plants for nutrient, light, moisture and space decreased the performance of individual plants. Increase in pods/plant with decrease in plant population or increase in spacing was also reported earlier by Yaragoppa et al (2003) and Sangeetha et al (2011) in *dhaincha and* Lamani et al (2004) and Shastri et al (2007) in sunnhemp. *Dhaincha* planted at the earliest with the widest row spacing recorded the maximum pods/plant due to synergistic effect between the two factors under study. The date of planting and row spacing significantly influence seeds/plant (Table 3). *Dhaincha* planted at the earliest recorded the maximum seeds/pod and the values decreased with delay in planting. Delayed planting decreased seeds/pod due to terminal moisture stress. Being an indeterminate plant, the pod and the seed setting spread over a longer period, even after

Table 4. Effect of date of planting and row spacing on yield and production economics of seed *dhaincha* (2019)

Date of planting	Row spacing (cm)			Mean
	80	120	160	
Date of planting				
Seed yield of *dhaincha* (t/ha)				
D_1: 13 June	1.271	1.030	0.788	1.030
D_2: 20 June	1.176	1.079	0.703	0.986
D_3: 27 June	0.913	0.825	0.675	0.804
D_4: 04 July	0.726	0.617	0.505	0.616
D_5: 11 July	0.712	0.599	0.490	0.601
Mean	0.959	0.830	0.632	0.807
CD p(=0.05)	D = 0.054, S = 0.037, D x S = 0.258, S x D = 0.082			
Stover yield of *dhaincha* (t/ha)				
D_1: 13 June	8.743	8.484	7.996	8.408
D_2: 20 June	8.696	8.115	7.882	8.231
D_3: 27 June	7.431	6.259	7.220	6.970
D_4: 04 July	6.499	5.047	4.738	5.428
D_5: 11 July	4.788	4.739	4.477	4.668
Mean	7.231	6.529	6.462	6.741
CD (p=0.05)	D = 0.909, S = 0.613, D x S = NS, S x D = NS			
Net return ($x10^3$ Rs/ha)				
D_1: 13 June	44.31	32.73	20.62	32.55
D_2: 20 June	37.43	36.38	15.23	29.68
D_3: 27 June	24.28	22.62	16.48	21.13
D_4: 04 July	15.86	12.79	8.80	12.48
D_5: 11 July	14.81	13.09	8.10	12.00
Mean	27.34	23.52	13.85	21.57
CD (p=0.05)	D = 3.67, S = 2.55, D x S =17.78, S x D = 5.71			
Return per rupee investment (Rs)				
D_1: 13 June	2.24	2.02	1.71	1.99
D_2: 20 June	2.02	2.16	1.53	1.90
D_3: 27 June	1.73	1.77	1.64	1.71
D_4: 04 July	1.53	1.49	1.38	1.47
D_5: 11 July	1.50	1.53	1.36	1.46
Mean	1.81	1.79	1.52	1.71
CD (p=0.05)	D = 0.13, S = 0.10, D x S = 0.67, S x D = 0.22			

Price of *dhaincha* seed Rs 62,940/t

withdrawal of monsoon. The widest row spacing recorded the maximum seeds/pod. Increase in seeds/pod with increase in spacing was reported by Parlawar et al (2001) and Kumar et al (2006) in *dhaincha and* Ulemale et al (2002) in sunnhemp. The date of planting influenced 1,000 seed weight significantly (Table 3). The earliest date of planting recorded the heaviest seeds and delay in planting decreased the test weight significantly. The early planting ensured supply of sufficient soil moisture during seed filling due to presence of monsoon-rain. This was in contrary to the findings of Ulemale et al (2002) who did not find any difference in 1,000 seed weight of sunnhemp among different sowing dates (15 June, 30 June and 15 July). However, the findings are in agreement with Yadav (2003) on cowpea under early sowing. The widest row spacing of 160 cm recorded the maximum test weight of seeds and the values decreased with closer row spacing but without significant differences. Similar findings were also reported earlier by Kumar et al (2006) and Chaudhary et al (2013) in *dhaincha.*

Yield: Planting time and row spacing influenced seed yield of *dhaincha* significantly (Table 4). Planting on 13 June gave the maximum seed yield of 1.031 t/ha and 20 June planting gave the statistically similar seed yield. Planting on 27 June, 3 July and 10 July decreased seed yield by 29, 40 and 42%, respectively compared to 13 June planting. The closest row spacing (80 cm) produced the maximum seed yield (0.96 t/ha), while 120 and 160 cm spacings recorded 18 and 34% less seed yields, respectively. Planting on 13 June at row spacing of 80 cm recorded the maximum seed yield of 1.271 t/ha while planting on 13 June at row spacing of 120 cm and planting on 20 June at row spacing of 80 and 120 cm recorded statistically similar seed yields. All other combinations of date of planting and row spacing recorded significantly lesser seed yield. In all the five dates of planting, seed yield decreased with increase in row spacing. Ulemale et al (2002) reported higher seed yield of sunnhemp with early sowing (15 June) at Akola, Maharashtra. The maximum seed yield at moderate spacing were also reported by Despande et al(2000), Lamani (2004) and Shastri et al(2007) in sunnhemp, and Parlawar et al(2001) and Sangeetha et al(2011) *in dhaincha*. These factors influenced stover yield of *dhaincha* significantly (Table 4). The earliest planting (13 June) recorded the maximum stover yield of 8.408 t/ha, while planting on 20 June recorded statistically similar stover yield with reduction in yield at subsequent planting dates. The closest row spacing recorded the maximum stover yield of 7.23 t/ha, but further increase in spacing decreased stover yield significantly. However, the interaction effects of both factors were non-significant for stover yield.

Economics: Planting *dhaincha* on 13 June 2019 resulted in maximum net return of Rs 32.55 × 10^3/ha while planting a week later generated statistically similar net return (Table 4). However, further delay in planting reduced net return significantly. The closest row spacing recorded the maximum mean net return of Rs 27.34x10^3/ha, whereas the other two row spacings recorded significantly lower values. The maximum mean net return of Rs 44.31 × 10^3/ha was obtained from *dhaincha* sown on 13 June at row spacing of 80 cm. Planting on 13 June at row spacing of 120 cm, and on 20 June at row spacing of 80 and 120 cm recorded statistically similar net return. The date of planting and row spacing influenced return/rupee investment significantly (Table 4). Planting on 13 June recorded the maximum mean return/rupee investment of Rs 1.99 while 20 June planting recorded statistically similar trend but delay in planting reduced profit planting *dhaincha* at the closest row spacing of 80 cm recorded further the maximum mean return/rupee investment of Rs 1.81 and 120 cm spacing was at par. Planting *dhaincha* on 13 June at row spacing of 80 cm recorded the maximum return/rupee investment of Rs 2.24 and planting on 13, 20 and 27 June at all the three row spacing recorded statistically similar results.

CONCLUSIONS

The optimum planting window for seed *dhaincha* was from 13 to 20 June (3rd week of June) in sub humid climate of coastal Odisha. Row spacings of 80 and 120 cm proved superior to 160 cm. Hence, it is advisable to plant seed *dhaincha* in the 3rd week of June in coastal Odisha at row spacing of 80 or 120 cm for maximizing productivity and profitability**.**

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Received 23 November, 2021; Accepted 02 April, 2022

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Indian Journal of Ecology (2022) 49(2): 417-423
DOI: https://doi.org/10.55362/IJE/2022/3539

Manuscript Number: 3539
NAAS Rating: 5.79

Efficacy of Herbicidal Combinations Tank Mixed with Zinc and Iron Sulphate against Weeds in Wheat (*Triticum aestivum*)

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Abstract: Weeds are affecting wheat production significantly and now days, micronutrients deficiency is also being observed in wheat growing areas. Field experiment was conducted at RRS, Bawal during *Rabi*season of 2018-19 to evaluate the efficacy of post-emergence herbicidal combinations with Zn or/and Fe against complex weed flora in wheat. Experiment consisted of 18 treatments. Four herbicidal combinations *viz*. clodinafop + metsulfuron@ 60 g ha^{-1}, sulfosulfuron + metsulfuron @ 32 g ha^{-1}, mesosulfuron + iodosulfuron @ 14.4 g ha^{-1}, pinoxaden + carfentrazone @ (50 + 20 g ha^{-1}) were evaluated for efficacy with Zn, Fe and with both Zn as well as Fe. Satisfactory weed control was observed with all the treatments of herbicidal combinations.Among sole herbicidal combinations, application of mesosulfuron + iodosulfuron (14.4 g ha^{-1}) resulted lowest population and dry weight of grassy weeds whereas application of pinoxaden + carfentrazone (50 + 20 g ha^{-1}) was most effective against broad leaved weeds. Tank mixing of Fe improved the efficacy of herbicidal combinations. Efficacy of herbicidal combinations was further increased when Zn was tank mixed with herbicidal combinations. Highest weed control efficiency was recorded when herbicidal combinations were applied as tank mixed with both, Zn and Fe sulphate.

Keywords: Efficacy, Compatibility, Zinc sulphate, Fe sulphate

Wheat (*Triticum aestivum* L.) is one of the major cereal food crops of the world and has very important role in attaining food security. There is more noteworthy extension to build wheat efficiency by conquering any hindrance among potential and accomplished yield. Wheat productivity is an after effect of numerous components, yet weed administration is one of the major and less minded reasons for low yield. Introduction of dwarf wheat varieties coupled with intensive input use led to complex problem of both grassy and broad leaved weeds. Grassy weeds, broadleaf weeds and complex flora reduce wheat yield upto 30, 24 and 48 percent, respectively and wheat yield varies upto the extent of 22 per cent due to the weeds (Khan and Haq 2002). Therefore, weed management is very important for achieving higher wheat production. Among the various methods of weed management, chemical weed control is more efficient, less costly and less time consuming.

Another factor affecting wheat productivity and quality is imbalanced fertilization and deficiency of nutrients specially micronutrients. Zn and Fe which are essential micronutrients for plants. They are involved in many enzymatic reactions and metabolic processes. They play substantial role in basic biological processes like nitrogen fixation, energy transfer and protein synthesis, photosynthesis etc. The deficiency of Zn and Fe in soils is a worldwide problem. Approximately 50 per cent of wheat-cultivated soil globally is considered poor in bio-available Zn (Cakmak and Kutman 2018) and about 30 per cent of arable cultivated soils across the globe are deficient in Zn and Fe both. In India, 49 and 15 per cent soils were deficient in Zn and Fe, respectively (Singh 2008, Shukla et al 2012). Zn and Fe availability have considerable spatial variability in trans-gangetic plains and they are in acute shortage in some regions. Wheat yield as well as its quality can be improved by foliar application of Zn and Fe alone or together. Soil and foliar application of zinc and iron in wheat impacts the yield contributing characteristics. Foliar application of iron and zinc increases their concentration in wheat grain as well as in flour (Zhang et al 2010). Time of spray of micronutrients mostly coincides with the time of application of post-emergence herbicides. The co-application of micronutrients with other agro-chemicals have advantages like reduced production costs and soil compaction. But very less information is available about the efficacy of herbicidal combinations with the zinc and iron sulphate. For instance, application of zinc does not alter the efficiency of herbicide mixture of tribenuron and isoproturon in wheat. Atrazine, chloramben and propachlor are compatible with liquid fertilizers. Therefore, herbicidal combinations tank mixed with zinc and iron sulphate could be viable option. Therefore, it needs to be further explored with herbicidal combinations tank mixed with zinc and iron sulphate.

MATERIAL AND METHODS

Field experiment was conducted was conducted at

Choudhary Charan Singh Haryana Agricultural University, Regional Research Station, Bawal (Rewari) during Rabi season of 2018 – 19. Soil of experimental site was deficient in available zinc (0.56) and sufficient in available iron (4.51 ppm). Experiment was conducted by using Randomized Block Design (RBD) having 18 treatments, each replicated thrice. Crop was raised with recommended package of practices except weed management. Treatments of weed management were applied at 35 days after sowing (DAS) in different plots of size 6.0 m x 2.2 m. Treatments consist of sole application of four herbicidal combinations *viz*. clodinafop + metsulfuron (60 g ha^{-1}), sulfosulfuron + metsulfuron (32 g ha^{-1}), mesosulfuron + iodosulfuron (14.4 g ha^{-1}) and pinoxaden + carfentrazone (50 + 20 g ha^{-1}); tank mixed application of above herbicidal combinations with $FeSO_4$ (0.5%); tank mixed application of above herbicidal combinations with $ZnSO_4$ (0.5%) + urea (2.5%); tank mixed application of above herbicidal combinations with $ZnSO_4$ (0.5%) + urea (2.5%) + $FeSO_4$ (0.5%); rest two were weedy check and weed free. Observations of weeds were recorded at different stages of crop growth. Observation on weed density and dry matter were recorded using standard methods. Weed control efficiency (WCE) was calculated using formula:

$$WCE\ (\%) = \frac{wb - wa}{wb} \times 100$$

Where,

wb = Dry weight of weeds in weedy plot, and wa = Dry weight of weeds in treated plot.

Statistical analysis of data: All the experimental data for various weed parameters was statistically analysed by online computer programme OPSTAT (Sheoran et al 1998).

RESULTS AND DISCUSSION

Weed Density

Phalaris minor: All the herbicidal combinations alone or mixed with zinc or/and iron significantly reduced the density of *P. minor* over weedy check (Table 1). More reduction in density of *P. minor* was recorded where herbicidal combinations were applied simultaneously with Zn or Fe than alone application of herbicidal combinations. Application of herbicidal combinations with both zinc and iron further reduced the density of *P. minor* as compared to their application with either Zn or Fe separately. However,

Table 1. Effect of herbicidal combinations and their tank mixtures with zinc or/and iron sulphate on density of *P. minor*

Treatment	Dose (g ha^{-1})	*P. minor* (No./m^2) DAS		
		30	60	90
Clodinafop + metsulfuron	60	8.05 (64.30)	3.25 (9.60)	2.96 (7.87)
Sulfosulfuron + metsulfuron	32	7.95 (63.03)	3.24 (9.60)	2.89 (7.47)
Mesosulfuron + iodosulfuron	14.4	7.92 (62.60)	2.93 (8.37)	2.43 (5.47)
Pinoxaden + carfentrazone	50 + 20	7.92 (62.47)	3.24 (9.50)	2.91 (7.50)
Clodinafop + metsulfuron + $ZnSO_4$ + urea	60	8.12 (65.53)	3.18 (9.13)	2.85 (7.17)
Sulfosulfuron + metsulfuron + $ZnSO_4$ + urea	32	7.68 (58.63)	3.13 (8.80)	2.75 (6.83)
Mesosulfuron + iodosulfuron + $ZnSO_4$ + urea	14.4	7.88 (61.47)	2.75 (6.83)	2.12 (3.93)
Pinoxaden + carfentrazone + $ZnSO_4$ + urea	50 + 20	7.87 (61.33)	3.04 (8.60)	2.65 (6.63)
Clodinafop + metsulfuron + $FeSO_4$	60	8.09 (64.80)	3.22 (9.37)	2.93 (7.60)
Sulfosulfuron + metsulfuron + $FeSO_4$	32	7.87 (61.27)	3.22 (9.37)	2.84 (7.20)
Mesosulfuron + iodosulfuron + $FeSO_4$	14.4	8.06 (64.40)	2.85 (7.67)	2.24 (4.33)
Pinoxaden + carfentrazone + $FeSO_4$	50 + 20	7.94 (62.47)	3.08 (9.23)	2.70 (7.07)
Clodinafop + metsulfuron + $ZnSO_4$ + urea + $FeSO_4$	60	7.45 (54.83)	2.88 (8.60)	2.56 (6.57)
Sulfosulfuron + metsulfuron + $ZnSO_4$ + urea + $FeSO_4$	32	7.80 (60.17)	2.82 (8.20)	2.54 (6.27)
Mesosulfuron + iodosulfuron + $ZnSO_4$ + urea + $FeSO_4$	14.4	8.11 (65.13)	2.51 (6.30)	2.02 (3.47)
Pinoxaden + carfentrazone + $ZnSO_4$ + urea + $FeSO_4$	50 + 20	7.60 (58.20)	2.77 (8.03)	2.54 (6.17)
Weedy check	--	8.07 (64.47)	7.36(53.87)	7.14(50.37)
Weed free	--	8.02 (63.83)	1.00 (0.00)	1.00 (0.00)
C.D. (p=0.05)		NS	1.36	1.26

Original data given in parenthesis was subjected to square root transformation ($\sqrt{x+1}$)

reduction in density was not significant.

Chenopodium album* and *Chenopodium murale : Density of *C. album* and *C. murale* was statistically similar among all treatments at 30 DAS (Table 2). *C. album and C. murale* population was significantly reduced under all the treatments as compared to weedy check. The population of these weedsunder all herbicidal combinations and their mixtures with Zn or/and Fe was at par with each other at 60 and 90 DAS.

***Angallis arvensis* and miscellaneous weeds:** All the herbicidal treatments significantly reduced the density of *A. arvensis* and miscellaneous weeds over weedy check (Table 3). Among the herbicidal combinations, lowest density of these weeds was recorded under pinoxaden + carfentrazone (50 + 20 g/ha) followed by application of mesosulfuron + iodosulfuron (14.4 g/ha). More reduction in density of these weedswas recorded when herbicidal combinations were applied simultaneously with zinc or iron. Application of combined (Zn + Fe) with respective herbicidal combination further reduced the weeds density. However, reduction in density was not significant. Among all herbicidal treatments, lowest density of these weeds was recorded under

Table 2. Effect of herbicidal combinations and their tank mixtures with zinc or/and iron sulphate on density of *C. album* and *C. murale*

Treatment	Dose (g ha^{-1})	Weed density (No./m^2)					
		30 DAS		60 DAS		90 DAS	
		C. album	*C. murale*	*C. album*	*C. murale*	*C. album*	*C. murale*
Clodinafop + metsulfuron	60	8.17 (65.97)	6.24 (38.30)	3.11 (8.84)	2.56 (5.93)	2.69 (6.40)	2.36 (4.57)
Sulfosulfuron + metsulfuron	32	7.99 (63.03)	5.99 (35.37)	3.10 (8.67)	2.49 (5.47)	2.63 (6.27)	2.27 (4.17)
Mesosulfuron + iodosulfuron	14.4	7.96 (62.60)	5.96 (34.93)	2.70 (6.57)	2.37 (4.67)	2.32 (4.37)	2.11 (3.50)
Pinoxaden + carfentrazone	50 + 20	7.94 (62.47)	5.97 (34.80)	2.38 (4.84)	2.18 (3.80)	1.96 (2.87)	1.76 (2.17)
Clodinafop + metsulfuron + $ZnSO_4$ + urea	60	8.14 (65.53)	6.23 (37.87)	2.88 (8.27)	2.41 (5.03)	2.40 (5.17)	2.23 (4.03)
Sulfosulfuron + metsulfuron + $ZnSO_4$ + urea	32	7.70 (58.63)	5.63 (30.80)	2.83 (7.27)	2.38 (4.87)	2.38 (5.03)	2.14 (3.67)
Mesosulfuron + iodosulfuron + $ZnSO_4$ + urea	14.4	8.09 (64.80)	5.88 (33.80)	2.56 (6.23)	2.23 (4.00)	2.21 (3.93)	1.94 (3.20)
Pinoxaden + carfentrazone + $ZnSO_4$ + urea	50 + 20	8.08 (64.67)	6.14 (37.00)	2.23 (4.19)	1.99 (3.13)	1.84 (2.53)	1.59 (1.80)
Clodinafop + metsulfuron + $FeSO_4$	60	8.21 (66.80)	6.33 (39.13)	3.04 (8.48)	2.49 (5.23)	2.55 (5.50)	2.28 (4.23)
Sulfosulfuron + metsulfuron + $FeSO_4$	32	8.07 (64.60)	6.14 (36.93)	2.95 (7.79)	2.46 (5.03)	2.50 (5.27)	2.22 (3.93)
Mesosulfuron + iodosulfuron + $FeSO_4$	14.4	8.27 (67.73)	6.40 (40.07)	2.63 (6.35)	2.34 (4.47)	2.27 (4.20)	2.04 (3.33)
Pinoxaden + carfentrazone + $FeSO_4$	50 + 20	8.15 (65.80)	6.22 (38.13)	2.28 (4.63)	2.11 (3.47)	1.88 (2.60)	1.67 (2.03)
Clodinafop + metsulfuron + $ZnSO_4$ + urea + $FeSO_4$	60	7.66 (58.17)	5.61 (30.50)	2.73 (6.92)	2.37 (4.87)	2.19 (4.23)	2.05 (3.60)
Sulfosulfuron + metsulfuron + $ZnSO_4$ + urea + $FeSO_4$	32	8.01 (63.50)	6.07 (35.83)	2.62 (6.23)	2.28 (4.33)	2.07 (4.07)	2.03 (3.17)
Mesosulfuron + iodosulfuron + $ZnSO_4$ + urea + $FeSO_4$	14.4	8.32 (68.47)	6.41 (40.13)	2.40 (5.19)	2.17 (3.83)	2.02 (3.60)	1.85 (2.53)
Pinoxaden + carfentrazone + $ZnSO_4$ + urea + $FeSO_4$	50 + 20	7.89 (61.53)	5.88 (33.90)	2.17 (3.77)	1.93 (2.77)	1.79 (2.33)	1.52 (1.40)
Weedy check	--	8.28 (67.80)	6.39 (40.13)	7.41 (54.48)	5.89 (34.50)	7.15 (50.17)	5.54 (30.23)
Weed free	--	8.14 (65.83)	5.96 (34.83)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
C.D. (p=0.05)		NS	NS	1.07	0.82	0.92	0.73

Original data given in parenthesis was subjected to square root transformation ($\sqrt{x+1}$)

pinoxaden + carfentrazone (50 + 20 g/ha) + $ZnSO_4$ (0.5 %) + urea (2.5 %) + $FeSO_4$ (0.5 %).

Similar reduction in population was reported by Punia and Yadav (2014). Addition of Zn or/and Fe further reduced the population of these two weeds. Reduction in weed density may be attributed to the robustness and more competition offered by the wheat crop to the weeds. Chinnathurai et al (2012) also reported that foliar spray of micronutrients reduced the weed density. More than 80 per cent reduction in density of *Rumex dentatus* and other broad leaf weeds was reported under mesosulfuron + iodosulfuron earlier also (Kaur et al 2007). Addition of Zn or/and Fe further reduced the population of miscellaneous weeds. Marwat et al (2007) reported that Zn application to crops (seed soaking, foliar or soil application) reduces the density of weeds.

Dry weight of weeds: All treatments recorded significant decrease in dry matter accumulation of grassy weeds as well as broad leaved weeds as compared to weedy check (Table 4). Among the herbicidal combinations, mesosulfuron + iodosulfuron (14.4 g/ha) was most effective which resulted into 2.65 and 5.40 g/m^2 dry weight of grassy weeds followed by 3.70 and 7.81 g/m^2 under pinoxaden + carfentrazone (50

Table 3. Effect of herbicidal combinations and their tank mixtures with zinc or/and iron sulphate on density of *Angallis arvensis* and miscellaneous weeds

Treatment	Dose (g ha^{-1})	Weed density (No./m^2)					
		30 DAS		60 DAS		90 DAS	
		Angallisarvensis	Miscellaneous	*Angallisarvensis*	Miscellaneous	*Angallisarvensis*	Miscellaneous
Clodinafop + metsulfuron	60	3.25 (9.67)	3.56 (11.90)	2.29 (4.30)	2.10 (3.47)	2.05 (3.23)	1.99 (3.01)
Sulfosulfuron + metsulfuron	32	3.42 (10.77)	3.77 (13.23)	2.17 (3.70)	2.06 (3.23)	1.94 (2.80)	1.95 (2.81)
Mesosulfuron + iodosulfuron	14.4	3.08 (8.57)	3.23 (9.43)	2.03 (3.23)	1.91 (2.77)	1.83 (2.43)	1.82 (2.41)
Pinoxaden + carfentrazone	50 + 20	2.97 (7.87)	3.44 (10.83)	1.86 (2.53)	1.76 (2.17)	1.69 (1.93)	1.69 (1.87)
Clodinafop + metsulfuron + $ZnSO_4$ + urea	60	3.15 (9.00)	3.75 (13.13)	2.10 (3.67)	2.00 (3.13)	1.89 (2.77)	1.90 (2.73)
Sulfosulfuron + metsulfuron + $ZnSO_4$ + urea	32	3.08 (8.67)	3.72 (12.87)	2.02 (3.33)	1.92 (2.87)	1.82 (2.53)	1.84 (2.50)
Mesosulfuron + iodosulfuron + $ZnSO_4$ + urea	14.4	3.38 (10.53)	3.63 (12.20)	1.94 (2.93)	1.84 (2.53)	1.76 (2.21)	1.75 (2.20)
Pinoxaden + carfentrazone + $ZnSO_4$ + urea	50 + 20	2.93 (7.63)	3.47 (11.13)	1.79 (2.30)	1.70 (1.97)	1.64 (1.73)	1.62 (1.70)
Clodinafop + metsulfuron + $FeSO_4$	60	3.19 (9.20)	3.39 (10.53)	2.17 (3.87)	2.02 (3.33)	1.95 (2.93)	1.94 (2.90)
Sulfosulfuron + metsulfuron + $FeSO_4$	32 |	3.14 (8.93)	3.48 (11.10)	2.13 (3.60)	1.97 (3.10)	1.93 (2.73)	1.89 (2.70)
Mesosulfuron + iodosulfuron + $FeSO_4$	14.4	3.35 (10.40)	3.17 (9.30)	1.97 (3.03)	1.86 (2.63)	1.79 (2.30)	1.77 (2.30)
Pinoxaden + carfentrazone + $FeSO_4$	50 + 20	2.94 (7.67)	3.60 (11.97)	1.82 (2.33)	1.74 (2.03)	1.66 (1.77)	1.66 (1.77)
Clodinafop + metsulfuron + $ZnSO_4$ + urea + $FeSO_4$	60	3.02 (8.23)	3.13 (8.83)	1.94 (2.90)	1.83 (2.50)	1.77 (2.20)	1.74 (2.17)
Sulfosulfuron + metsulfuron + $ZnSO_4$ + urea + $FeSO_4$	32	3.39 (10.53)	3.14 (9.13)	1.95 (2.87)	1.82 (2.47)	1.76 (2.17)	1.75 (2.13)
Mesosulfuron + iodosulfuron + $ZnSO_4$ + urea + $FeSO_4$	14.4	2.95 (7.70)	3.61 (12.03)	1.83 (2.37)	1.73 (2.03)	1.67 (1.80)	1.66 (1.77)
Pinoxaden + carfentrazone + $ZnSO_4$ + urea + $FeSO_4$	50 + 20	2.90 (7.43)	3.50 (11.27)	1.73 (2.10)	1.64 (1.80)	1.59 (1.58)	1.57 (1.57)
Weedy check	--	3.26 (10.10)	3.47 (11.47)	5.39 (28.10)	4.84 (22.47)	4.71 (21.20)	4.53 (19.50)
Weed free	--	3.05 (9.00)	3.53 (11.80)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
C.D. (p=0.05)		NS	NS	0.60	0.60	0.53	0.54

Original data given in parenthesis was subjected to square root transformation ($\sqrt{x+1}$)

+ 20 g/ha) at 60 and 90 DAS, respectively. Highest reduction in dry weight of broad leaf weeds was under pinoxaden + carfentrazone (50 + 20 g/ha) closely followed by application of mesosulfuron + iodosulfuron (14.4 g/ha). Application of clodinafop + metsulfuron (60 g/ha) was least effective among herbicidal combinations and witnessed highest dry weight of grassy and BLW.The addition of Zn or Fe individually to the herbicidal combinations decreased dry weight of broad leaf weeds insignificantly over sole application of herbicides. The addition of Zn to herbicidal combinations caused more reduction in dry weight of broad leaf weeds than addition of Fe with herbicidal combinations. Application of herbicidal combinations with both, Zn and Fe (Zn + Fe) further reduced dry weight of broad leaf weeds, although insignificantly. Similar reduction in dry weight of grassy as well as broad leaf weeds due to application of herbicidal combinations has been reported by Kumar et al (2014) and Tiwari et al (2016). The reduction in dry weight of weeds (both grassy and broad leaf) was due to mortality of weeds by herbicidal combinations which caused inhibition of some enzymes involved in vital plant processes. This is due to reduction in dry weight of grassy as well as broad leaf weeds due to tank mixing of Zn or/and Fe with herbicidal combinations could be the indirect effect of these micronutrients on weeds by mechanism of competitive advantage to crop plants over weeds. Application of micronutrients might have increased crop competitive ability. Similar reduction in dry weight of weeds due to tank mixing of nutrients with herbicides was reported by Sabeti (2015).

Weed control efficiency: Weed control efficiency of different herbicidal combinations and their mixtures with zinc or/and iron on grassy and BLW in wheat was determined at 60 and 90 DAS (Table 5). Among herbicidal combinations, mesosulfuron + iodosulfuron @ 14.4 g/ha and pinoxaden + carfentrazone (50 + 20 g/ha) were most effective herbicidal combination against grassy and BLW, respectively. Tank mixing of herbicidal combinations with Zn or/and Fe exerted positive effect and improved their weed control efficiency. Mesosulfuron + iodosulfuron @ 14.4 g/ha resulted into maximum control of complex weed flora. Similar results have been reported by Singh (2019) and Pal et al (2016).

Addition of micronutrients to herbicides increased weed control efficiency of herbicides. Application of herbicidal combinations mixed (Zn + Fe) enhanced the efficacy of

Table 4. Effect of herbicidal combinations and their tank mixtures with zinc or/and iron sulphate on dry weight of grassy and broad leaved weeds

Treatment	Dose (g ha^{-1})	Dry weight (g/m^2) of grassy weeds		Dry weight (g/m^2) of broad leaved weeds	
		60 DAS	90 DAS	60 DAS	90 DAS
Clodinafop + metsulfuron	60	2.18 (3.95)	3.04 (8.51)	2.70 (6.48)	3.42 (10.92)
Sulfosulfuron + metsulfuron	32	2.16 (3.74)	2.91 (7.87)	2.61 (5.93)	3.26 (9.78)
Mesosulfuron + iodosulfuron	14.4	1.80 (2.65)	2.43 (5.40)	2.42 (5.07)	2.89 (7.34)
Pinoxaden + carfentrazone	50 + 20	2.14 (3.70)	2.91 (7.81)	2.24 (4.17)	2.43 (5.47)
Clodinafop + metsulfuron + $ZnSO_4$ + urea	60	2.15 (3.71)	2.86 (7.75)	2.54 (5.87)	3.20 (9.73)
Sulfosulfuron + metsulfuron + $ZnSO_4$ + urea	32	2.07 (3.42)	2.76 (7.02)	2.39 (5.33)	3.10 (8.92)
Mesosulfuron + iodosulfuron + $ZnSO_4$ + urea	14.4	1.67 (2.36)	2.26 (5.12)	2.21 (4.40)	2.57 (5.92)
Pinoxaden + carfentrazone + $ZnSO_4$ + urea	50 + 20	2.04 (3.29)	2.77 (7.05)	2.13 (3.67)	2.25 (4.55)
Clodinafop + metsulfuron + $FeSO_4$	60	2.13 (3.80)	2.97 (8.05)	2.60 (6.20)	3.31 (10.24)
Sulfosulfuron + metsulfuron + $FeSO_4$	32	2.11 (3.54)	2.81 (7.49)	2.51 (5.77)	3.16 (9.47)
Mesosulfuron + iodosulfuron + $FeSO_4$	14.4	1.74 (2.54)	2.30 (5.17)	2.33 (4.69)	2.83 (7.17)
Pinoxaden + carfentrazone + $FeSO_4$	50 + 20	2.08 (3.51)	2.84 (7.53)	2.21 (3.87)	2.39 (5.16)
Clodinafop + metsulfuron + $ZnSO_4$ + urea + $FeSO_4$	60	1.99 (3.63)	2.76 (7.08)	2.30 (4.67)	2.88 (7.73)
Sulfosulfuron + metsulfuron + $ZnSO_4$ + urea + $FeSO_4$	32	1.92 (3.04)	2.68 (6.45)	2.27 (4.60)	2.83 (7.29)
Mesosulfuron + iodosulfuron + $ZnSO_4$ + urea + $FeSO_4$	14.4	1.60 (2.02)	2.18 (4.39)	2.17 (3.80)	2.39 (5.79)
Pinoxaden + carfentrazone + $ZnSO_4$ + urea + $FeSO_4$	50 + 20	1.90 (2.86)	2.60 (6.41)	2.06 (3.37)	2.08 (4.22)
Weedy check	--	4.95 (23.56)	7.38 (53.60)	6.55 (41.97)	8.62 (73.30)
Weed free	--	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
C.D. (p=0.05)		1.05	1.39	0.97	1.27

Original data given in parenthesis was subjected to square root transformation ($\sqrt{x+1}$)

Table 5. WCE of herbicidal combinations and their tank mixtures with zinc or/and iron sulphate on grassy and BLW

Treatment	Dose (g ha^{-1})	WCE (%) grassy		WCE (%) BLW	
		60 DAS	90 DAS	60 DAS	90 DAS
Clodinafop + metsulfuron	60	83.23	84.13	84.56	85.11
Sulfosulfuron + metsulfuron	32	84.13	85.32	85.86	86.66
Mesosulfuron + iodosulfuron	14.4	88.74	89.93	87.93	89.98
Pinoxaden + carfentrazone	50 + 20	84.28	85.44	90.07	92.54
Clodinafop + metsulfuron + $ZnSO_4$ + urea	60	84.27	85.55	86.02	86.73
Sulfosulfuron + metsulfuron + $ZnSO_4$ + urea	32	85.50	86.90	87.29	87.84
Mesosulfuron + iodosulfuron + $ZnSO_4$ + urea	14.4	89.97	90.45	89.52	91.93
Pinoxaden + carfentrazone + $ZnSO_4$ + urea	50 + 20	86.05	86.84	91.26	93.79
Clodinafop + metsulfuron + $FeSO_4$	60	83.87	84.98	85.23	86.03
Sulfosulfuron + metsulfuron + $FeSO_4$	32	84.99	86.02	86.26	87.09
Mesosulfuron + iodosulfuron + $FeSO_4$	14.4	89.20	90.36	88.82	90.22
Pinoxaden + carfentrazone + $FeSO_4$	50 + 20	85.10	85.95	90.79	92.96
Clodinafop + metsulfuron + $ZnSO_4$ + urea + $FeSO_4$	60	84.61	86.79	88.88	89.45
Sulfosulfuron + metsulfuron + $ZnSO_4$ + urea + $FeSO_4$	32	87.10	87.96	89.04	90.05
Mesosulfuron + iodosulfuron + $ZnSO_4$ + urea + $FeSO_4$	14.4	91.44	91.80	90.95	92.10
Pinoxaden + carfentrazone + $ZnSO_4$ + urea + $FeSO_4$	50 + 20	87.87	88.03	91.98	94.25
Weedy check	--	0.00	0.00	0.00	0.00
Weed free	--	100.00	100.00	100.00	100.00

herbicides and resulted into more increase in weed control efficiency in comparison to their separate application. This increase in weed control efficiency could be explained as the enhanced competitive ability of the wheat crop to suppress the weeds due to application of micronutrients. Similar results were reported by Sabeti (2015) wherein about 10 per cent increase in herbicide efficacy was reported due to tank mixture of micronutrients and herbicides.

CONCLUSION

Based on the above findings, it is concluded that all four herbicidal combinations tested under study were compatible with Zn or/and Fe. Application of mesosulfuron + iodosulfuron @ 14.4 g/ha + $ZnSO_4$ (0.5 %) + urea (2.5 %) + $FeSO_4$ (0.5 %) was most effective treatment to control the complex weed flora in wheat. This treatment resulted into highest weed control efficiency followed by pinoxaden + carfentrazone @ (50 + 20 g/ha) + $ZnSO_4$ (0.5 %) + urea (2.5 %) + $FeSO_4$ (0.5 %). Further research on different herbicidal combinations with different micronutrients in various crops will explore the new aspects of weed cum nutrient management for efficient and economic weed management.

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Received 07 November, 2021; Accepted 12 March, 2022

Indian Journal of Ecology (2022) 49(2): 424-429
DOI: https://doi.org/10.55362/IJE/2022/3540

Manuscript Number: 3540
NAAS Rating: 5.79

Vegetation and Soil Carbon Pool in Chirpine (*Pinus roxburghii Sarg.*) Forest of Mahabharat Hill, Nepal

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Abstract: This study analyzed the vegetation and soil carbon stock in natural *Pinus roxburghii* forest in Mahabharat hill of Bagmati Province, Nepal. Systematic random sampling method was applied for forest inventory and forest biomass was estimated by using standard allometric models. Soil samples were taken from soil profile up to 60 cm depth at the interval of 20 cm. Total carbon stock in *Pinus roxburghii* forest was found 193.54 t ha^{-1} and 226.54 t ha^{-1} for Aphnai CF and Okhe CF, respectively. Among the carbon pools carbon stock was found in the order of above ground carbon stock > soil organic carbon stock > below ground carbon stock for both CF. The forest carbon stock showed a positive relationship with biomass, tree diameter, and height but no relationship with tree density. The study concluded that forest vegetation and soil can play vital role on carbon sequestration and subsequently mitigating the problem of global warming.

Keywords: *Pinus roxburghii*, Biomass, Carbon, Soil

Carbon (C) sequestration is the long-term storage of atmospheric C in plants, soils, geologic formations, and the ocean. Forests play an important role in the global C cycle by sequestering, large amounts of atmospheric carbon dioxide (CO_2) in plant biomass and soil (Brown 2001, Acharya et al 2011, Ghimire 2021). The carbon pool in a forest can be categorized into biotic (vegetative carbon) and pedologic (soil carbon) components. Forest vegetation and soils share about 60% of the world's terrestrial carbon (Winjum et al 1992). They are an important carbon sink; store huge amount of ambient C into the growth of woody biomass through the process of carbon dioxide (CO_2) photosynthesis and soil organic carbon (SOC) through plant residues and other organic solids. (Brown et al 1996, Lal 2005, Zhao et al 2019). Therefore, assessing carbon sequestration in existing forest ecosystem is important as it enable us to project carbon sequestration overtime.

Atmospheric CO_2 including other Green House Gases (GHGs) are increasing day by day and are causing global warming, making difficult to sustain human life. Response to this concern have focused on reducing emissions of GHGs, particularly CO_2, and on measuring C absorbed by stored in forests, soils and ocean. Carbon sequestration by forest ecosystem is significantly important in mitigating the increasing problem of global warming (IPCC 2001). Carbon sequestration potential of a forest determines its capacity as a sink for sequestrating atmospheric carbon as stand biomass and soil. One important mechanism to manage this is to increase biological sinks of atmospheric carbon in forests (Brown et al 1996, Ostrowska et al 2010, Pandey et al 2016, Chauhan et al 2016, Ghimire 2021). Therefore, there is a high potential for enhancing the carbon sequestration in the vegetation and soils of forest ecosystems through improved conservation of these resources.

Chirpine (*Pinus roxburghii*) pine is the common conifer species found in mid-hill forests of Nepal between 900 m and 1950 m (Jackson 1994). Currently, *Pinus roxburghii* species accounts for almost nine per cent of the total forest area, making *Pinus roxburghii* the third major species of Nepalese forests (DFRS 2015). Among the different terrestrial ecosystems, conifer forests are major carbon reservoirs (Gucinski et al 1995, Pant and Tewari 2014, Ghimire 2021). Their contribution to climate change mitigation is recognized both by their ability to uptake carbon dioxide from the atmosphere through photosynthesis as for the big storing capacity in biotic and abiotic component. Therefore, knowledge of species that can sequester maximum carbon in live biomass is essential. One important approach to sequester atmospheric carbon in expanding biological sinks is forest (Gucinski et al 1995, Oli and Shrestha 2009, Lee et al 2014, Ghimire 2021, Sharma et al 2022). In this context, the current study focuses on analyzing the carbon stock in vegetation and soil layer in *Pinus roxburghii* forest of Mahabharat hill of Nepal. The information will later be useful to planner and policy maker to developed appropriate plan and strategy. It is also anticipated that the study will benefit communities managing the local forest by supporting them to realize the benefits of schemes such as REDD+ and in providing a more information basis for decision-making in management of *Pinus roxburghii* forest in the future.

MATERIAL AND METHODS

Two community forests namely: Aphnai Community Forest (CF) and Okhe Community Forest (CF) dominated by *Pinus roxburghii* were selected for the study (Fig. 1). The study area lies in Bhimphedi Rural Municipality of Makawanpur district, located between 27°21' to 27°40' N to 84°41' to 84°35' E, respectively. The district's terrain varies from valley plain to Mahabharat range and exhibits the subtropical to temperate climate. The maximum temperature rises up to 34 degree Celsius and falls down as low as minus 1.6 degree Celsius. The average annual rainfall, generally, varies from 1900 mm to 2300 mm. Bhimphedi Rural Municipality characterized by upper tropical to temperate climate (DDC 2018).

Both the community forest lies in Mahabharat hill of Makawanpur district in Bagmati Province. Aphnai CF covers an area of 283.67 ha and Okhe CF covers 277.54 ha (Table 1). Natural *Pinus roxburghii* is the major species in both the forest with sparse occurrence of other species like *Shorea robusta* and *Schima wallichii*.

Sampling design: Systematic random sampling technique was used to carryout forest C inventory. Sample plots were laid out following the forest carbon stock measurement guidelines for measuring carbon stocks in community-managed forests as recommended by ANSAB (2011). Concentric circular plots of size 500 m^2, for tree (dbh >30 cm), 100 m^2 for poles (dbh 10 to 29.9 cm) and 1 m^2 for undergrowth (i.e. regeneration, grasses and herbs) was laid out respectively to measure forest biomass. A total of 51 plot i.e. 27 and 24 plots each was laid out in Aphnai CF and Okhe CF, respectively.

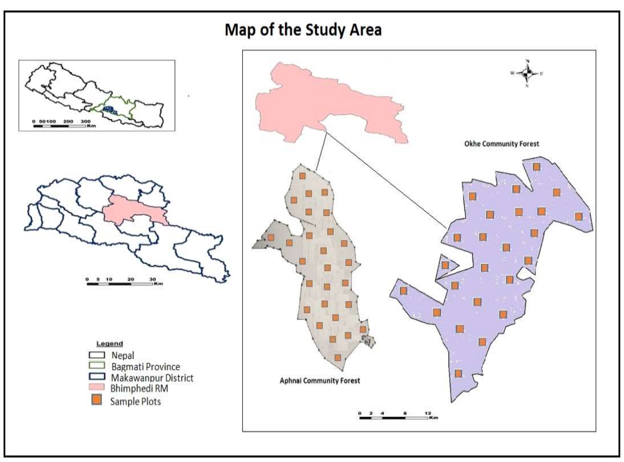

Fig. 1. Map representing the study area

Forest measurement: Diameter at breast height (dbh) and height of each tree was measured within 27 and 24 plots in *Pinus roxburghii* forest of Aphnai CF and Okhe CF, respectively. Diameter tape was used for measuring diameter at breast height (DBH) while height of each tree was estimated using Abney's level. All the under storey regeneration, grasses, and herbs within 1 m^2 plots were clipped and the fresh weight of those samples were recorded and representative sub-sample of 500g was taken to laboratory for carbon stock analysis.

Soil sampling: Soil profile was dug at center part of the each plot up to 60 cm depth of three different intervals (0-20 cm, 21-40 cm and 41-60 cm). A core ring sampler (7 cm diameter and 10 cm length) was used to take samples of soil for bulk density determination. All the samples were bagged, labeled and sent to the laboratory for further analysis.

Aboveground tree-pole biomass and carbon estimation: The logarithmic transformation of the algometric formula was used to estimate above ground biomass. The above-ground tree-pole biomass was calculated using the equations suggested by Chave et al (2005).

$$AGTB = 0.0509 * \rho D^2 H \ldots\ldots\ldots\ldots\ldots (i)$$

Where,

AGTB =above ground tree biomass (kg)

ρ = Wood Specific Gravity (g cm^{-3})

D=tree-pole diameter at breast height (cm)

H= tree height (m)

The value of ρ for *Pinus roxburghii*, is taken as 0.650 g cm^{-3} (Jackson 1994).

Biomass stock densiies are converted to carbon stock densiies using the IPCC (2006) default carbon fraction of 0.47.

Undergrowth biomass and carbon estimation: To estimate the undergrowth biomass samples were taken destructively in the field with in the plot size of 1 m^2. Collected sample were oven dried for 72 hours at 60° C and oven dry weight was recorded. Then, the amount of biomass per unit area was calculated by using the formula as prescribed ANSAB (2011).

$$UGB = \frac{W_{field}}{A} * \frac{W_{subsampledry}}{W_{subsamplewet}} * \frac{1}{1000} \ldots\ldots\ldots\ldots\ldots (ii)$$

Where,

UGB = biomass of regeneration, herbs, and grasses (t ha^{-1})

W_{field} = weight of the fresh field sample of leaf litters, herbs and grasses, destructively sampled within an area of size A (g)

Table 1. General information of studied community forests

Name of CF/Area (ha)	District/Province	Geographic region/Altitude (m)	Major species
Aphnai CF (283.67)	Makawanpur/Bagmati Province	Mahabharat hill (900-1600)	*Pinus roxburghii*
Okhe CF (277.54)	Makawanpur/Bagmati Province	Mahabharat hill (900-1450)	*Pinus roxburghii*

$W_{subsampledry}$ = weight of oven dry sub sample of leaf litter, herb and grasses taken to the laboratory to determine moisture content (g);

$W_{subsample\ wet}$ = weight of fresh sub sample of leaf litters, herbs and grasses taken to the laboratory to determine moisture content (g); and

A = size of the area in which leaf litter, herb and grass were collected (ha)

The carbon content in undergrowth is calculated by multiplying undergrowth biomass the IPCC (2006) default carbon fraction of 0.47.

Belowground biomass estimation: Below ground biomass includes biomass roots of trees below the ground. Root-shoot ratio method of 1:5 as suggested by MacDicken (1997) was used to estimate the belowground biomass. According to this belowground biomass is 20% of aboveground tree-pole biomass.

Below-ground biomass = Above-ground biomass* 0.20.................(iii)

The carbon content in belowground is calculated by multiplying belowground biomass the IPCC (2006) default carbon fraction of 0.47.

Bulk density analysis: Soil bulk density was determined using core sampling method (Blake and Hartge 1986). Oven dry weights of soil samples were determined for moisture correction. The dried soil (at 105 °C temperature for 24 hours) was then passed through a 2 mm sieve to differentiate stones. The sieved soil was weighed and volume of stones was recorded for stone correction. Then, following formula as suggested by Pearson et al (2005) was used to calculate the bulk density.

Bulk density ((g cm^{-3})) = (Oven dry weight of soil in gm)/ (Volume of the soil in cm^3)……(iv)

Where,

Volume of the soil= Volume of core – Volume of the stone

Soil organic carbon (SOC) analysis: Walkley-Black wet oxidation method was used to analyze soil organic carbon (SOC) content percent (Walkley and Black 1934). The total SOC was then calculated by using the formula as suggested by Chhabra et al (2003).

SOC = ρ * d * %C……………..(v)

Where,

SOC = Soil organic carbon stock per unit area (t ha^{-1})

ρ = soil bulk density (gm cm^{-3})

d = thickness of horizon (cm)

%C = Organic carbon content %

Estimation of total carbon stock: The carbon stock density was calculated by summing the carbon stock of the individual carbon pool of forests using the following formula.

Total carbon stock = Aboveground carbon stock + Belowground carbon stock + Soil organic carbon stock……………..(vi)

Furthermore, correlation analysis was performed to access the variation of C stock with stand density, tree dbh, height tree and biomass.

RESULTS AND DISCUSSION

Average DBH and height of *Pinus roxburghii* forests under study: The average number of trees per hectare of *Pinus roxburghii* was found 92 and 95 in Aphnai CF and Okhe CF, respectively. While mean diameter, and mean height of *Pinus roxburghii* forest stand was found 30 cm and 32 cm; 17 m and 19 m for Aphnai CF and Okhe CF, respectively (Table 2). A study conducted in Kathmandu valley revealed mean DBH and height of 35 cm and 24 m in *Pinus roxburghii* forest. Similarly, Ghimire (2021) also reported mean DBH and height of 30 cm and 19 m in pine forest (including *Pinus roxburghii* and *Pinus wallichiana*) in Mahabharat hill of Makawanpur district Nepal. The result of this study is in line with Baral et al (2009) who reported mean DBH and height of 31 cm and 18 m respectively in *Pinus roxburghii* forest of Lalitpur district, Nepalese.

Aboveground biomass and carbon stock: The result found that total aboveground biomass in *Pinus roxburghii* forest was recorded 241.96 t ha^{-1} (232.68 t ha^{-1} tree-pole biomass and 9.28 t ha^{-1} undergrowth biomass) in Aphnai CF and 299.36 t ha^{-1} (289 t ha^{-1} tree-pole biomass and 10.36 t ha^{-1} undergrowth biomass) in Okhe CF respectively (Table 3).

Accordingly, the total aboveground carbon stock was found 113.76 t ha^{-1} (109.40 and 4.36 t ha^{-1} under above and below ground, respectively) and 140.87 t ha^{-1} (136 and 4.87 t ha^{-1} under above and below ground, respectively) in Aphnai CF and Okhe CF, respectively (Table 4). Aryal et al (2013) reported 173.3 t ha^{-1} of aboveground biomass carbon stock in

Table 2. Properties of *Pinus roxburghii* forest stand of two CF

Name of CF	Density ha^{-1}	DBH (cm)			Height (m)		
		Minimum	Maximum	Mean	Minimum	Maximum	Mean
Aphnai CF	92	10.00	82.00	30.00	6.00	35.00	17.00
Okhe CF	95	11.00	84.00	32.00	8.00	38.00	19.00

Pinus roxburghii forests in the hill of Lalitpur district, Nepal. Similarly, Ghimire (2021) also found 83.71 t ha^{-1} of aboveground carbon stock in pine forest of Makawanpur district Nepal.

Below ground biomass and carbon stock: Biomass and carbon stock represent the biomass and carbon in the root portion of the forest. In this study belowground biomass were found 46.54 t ha^{-1} and 57.80 t ha^{-1} in Aphnai CF and Okhe CF, respectively. Accordingly, belowground carbon stocks were found 21.88 t ha^{-1} and 27.16 t ha^{-1}, respectively in Aphnai CF and Okhe CF.

Soil Carbon Stock

Bulk density and soil organic carbon content: The range of bulk density (BD) in two community forests based on the soil profile depths (0-60 cm) is presented in Table 4. The study found some variation in BD with respect to depth in both CF. There was a gradual increase in BD with increase in soil depth in both CF. The minimum BD (0.94 gm cm^{-3}) was recorded at top soil layer (0-20 cm) in Okhe CF, whereas, maximum BD (1.25 gm cm^{-3}) at the 41-60 cm soil profile layer in Okhe CF. Furthermore, soil organic carbon content was decrease with increase in soil profile depths (Table 4).

Soil organic carbon (SOC) stock: In this study SOC stock was found to be higher at upper layers that gradually decreased as soil depth increased in both CF. Higher SOC stock (28.20 t ha^{-1}) was found at the top soil layer (0-20 cm) in Okhe CF while lower SOC stock (13.16 t ha^{-1}) was reported at the depth of 41-60 cm in Okhe CF (Table 5). Accordingly, total SOC stock was found 57.85 t ha^{-1} and 58.51 t ha^{-1} in Aphnai CF and Okhe CF respectively. The result is in line with Ghimire (2021) who reported 41.30 t ha^{-1} of SOC stocks in pine forest of Daman hill of Makawanpur district, Nepal. A soil study conducted in Garhwal Himalayan Region of India revealed 46.07 t ha^{-1} of soil organic carbon stock in *Pinus roxburghii* forest in 0-30 cm soil layer (Gupta and Sharma 2011).

Total carbon stock: The Aphnai CF has 193.54 t ha^{-1} of total carbon stock (with 113.76 t ha^{-1} aboveground, 21.88 t ha^{-1} belowground and 57.85 t ha^{-1} soil organic carbon stock), whereas Okhe CF has 226.54 t ha^{-1} total carbon stock (with 140.87 t ha^{-1} aboveground, 27.16 t ha^{-1} belowground and 58.51 t ha^{-1} soil organic carbon stock). Of the total carbon stock more than 50% was found to be accumulated in aboveground pool for both CF. Sharma et al (2020) reported 107.5 t ha^{-1} of total carbon stock (excluding soil carbon stock) in *Pinus roxburghii* forest of hilly area of Kathmandu district, Nepal. A similar finding of biomass carbon stock was also observed by Kafle (2014) and Ghimire (2021) in Daman hill of Makawanpur district, Nepal.

Correlation analysis: The correlation analysis (Table 6) showed that the C stock in *Pinus roxburghii* forest was positively correlated with plant biomass, DBH, and height however, there is no relationship with tree density. A similar finding was also observed by Sharma et al (2020) in *Pinus roxburghii* forest of Kathmandu valley. Similarly, vegetation carbon stock was positively correlated with biomass, DBH,

Table 5. Soil organic carbon stock (t ha^{-1}) in *Pinus roxburghii* forest in two CF

Soil depth (cm)	Aphnai		Okhe CF	
	Mean	SD	Mean	SD
0-20	24.61	2.06	28.20	1.06
21-40	18.30	2.01	17.15	1.09
41-60	14.94	1.82	13.16	1.90
Total	57.85		58.51	

Table 3. Distribution of aboveground biomass (t ha^{-1}) in *Pinus roxburghii* forest stand in two CF

Name of CF	Above ground tree biomass (t ha^{-1})		Undergrowth biomass		Total above ground biomass (t ha^{-1})
	Mean	SD	Mean	SD	
Aphnai CF	232.68	18.75	9.28	1.04	241.96
Okhe CF	289.00	22.00	10.36	1.02	299.36

Table 4. Bulk density and SOC content (%) in *Pinus roxburghii* forest in two CF

Soil depth (cm)	Aphnai CF				Okhe CF			
	Bulk density (gm cm^{-3})		Organic carbon (%)		Bulk density (gm cm^{-3})		Organic carbon (%)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0-20	0.97	0.90	1.48	0.92	0.94	0.80	1.62	1.02
21-40	1.10	0.80	1.15	1.05	1.08	0.65	0.95	1.07
41-60	1.22	0.60	0.94	0.83	1.25	0.52	0.92	0.70

Table 6. Correlation analysis between carbon stock (t ha^{-1}), biomass (t ha^{-1}), tree density (tree ha^{-1}), diameter (cm) and height (m) in two CF

For Aphnai CF					
Variables	Carbon stock	Biomass	Density	DBH	Height
Carbon stock	1	1*	0.22	0.52*	0.64*
Biomass	1*	1	0.22	0.52*	0.64*
Density	0.22	0.22	1	-0.64*	-0.35
DBH	0.52*	0.52	-0.63*	1	0.70*
Height	0.64*	0.64*	-0.35	0.70*	1
For Okhe CF					
Variables	Carbon stock	Biomass	Density	DBH	Height
Carbon stock	1	1*	0.24	0.55*	0.65*
Biomass	1*	1	0.24	0.55*	0.65*
Density	0.24	0.24	1	-0.60*	-0.40
DBH	0.55*	0.55*	-0.60*	1	0.72*
Height	0.65*	0.65*	-0.40	0.72*	1

* $p< 0.05$ is considered as statistically significant

and height. Tree density was negatively correlated which is in accordance with Thapa-Magar and Shrestha (2015) and Shaheen et al (2016). Therefore, tree DBH, height, and biomass are the determinant variable for forest C.

CONCLUSIONS

The study was focused in only one species i.e. *Pinus roxburghii*. *Pinus roxburghii* forest has 193.54 t ha^{-1} and 226.54 t ha^{-1} total carbon stocks in Aphnai CF and Okhe CF, respectively. Carbon stocks in different pool of *Pinus roxburghii* forest was found in the order of above ground carbon stock > soil organic carbon stock > below ground carbon stock for both CF. The result showed that the tree DBH, height, and biomass were the determining factors for forest C, which positively affected the forest C stock, while tree density has no effect on forest C stock.

ACKNOWLEDGEMENTS

The author would like to thank Aphnai and Okhe Community Forest User Group Committee members for their support during field work. I am thankful to the Regional Soil Laboratory, Hetauda for extending laboratory facilities.

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Indian Journal of Ecology (2022) 49(2): 430-434
DOI: https://doi.org/10.55362/IJE/2022/3541

Manuscript Number: 3541
NAAS Rating: 5.79

Efficiency of Mycorrhiza Associated with *Piper mullesua* Plantlets under Acidic Soil Condition

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Abstract: The investigation was carried out to study the efficiency of arbuscular mycorrhizal fungi in up taking plant nutrients for the *Piper mullesua* plantlets grown in acidic soil condition. In the present study, *Piper mullesua* seedlings were infected with ten different strains of AM fungi and one without inoculation of AM fungi under controlled soil pH (4.5). Growth parameters and plant nutrients of AM infected plants were higher than those of non-mycorrhizal controls, which confirm the contribution of AM fungi. The two mycorrhizal fungal species *G. macrocarpum* and *G. hoi* were most efficient in pH 4.5 and encouraged the growth of the plantlets *P. mullesua*. The correlation coefficient between plant biomass and phosphatase activity was highly significant in case of *G. macrocarpum* associated with *P. mullesua* plantelts under acidic soil condition which confirms potentiality of the fungal inoculums in acidic soil.

Keywords: Mycorrhizal fungi, Acidic soil, pH, *Piper mullesua*, Phosphatase

Piper mullesua D. Don. (syn *P. brachystachyum* Wall ex Hook. fis indigenous to Arunachal Pradesh (India) and widely distributed in the Eastern Himalayan region at an altitude of about 600m to 1500m. It is an important medicinal plant belonging to the family *Piperaceae.* Roots and fruiting spikes are used in treating diarrhea, indigestion, jaundice, urticacia, abdominal disorder, horseness of voice, asthma, cough, piles, malaria fever, vomiting wheezing, chest conjestion, throat infection, worms and sinusitis. *Piper mullesua* is also considered as a rejuvenating plant. Myristicin, a 1,3-benzodioxole has been extracted from the hexane fraction of alcohol extract of fruit bearing inflorescence of *Piper mullesua* which has insecticidal properties (Srivastva et al 2001). Soil pH is known to have considerable effect on plant growth which influences the mobilization and availability of various essential and functional elements in soil (Ingrid et al 2002). Generally nitrogen and phosphorus are available to plants at a soil at pH range of 5.5 to 6.5 and on lowering the soil pH elements become unavailable to plants. Among the factors aluminum (Al) toxicity has been regarded as the main factor responsible for decreasing soil fertilities by decreasing availability of essential plant nutrients in acid soil. In neutral or alkaline soil solution, Al is present as harmless oxides and aluminosilicates (Martens 2001). However in soils below 5.5, the solubility of aluminum increases greatly and is released into the soil solution in the form of toxic ions to plants [$Al(OH)^{2+}$, Al^{3+} and $Al(H_2O)_6{}^{3+}$] (Kochian et al 2004, Roupheal et al 2015). To mitigate the negative effects of acid soils on plants, several management practices are typically implemented, such as lime application, P fertilization, and selection/use of Al-resistant plant genotypes. In addition, the inoculation/preservation of plants and soils with symbiotic arbuscular mycorrhizal (AM) fungi is another management alternative (Borie et al 2010).

Arbuscular mycorrhizal fungi are obligated symbionts of about 80 % terrestrial plants, some of them growing in soils with serious constraints (Smith and Read 2008). Arbuscular Mycorrhizal symbiosis allows a bidirectional interchange of nutrients and energy (Barea et al 2013, Smith and Read 2008). Essentially, host plants improve their water and nutrient absorption capacity, and fungi receive carbon compounds. The AM symbiosis is involved in plant adaptation to stressful soil conditions (Seguel et al 2013). Numerous studies have demonstrated that the Mycorrhizal fungi are widely distributed in acid soils and show relative tolerance to Al3+, Guo et al 2012, Fritz et al 2010). The formation of mycorrhizae could regulate the relationship between soil aluminum, phosphorus and plant, protecting roots from the Al toxicity (Vandamme et al 2013). However, mycorrhizal fungi differ in wide functional diversity among AM fungal genera and species in their capacity to alter the rhizosphere (Kelly et al 2005, Klugh and Cumming 2007), their responses to soil pH (Cavallazzi et al 2007), and in their colonization with plant species (Orłowska et al 2005). Therefore, selecting effective AMF strains might be an alternative choice in improving the growth of *P. mullesua* in acid soils. In this study, investigated the growth and mineral composition of *P. mullesua* plantlets to inoculation with introduced mycorrhizal fungal inocula under the influence of an abiotic stress, the strongly acidic soil condition.

MATERIAL AND METHODS

The study was carried out in and around Doimukh area of Papum Pare district and Pasighat area of East Siang District of Arunachal Pradesh (26º30′ N-29 º30′ N Latitude and 91 º30′E-97 º30′E Longitude; altitude 100-600m asl). The region experiences a humid tropical climate (rainfall 110-160 cm; annual temperature 12 ºC-37 ºC). The vegetation type corresponds to tropical semi-evergreen forest. The soil texture of area ranges from sandy loam to loamy sand and pH ranges from 4.9-6.7.

Raising of piper plantlets: Plantlets of piper were raised through stem cuttings. The plantlets were raised in sterilized sand and soil mixture (3:1).

Isolation and collection of mycorrhizal fungi: Soil samples were collected from different locations in Arunachal Pradesh for isolation of VAM fungal spores. Samples were taken from depth of 0-15 cm under various land use systems such as forest area, jhum fields, home gardens as well as natural habitat of piper plants. Mycorrhizal fungal spores were isolated from soil . Ten AM fungal species i.e., *G. etunicatum, G. versiforme, G. albidum, G. claroidium, G.occulatum, G. macrocarpum, G. hoi, G. aggregatum, G. fasciculatum, G. aurantium* were selected to carry out the experiment.

Experimental details: A pot experiment was carried out with 11 treatments viz., non-mycorrhizal P. mullesua plantlets as control and plantlets inoculated with the above mentioned ten mycorrhizal inocula at soil pH 4.5. To maintain the required soil pH level, elemental sulfur was used (250g/10kg soil) to lower the existing soil pH up to 4.5. A healthy piper plantlet was planted in each pot inoculating with 50 gm of AM fungi cultured soil. Eight replicates of *P. mullesua* plantlet were taken per treatment. Pots were kept in mist chamber and harvesting was done after 90 days after transplanting.

Laboratory analysis: Growth parameters like shoot and root length as well as plant biomass was determined by drying them separately in hot air oven at 60 ºC for 48 hours. The percentage of the root colonized by VAM fungi were determined (Brundreett et al (1996). The chlorophyll content of leaf of *P. mullesua* was estimated by the method of Witham et al (1971). The total nitrogen and phosphorus content of plant material was determined by the Kjehldahl method and Vanadomolybdate method respectively (Juo 1982). The activity of Phosphatase was estimated by method suggested by Tabatabai and Bremner (1969).

RESULTS AND DISCUSSION

Shoot and root length: The plant growth responses with respect to plant biomass, phosphatase activity, plant nitrogen content and plant phosphorus content were significantly higher in all the plants inoculated with mycorrhizal inocula than the non-inoculated plantlets. Difference was observed in shoot length and root length among the plantlets of *P. mullesua* infected with different mycorrhizal isolates (Table 1). The plantlets of *P. mullesua* inoculated with mycorrhizal fungi *G. macrocarpum* produced highest shoot length (4.96 cm) and lowest in the seedlings inoculated with *G. aurantium* (2.833 cm) which is higher than the non-inoculated seedlings of *P. mullesua* (2.00 cm). Highest root length was in the seedlings inoculated with *G. albidum* (22.83 cm) followed by *G. aurantium* . The, lowest root length was in the seedlings inoculated with *G. aggregatum* (20.16 cm). The root length of non-mycorrhizal plantletes of *P. mullesua* was significantly lower (17.00 cm) than the plantlets inoculated with mycorrhizal fungi. Huang et al (2017) observed that in acidic soil condition plant height, branching number, shoot and root weight, and root growth all reduced with increased soil Al3+ concentrations.

Total biomass: The biomass production of *P. mullesua* plantlets varied significantly among the plantlets infected with different mycorrhizal isolates. The plantlets inoculated with *G. macrocarpum* and *G. aggregatum* (0.395 gm) showed higher biomass followed by *G. hoi* and *G. fasciculatum* (Table 1). Plantlets of *P. mullesua* inoculated with *G. versiforme* and *G. claroidium* produced least biomass (0.28 gm). The total biomass in case of non-mycorrhizal plantlets was 0.252 gm, which was less than the inoculated with mycorrhizal fungi. Shoot length and plant biomass of AM infected plants were higher than those of non-mycorrhizal controls, which confirms the results of Colla et al (2008) and Wan et al (2008).

Table 1. Shoot and root length of *Piper mullesua* seedlings inoculated with various mycorrhizal isolates at pH 4.5

VAM fungal species	Shoot length (cm)	Root length (cm)	Biomass (gm)
Control (NM)	2.00	17.00	0.252
Glomus etinucatum	3.16	20.66	0.286
G. versiforme	3.00	20.5	0.281
G. albidum	4.00	22.83	0.338
G. claroidium	3.33	20.67	0.281
G. occultum	4.66	21.67	0.371
G. macrocarpum	4.96	22.00	0.395
G. hoi	4.66	21.16	0.384
G. aggregatum	3.67	20.16	0.352
G. fasciculatum	3.16	21.33	0.311
G. aurantium	2.83	22.50	0.303

Chlorophyll content, percent infection and survivility: The highest chlorophyll content was in the seedlings inoculated with *G. hoi* (1.753 mg/gm) followed by *G. macrocarpum* and *G. aggregatum* (Table 2). Least chlorophyll content was observed in the seedlings inoculated with *G. etinucatum* (1.510 mg/gm) and it was higher than the controlled. Chlorophyll concentration was higher in the AM inoculated seedlings as compared to the non-mycorrhizal control plants, suggesting that the mineral acquisition was higher in AM infected seedlings. Wang et al (2008) observed that chlorophyll content was higher in AM plants than in uninoculated plants. Roots of inoculated *Piper mullesua* seedlings were well colonized with AM fungi and no infection was observed in uninoculated seedlings. The percentage of mycorrhizal infection in the roots of *P. mullesua* showed variation among different *Glomus* species and was highest in the roots of seedlings inoculated with *G. aurantium* (66.67%) and least with *G. fasciculatum* (23.33%) (Table 2). There was no correlation between percent root infection and pH of soil. The percentage of survivility shown highest in the seedlings inoculated with *G. aggregatum* and *G. albidum* (60%) as compared to the non-mycorrhizal plant (30%) (Table 2).

Phosphatase, phosphorus and nitrogen content of plantlets: The phosphatase content was also significantly varied among the different mycorrhizal strains and was highest in the seedlings inoculated with G. *macrocarpum* (24.9 µg/gm) followed by *G. hoi* and G. *accultum* (Table 3). The least phosphatase content was in the seedlings inoculated with *G. versiforme* (19.97 µg/gm), which is higher than the non-mycorrhizal *Piper mullesua* seedlings (17.77 µg/gm). The phosphatase content in the seedlings of both AM inoculated and non-mycorrhizal one was greater under acidic soil condition. This may be due to the fact that the extracellular and intracellular phosphatase had greater activity at low pH (Joner et al 2000) and increased in mycorrhizal colonization under this stressed condition. In the present study, the phosphatase activity showed significant positive correlation with the plant phosphorus (r=0.842). Similar result was reported by Aarle et al (2002) under P-deprived condition sand phosphatase was correlated to shoot phosphorus concentration and plant growth.

The phosphorus content in the shoots of *P. mullesua* seedlings inoculated with *G. macrocarpum* was highest (0.0255 gm $Kg^{-1}$and. least in the seedlings inoculated with *G. etinucatum* (0.0204gm Kg^{-1}) (Table 3). However the variation was not significant among different mycorrhizal isolates and non mycorrhizal one. Our results are in accordance with the previous findings. Several studies were demonstrated that edaphic conditions of acidic soils limit plant growth, mainly due to Al3+ phytotoxicity, which reduces water and nutrient acquisition from soils and severely limits root growth of sensitive species. Increased concentration of Al^{3+} cause to the damage of the root tip, leading to the inhibition of root growth and ultimately limiting the plants from adsorbing nutrients and water from soil solution (Langer et al 2009, Huang et al 2017). In such conditions, the association of symbiotic arbuscular mycorrhizal (AM) fungi with plant roots often modifies plant response to acid soil factors through enhanced P acquisition and reduced Al exposure (Aguilera et al 2015). Similar results were in present experiment where acquisition of P was higher in mycorrhizal seedlings than the non-mycorrhizal control plants . This may be due to the extending of extra radical mycelium of the mycorrhizal fungi.

Table 2. Chlorophyll, infection and survivality of *P. mullesua* seedling infected with different arbuscular mycorrhizal isolates at pH 4.5

VAM fungal species	Total chlorophyll (mg gm^{-1})	Infection (%)	Survivality (%)
Control (NM)	1.6008	-	40
Glomus etinucatum	1.7108	40.00	50
G. versiforme	1.7232	43.33	40
G. albidum	1.7368	53.33	60
G. claroidium	1.7425	46.67	40
G. occultum	1.5563	53.33	30
G. macrocarpum	1.7377	16.67	50
G. hoi	1.7530	50.00	40
G. aggregatum	1.5980	26.67	60
G. fasciculatum	1.7688	23.33	30
G. aurantium	1.7033	66.67	40

Table 3. P-ase, phosphorus and nitrogen content in the roots of *P. mullesua* seedling infected with different mycorrhizal isolates at pH 4.5

VAM Fungal species	P-ase (µg gm^{-1})	Phosphorus (gm kg^{-1})	Nitrogen (%)
Control (NM)	17.77	0.0185	0.23
Glomus etinucatum	20.13	0.0204	0.33
G. versiforme	19.87	0.0208	0.47
G. albidum	21.20	0.0214	0.47
G. claroidium	20.97	0.0216	0.37
G. occultum	23.60	0.0244	0.56
G. macrocarpum	24.90	0.0255	0.56
G. hoi	24.13	0.0231	0.51
G. aggregatum	20.40	0.0225	0.28
G. fasciculatum	23.47	0.0210	0.47
G. aurantium	21.43	0.0217	0.33

Table 4. Linear correlation coefficients between plant biomass and phosphatase (P-ase), phosphorus (P) and nitrogen (N) in *P. mullesua* seedlings infected with different mycorrhizal isolates

Mycorrhizal isolates	P-ase	P	N
Control	-0.76	0.956*	0.733
G. etinucatum	-0.439	0.53	0.122
G. versiforme	-0.392	0.152	0.6
G. albidum	-0.838	-0.6	0.452
G. claroidium	-0.318	0.766	0.980**
G. occultum	0.202	-0.979*	0.746
G. macrocarpum	0.983**	0.603	0.930*
G. hoi	-0.285	-0.526	0.045
G. aggregatum	0.164	-0.999***	-0.987**
G. fasciculatum	0.489	0.846	0.912*
G. aurantium	0.979*	0.979*	0.316

*p>0.05, **p>0.01, ***p>0.001

The effect of pH on the Nitrogen content of mycorrhizal and non-mycorrhizal seedlings was not significant (Table 3). However, nitrogen percentage was highest in *G. accultum* and *G. macrocarpum* (0.56%) whereas was only 0.23% in the shoots of non mycorrhizal seedlings. In this experiment, concentration of phosphorus and nitrogen were higher in AM infected plant than non-mycorrhizal control plants. An increase in mineral uptake by mycorrhizal plants in various plants has been reported by various workers, but the extent of increase in uptake of each element differs depending on the plant species and experimental conditions (Gaur & Adholeya 2002). Increased growth associated with AM infection in nutrient deficient soils has been attributed to enhanced nutrient uptake, especially N and P. AM infected plants appeared efficient in improving nutrient uptake, particularly in seedlings inoculated with G. macrocarpum. Similar results were recorded by Caravaca et al (2006). *G. mosseae* was the best in uptaking both the element from soil.

The correlation coefficient of plant biomass with plant phosphatase showed significant positive correlation by the seedlings infected by G. macrocarpum and *G. aurantium*. The plant phosphorus however has significant negative correlation in the seedlings infected with *G. occultum* and *G. aggregatum*. In case of non-mycorrhizal one, a significant positive correlation was observed. The positive correlation was observed in the mycorrhizal seedlings between plant biomass and plant nitrogen (Table 4).

CONCLUSION

Inoculation of mycorrhizal fungi in *Piper mullesua* plantlets resulted better plant parameters as compared to non-mycorrhizal plantlets. Among the mycorrhizal inoculums, *G. macrocarpum* and *G. hoi* were most efficient in pH 4a.5 and encouraged the growth of the plantlets. The plant biomass and phosphatase activity of *P. mullesua* plantlets were significantly increased in acidic soil on inoculation of *G. macrocarpum* fungal inocula.

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Received 22 October, 2021; Accepted 21 December, 2021

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Indian Journal of Ecology (2022) 49(2): 435-439
DOI: https://doi.org/10.55362/IJE/2022/3542

Manuscript Number: 3542
NAAS Rating: 5.79

Impact of Various Organic and Inorganic Sources of Fertilizers on Yield, Yield Attributes, and Nutrients Accumulation in Direct Seeded Basmati Rice

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Abstract: A field experiment was carried out at CCS HAU, College of Agriculture, Kaul farm during *kharif* 2019, to study the effects of different organic, inorganic, and integrated sources on yield, yield attributes, nutrients accumulation, and economics of direct seeded basmati rice.The experiment was planned in a randomized block design with ten treatments including NPK, biogas slurry and vermicompost along and in combination. The treatments $N_{37.5}P_{15}K_{15}$ + Vermicompost @ 4 t ha^{-1} and $N_{37.5}P_{15}K_{15}$ + Biogas slurry@ 4 t ha^{-1} were at par in plant height, effective tillers^2, harvest index, grain and straw yields of rice crop, but statistically superior over control. Yield attributes and straw yields, in these treatments were at par with $N_{75}P_{30}K_{30}$. Similar trend was observed in nutrient content (NPK) and their uptake by crop. However, micronutrient's content and their uptake in rice is increased with the application of vermicompost or biogas slurry (2 and 4 t ha^{-1}) alone or with integrated use of inorganic fertilizers. Highest benefit: cost (B:C) ratio was observed in $N_{75}P_{30}K_{30}$ compared to organic manures because of getting higher reruns and lower cost of cultivation.

Keywords: Biogas slurry, Direct seeded basmati rice, Economics, Inorganic sources, Organic sources

India is the 2nd largest producer of rice *(Oryza sativa* L.) in the world with covering area of about 42.94 million hectares. The total production and productivity of rice in the country amounted to 122.27 million tonnes, and 2705 kg ha^{-1}, respectively during 2020-21. In Haryana, rice was cultivated on an area of about 4.59 million hectares with total production and productivity of 17.86 million tonnes and 3891 kg ha^{-1}, respectively during 2019-20 (Anonymous 2020). Basmati rice occupies about 1.94 m ha in the country and the two states viz. Punjab and Haryana account for 72% of total basmati rice produced in India (APEDA 2019). Direct seeding of rice refers to the process of establishing the crop from seeds sown in the field rather than by transplanting seedlings from the nursery. Direct seeding avoids three basic operations namely, puddling, transplanting and maintaining standing water (Joshi et al 2013). Repeated puddling adversely affects soil physical properties. As a consequence, following non-rice upland crop in rotation can be adversely affected due to the ill effects of puddling (Kalita et al 2020). To sustain the long-term production of rice, more efficient alternative methods of rice productions are needed. In recent years, water table is running down at a very alarming rate globally, thus, limiting the scope for cultivation of high-water requiring crops. Therefore, there is an immense need of searching alternate method of rice cultivation and direct seeding of rice seems to be such alternative. It is universally accepted that neither use of organic manures alone nor chemical fertilizers can accomplish the sustainability of the crops yield under the modern intensive farming (Kamble et al 2018). However, the use of organic manures alone might not meet the plant requirement due to presence of relatively low levels of nutrients (Timsina 2018). Therefore, in order to make the soil well supplied with all the plant nutrients in the readily available form and to maintain good soil health, it is vital to use organic manures in integrated with inorganic fertilizers to obtain optimum yields (Sahu et al 2017). Integrated nutrients management increases the yield and nutrient uptake (Mohanty et al 2013). After going through the above facts in the mind, the present study was initiated to find out the impact of various organic and inorganic sources of fertilizers on yield and yield attributes, nutrient content, and their uptake in direct seeded basmati rice.

MATERIAL AND METHODS

Experimental set-up: A field experiment with direct seeded rice was conducted at CCS HAU, College of Agriculture, Kaul farm during *kharif* 2019. The chemical composition of soil is presented in Table 1. The experiment was laid out in a randomized block design (RBD) with ten treatments (Table 2). The experimental plot size was 4.8 x 3.6 m^2, while the spacing was 20 x 15 cm. Irrigation was applied as per crop requirement. After three weeks of sowing thinning and weeding were done. Organic source (vermicompost or biogas slurry) were applied one day before sowing and incorporated as per treatments. However, the average composition of NPK in vermicompost (1.6, 0.75 and 0.8%) and biogas slurry (1.4, 0.6 and 0.8%) respectively. Inorganic fertilizers were applied as per recommended dose. The recommended dose of N, P_2O_5 and K_2O for direct seeded basmati rice is 75, 30, and 30 kg ha^{-1}. Nitrogen was applied in three split doses whereas P and K were applied as basal dose only. Source of N, P_2O_5 and K_2O was urea, SSP and MOP. Harvesting was done manually and after that plants were dried then threshed manually. Grains were separated manually from straw and weight of grains and straw was recorded for the crop yield estimation. The weights of grains and straw were recorded as per treatments and expressed in kg ha^{-1}.

Plant analysis: At crop harvest, grain and straw samples each from each plots were collected, dried plant parts were chopped down using a chopper machine.The grain and straw samples were digested separately in di-acid mixture of sulphuric acid (H_2SO_4) and perchloric acid ($HClO_4$) in ratio 9:1 for nitrogen (N), phosphorus (P) and potassium (K)analysis, while the micronutrients were analysed in di-acid mixture of nitric (HNO_3) and perchloric acid ($HClO_4$) in ratio 4:1 with the help of AAS (Atomic absorption spectrophotometer) by the following standard methods (Antil et al 2002).

Data analysis: The crop data subjected to statistically analysis using the OPSTAT statistical software package.

RESULTS AND DISCUSSION

Yield and yield attributes: The plant height, number of effective tiller, grain yield, straw yield and harvest index increased significantly in all the treatment compared to control (Table 3). The higher plant height, number of effective tiller, grain yield, straw yield and harvest index was attained under T_9 which was statistically at par with T_6. The application of organic manures (vermicompost or biogas slurry) alone or in combination of with chemical fertilizers improved the yield and yield attributes of direct seeded rice over control treatment, where no fertilizers were added. These results are in corroborate with the findings of earlier researchers (Borah et al 2016, Nagaraj et al 2018, Kakkar et al 2020). The highest yield thus obtained might be ascribed to improved physico-chemical and biological properties of soil, which have led to better plant growth and increased nutrient use efficiency under integrated nutrient supply system, and ultimately led to increased yield and improved yield attributes characters of rice.

Nutrient N, P and K content and uptake: The significantly highest N, P and K content and their uptake in grain and straw of rice crop was observed under integrated application of organics (T_9, T_6) over organics or chemical fertilizers alone (Table 4). This may be attributed to the addition of organics and fertilizers as a more readily available source of nutrients in the soil for the rice crop. Similar results have also been reported by Gill and Aulakh (2018) and Sharma et al (2015). The presence of chemical fertilizer along with organic manure might have fasten the decomposition of manures and have led to release of more nutrients in the soil (Ankush et al 2021). The higher nutrient uptake is related to increased nutrient availability and better root growth of the crop (Malav and Ramani 2017). However, among organics, highest nutrient content and uptake was recorded with vermicompost as compared to biogas slurry due to its nutrient composition. The increase in N uptake might be linked to a steady supply of nutrients, along with lower N losses by denitrification or leaching, which could have boosted the cognition between plant N requirement and soil supply (Tilahun et al 2013). Inorganics alone resulted in lower N uptake due to poor availability and higher nutrient loss (Selim 2020). The application of organic manures reduced P fixation and increased its availability in the soil thereby enhanced uptake under application of organics alone or in combination with chemical fertilizers (Tilahun et al 2013).

Table 1. Initial soil chemical properties

Parameter	Value
pH	8.66
EC (dS m^{-1})	0.11
Organic carbon (%)	0.50
Available nitrogen (kg ha^{-1})	115
Available phosphorus (kg ha^{-1})	21.47
Available potassium (kg ha^{-1})	360
DTPA-Fe	14.75
DTPA-Mn	2.95
DTPA-Cu	1.34
DTPA-Zn	1.80

Table 2. Treatments details

Control	:	T_1
N_{75} P_{30} K_{30}	:	T_2
$N_{37.5}$ P_{15} K_{15}	:	T_3
Biogas slurry (4 t ha^{-1})	:	T_4
$N_{37.5}$ P_{15} K_{15} + Biogas slurry (2 t ha^{-1})	:	T_5
$N_{37.5}$ P_{15} K_{15} + Biogas slurry (4 t ha^{-1})	:	T_6
Vermicompost (4 t ha^{-1})	:	T_7
$N_{37.5}$ P_{15} K_{15} + Vermicompost (2 t ha^{-1})	:	T_8
$N_{37.5}$ P_{15} K_{15} + Vermicompost (4 t ha^{-1})	:	T_9
Vermicompost (2 t ha^{-1}) + Biogas slurry (2 t ha^{-1})	:	T_{10}

Micronutrient (Fe, Mn, Zn and Cu) content and their uptake: Micronutrients content and uptake were found to be increased under the application of organic manure (vermicompost or biogas slurry) alone or in combination with chemical fertilizers compared to chemical fertilizer alone (Table 5). Organic materials supply chelating agents, which helps in maintaining the solubility of micronutrients including Fe and Mn. Addition of organic matter (vermicompost or biogas slurry) improves soil structure which provides better soil aeration resulting increased availability of Fe. Readily available Fe released in soil as result of organic matter mineralization might have resulted in its increased uptake by rice. Similar results were reported by Sharma et al (2013) and Basha et al (2017). Nitrogen fertilization increased grain and straw yield and uptake of Fe in rice (Lakshmanan et al 2005). The difference in Mn content between grain and straw may be due to the slow movement of Mn in plants, as reported by Duhan and Singh (2002). Result showed a significant increase in Mn content in rice straw and grain with the application of vermicompost or biogas slurry alone or with their integrated use with NPK fertilizers. Similar results were also found by Basha et al (2017).

Table 3. Effect of organic and inorganic sources of nutrients on yield and yield attributes of direct seeded basmati rice

Treatments	Plant height (cm)	No. of effective tillers (m^{-2})	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)
T_1	100.07	208.33	1,956.32	3,348.52	36.90
T_2	106.20	244.33	3,031.68	4,265.70	41.55
T_3	103.80	218.67	2,366.16	3,658.30	39.28
T_4	103.07	228.00	2,510.20	3,871.42	39.32
T_5	104.40	237.33	2,873.93	3,934.53	42.22
T_6	107.40	247.33	3,386.31	4,379.90	43.60
T_7	103.13	228.00	2,502.43	3,870.03	39.27
T_8	104.40	234.00	2,848.13	3,957.22	41.85
T_9	107.07	250.00	3,420.20	4,316.78	44.21
T_{10}	103.03	227.00	2,516.16	3,841.95	39.58
CD (p = 0.05)	1.43	5.96	128.24	157.21	1.70

Table 4. Effect of organic and inorganic sources of nutrients N, P and K content indirect seeded basmati rice

Treatments	Nitrogen				Phosphorus				Potassium			
	Content (%)		Uptake (kg ha^{-1})		Content (%)		Uptake (kg ha^{-1})		Content (%)		Uptake (kg ha^{-1})	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1	1.10	0.46	21.52	15.50	0.454	0.208	8.88	6.95	0.46	1.46	9.00	48.89
T_2	1.32	0.54	40.02	23.04	0.500	0.260	15.16	11.09	0.52	1.69	15.82	72.09
T_3	1.26	0.48	29.81	17.56	0.460	0.228	10.88	8.34	0.50	1.53	11.91	55.98
T_4	1.28	0.51	32.13	19.79	0.483	0.239	12.13	9.23	0.51	1.57	12.74	60.80
T_5	1.30	0.53	37.36	20.80	0.491	0.249	14.12	9.81	0.52	1.64	14.94	64.55
T_6	1.34	0.56	45.34	24.62	0.516	0.270	17.48	11.84	0.54	1.72	18.28	75.34
T_7	1.28	0.53	32.03	20.40	0.483	0.238	12.09	9.21	0.52	1.57	12.93	60.62
T_8	1.30	0.53	37.03	20.92	0.491	0.250	13.99	9.88	0.52	1.64	14.81	64.90
T_9	1.34	0.56	45.83	24.22	0.515	0.270	17.62	11.66	0.54	1.73	18.47	74.67
T_{10}	1.28	0.53	32.21	20.27	0.482	0.238	12.14	9.15	0.51	1.60	12.92	61.48
CD (p= 0.05)	0.04	0.04	1.71	2.13	0.010	0.008	0.69	0.50	0.03	0.05	1.03	3.76

Table 5. Effect of organic and inorganic sources of nutrient on Fe, Mn, Zn and Cu content indirect seeded basmati rice

Treatments	Iron (Fe)				Manganese (Mn)				Zinc (Zn)				Copper (Cu)			
	Content (mg kg^{-1})		Uptake (g ha^{-1})		Content (mg kg^{-1})		Uptake (g ha^{-1})		Content (mg kg^{-1})		Uptake (g ha^{-1})		Content (mg kg^{-1})		Uptake (g ha^{-1})	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1	46.67	65.03	91.32	217.57	6.53	9.50	12.79	31.67	20.07	22.33	39.25	74.54	7.00	4.00	13.70	13.38
T_2	65.00	87.67	197.08	373.87	8.67	11.40	26.28	48.62	21.87	25.50	66.29	108.79	8.07	4.73	24.47	20.19
T_3	59.33	81.67	140.47	299.67	7.33	10.90	17.34	39.89	21.07	24.17	49.85	88.29	7.77	4.57	18.39	16.68
T_4	83.33	120.33	209.21	466.24	10.20	12.93	25.80	50.09	23.13	30.33	58.04	117.58	5.70	3.17	14.31	12.28
T_5	78.33	103.33	225.24	406.48	10.90	12.27	31.34	48.26	22.97	27.37	66.03	107.54	6.83	3.80	19.66	14.95
T_6	94.67	127.33	321.54	557.53	12.37	13.57	41.87	59.41	24.60	31.00	83.31	135.80	6.16	3.40	20.86	14.89
T_7	88.00	115.00	220.38	445.69	10.00	13.97	25.01	54.09	23.17	30.00	57.98	116.15	5.86	3.12	14.68	12.05
T_8	76.67	106.67	218.62	422.49	11.00	12.27	31.37	48.54	22.97	27.17	65.39	107.58	6.73	3.83	19.16	15.18
T_9	91.67	130.00	313.63	561.03	12.40	13.63	42.39	58.84	24.73	31.30	84.62	135.15	6.27	3.43	21.43	14.81
T_{10}	85.67	110.00	215.05	421.87	10.10	12.97	25.40	49.83	23.17	30.17	58.25	116.05	5.73	3.07	14.44	11.79
CD (p= 0.05)	23.73	27.21	71.79	108.42	2.21	1.60	6.47	6.42	2.10	4.21	5.77	17.14	NS	0.80	4.81	3.17

Table 6. Effect of organic and inorganic sources of nutrients on economic of direct seeded basmati rice

Treatments	Cost of cultivation (Rs ha^{-1})	Gross return (Rs ha^{-1})	Net return (Rs ha^{-1})	B: C
T_1	30920	73362	42442	1: 2.4
T_2	33962	113688	79726	1: 3.4
T_3	32441	88731	56290	1: 2.7
T_4	47920	94133	46213	1: 2.0
T_5	40941	107773	66832	1: 2.6
T_6	49441	126987	77546	1: 2.6
T_7	46920	93841	46921	1: 2.0
T_8	40441	106805	66364	1: 2.6
T_9	48441	128258	79817	1: 2.7
T_{10}	47420	94356	46936	1: 2.0

Economics: The cost of cultivation was higher where organic source were applied by combination with chemical fertilizers Table 6. Gross and net return were higher where chemical fertilizers alone or combined with 4 t ha^{-1} of organic manure were applied. The B: C ratio was higher where chemical fertilizers alone was applied because of low cost of cultivation as compared to organics application. Similar results have also been reported by Kumar et al (2014). Baishya et al (2010) reported that crop manured only with organics (100 % RDN through VC/FYM) paid minimum return per rupee invested even lower than that of the control plots.

CONCLUSIONS

Application of chemical fertilizers alone or conjoint use with any of the organics (vermicompost and biogas slurry) gave highest number of effective tiller per m^2, plant height, grain yield, straw yield and harvest index as compare to 100 % RDF. The maximum uptake of macro- and micronutrients by basmati rice were obtained in treatment where @ 4 t ha^{-1} of organic along with 50 % RDF through inorganic fertilizer were applied.

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Received 04 October, 2021; Accepted 22 February, 2022

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Indian Journal of Ecology (2022) 49(2): 440-445
DOI: https://doi.org/10.55362/IJE/2022/3543

Manuscript Number: 3543
NAAS Rating: 5.79

Integrative Study of Coastal Land-Based Pollution and Effects: Focus on Soil Properties

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Abstract: The discharge and dumping of untreated domestic and industrial wastes into estuaries, rivers, and nearshore waters are the principal sources of coastal pollution in the current study area. Ten soil samples were collected near the industry pollutant exit point near the seashore and towards Mangalore city and were undergo chemical and physical analysis. Also, both distilled water and seawater were used to determine the strength characteristics of the samples. SEM, XRD and EDS were used to determine the surface morphology, chemical compositions of samples. From the results, it was found that most of the samples collected were more or less not met the sufficient range for the agricultural activities. When soil samples undergo Compaction and UCS tests in the presence of seawater and distilled water, MDD and UCS values were decreased in the presence of seawater. From the SEM study, the majority of samples have crystalline texture. Carbon, Oxygen, Aluminium, Silicon, Iron and Mercury were major elements abundantly found in the collected soil samples when it undergoes EDS Analysis. From the XRD analysis, it was known that Quartz, illite, kaolinite, orthoclase, mica, halloysite are the major mineral compounds found in the collected soil samples.

Keywords: Compaction, Industrial waste, Coastal pollution, Soil properties, Mangaluru, Micronutrients, Seawater

Urbanization, industrialization, and a variety of agricultural activities all release significant amounts of pollutants into the surrounding aquatic ecosystems, including estuaries, rivers, oceans, seashores, and coastal wetlands. In the last few decades, with these activities, heavy metal contamination which is caused by industrial and domestic wastewater emissions, sewage irrigation, vehicle exhaust, and overuse of pesticides and fertilizers, has become more serious in many countries (Wu et al 2016). Many factors influence the accumulation of heavy metals in the soil's surface layer, including parent rock, soil properties, human activities, agricultural processes and industrial production (Khalaf and Khuder 2021). Some are essential micronutrients for plants and animals, making them important for human health and food production. All trace elements, however, become potentially toxic at high concentrations. Man-made trace metal input into the natural environment thus poses a number of ecological and health issues. A wide range of industrial activities generate wastes and contaminants that end up in the soil via direct disposal, spills, leaks, atmospheric deposition from air, and other means (Nadal et al 2009). Anthropogenic activities, in addition to natural weathering, are regarded as substantial source to increasing trace metal concentrations in soils (Devkota 2000, Singh 2004). Because soil pollution is the starting point for pollutant transportation to plants, animals, and even the atmosphere, many researchers confirmed that trace heavy metal pollution of surface soils as a result of intensive and extensive industrialization and urbanization has become a serious concern in many developing countries.

The Baikampady industrial region in Mangaluru has been suffering from environmental degradation for almost a decade. Industrial wastes from this area are routed into the coastal water, while municipal wastes from Mangalore are disposed of in a nullah adjacent to the Gurupura River, which flows into the coastal sea off Mangalore. Such releases could pollute the water, causing serious ecosystem changes, including the decrease of fisheries resources (Kiran 2020). Rivers that travel through varied land-use activities are exposed to a variety of contaminants, ranging in strength from point to non-point sources (Samanta et al 2005). Some of the problems reported in and around the Mangalore coastal area are disposal of untreated or partially treated industrial and domestic wastes on the water bodies, crude oil contamination of the soil, oil leakages in the underground soils, coastal erosion etc.

Various studies conducted so far in the Indian coastal environment indicate that discharges from industrial and domestic outfalls have degraded the coastal environments of Mumbai and Gujarat on the west coast and Pondicherry on the east coast (Zingde and Govindan 2000). Industrial pollution continues to be a major source of pollution in the environment. Numerous studies have already shown that locations in close proximity to industrial activity have considerable air, soil, and water contamination (De Bartomeo et al 2004, Landja et al 2004, Miro et al 2004). As a result, heavy metals in such heavily polluted soils may have detrimental health consequences (Huang et al 2019; Barbieri et al 2014). The current study was undertaken to examine the chemical and physical properties of soil from an industry pollutant exit point near the seashore and towards Mangalore city, also, the impacts of seawater and distilled water on the strength characteristics of soil were investigated.

MATERIAL AND METHODS

Mangaluru is located at 12.87°N 74.88°E in the Dakshina Kannada district of Karnataka. It has an average elevation of 22 m (72 ft) above mean sea level. Mangaluru coast is a belt of about 22 Kms with Arabian Sea in the West and the Western Ghats in the East. The area is characterized by tropical monsoon climate. The major industries located in and around Mangalore are: Mangalore Chemicals and Fertilizers Ltd. (MCF), Kudremukh Iron Ore Company Ltd. (KIOCL), Mangalore Refinery and Petrochemicals Ltd. (MRPL), Badische Anilin und Soda Fabrik (BASF), Indian Oil Corporation Limited (IOCL).

The soil is predominantly lateritic and alluvial in nature, with significant iron and aluminium content. The soil texture ranges from fine to coarse. The soil in valleys and intermediate slopes is rich in loam, whereas it is coarser on the top slopes. Silty and loamy soils are mainly found along river banks and in valley plains, and are of transported origin. They have a high infiltration capacity and are fertile, making them ideal for agriculture. Mangalore receives 4,242.5 millimeters of rain each year (167 inches). On average, the humidity level is at 78%.During the summer, the relative humidity is extremely high, approaching saturation levels. Mangalore has a tropical climate, with average temperatures ranging from 27 degrees Celsius (81 degrees Fahrenheit) to 34 degrees Celsius (93 degrees Fahrenheit) between the summer and winter months. The city's landscape is flat up to 30 kilometers (18.64 miles) inside the coast, and then abruptly turns to undulating hilly terrain in the Western Ghats to the east. Within the city, there are four hilly zones with natural valleys. Ten soil samples were collected near the industry pollutant exit point near the sea shore and towards the Mangalore city using standard sampling methods (Table 1).

For chemical analysis of soils, soil samples were taken at a depth of 10-30cm and collected individually in polythene bags according to conventional protocols (Srinivasamurthy 2010). The soil samples were air dried, crushed, and sieved through a 2mm sieve for analysis. Moisture content (MC), specific gravity (SG), atterberg limits, permeability test, grain sieve analysis, compaction test, unconfined compressive strength (UCS) tests were conducted. Scanning Electron Microscopy (SEM), X-ray powder Diffraction (XRD) and Energy Dispersive X-ray Spectroscopy (EDS) tests were conducted to know its morphology, elemental analysis/chemical characterization and mineralogical composition respectively. SEM-EDS are operated at 20 kV and images were taken at magnification levels up to 500-5000 times, Carbon tape was used to attach the powder samples to a holder. A thin layer of gold was also applied to the samples to provide an electrically conductive surface. Analysis of soil samples were done by adopting standard methods (Jackson 1958, Lindsay 1978) (Table 2).

RESULTS AND DISCUSSION

Chemical properties of soil: The pH of the soil varied from 4.4 to 6.9, most of the samples were acidic in nature with an average of 5.51 which is not suitable for agricultural activities

Table 1. Details of the soil sampling

Sampling code	Sampling locations	Geographical position	
		Latitude	Longitude
S1	Near MRPL, Thokur	12º 57 ' 51.6"N	74º 50 ' 10.9"E
S2	Near Adani Wilmar Ltd	12º 57 ' 10.1"N	74º 50 ' 10.9"E
S3	Near TOIL	12º56 ' 48.0"N	74º 50' 12.7"E
S4	Chitrapura	12º57'16.1"N	74º48'13.7"E
S5	Near NMPT	12º 56 ' 23.0"N	74º 48 ' 33.7"E
S6	Near IOCL	12º54 ' 54.9"N	74º 49 ' 00.1"E
S7	Near Kulur Junction	12º55'23.43"N	74º49'46.03"E
S8	Near BP Petroleum	12º54'51.82"N	74º50'3.28"E
S9	Along Edapally Pavel Highway	12º54'21.67"N	74º50'20.65"E
S10	Near KSRTC	12º53'53.64"N	74º50'40.43"E

(Table 3). EC of soil samples varied from 0.05 ds/m to 3.26 ds/m with an average value of 0.48 ds/m. EC of all the soil samples was within 1 dS/m except sample no.2.

Macronutrients in Soils

Organic carbon (OC): All the soil samples were in the low range as their OC content below 0.5 % except sample 2. OC content in the soils is important parameter from the fertility and physical properties points of view. Continuous cultivation, removal of agricultural wastes without return, and the effects of water and wind erosion, which preferentially remove the soil colloids, including the humidified organic fractions, can all be attributed for the low OC.OC of the soil samples ranges between 0.06 to 1.16% with an average OC of 0.312 %. Konthoujam 2(021) observed that, soil organic carbonwas higher at the surface soil (0-10 cm) than the deeper layers (10-20 cm and 20-30 cm).

Table 2. Soil testing methods

Test parameter	Methods
SG	IS 2720 (part 3/section 2)
Sieve analysis	IS 2720 (part 4) - 1985
Atterberg limits	IS 2720 (part 5) - 1985
Permeability	IS 2720 (part 17) - 1986
Compaction	IS 2720 (part 7) – 1980
UCS	IS 2720 (part 10) - 1991

Available phosphorus (P_2O_5): This varied from 5 to 160 kg/acre with an average of 30.8 kg/acre. Most of the samples were fall under low to medium value category as per the soil rating chart.

Available potassium (K_2O): K_2O ranged from 12 to 382 kg/acre with a mean value of 86.7 kg/acre. Most of the samples were fall under the low range category.

Available calcium (Ca) and magnesium (Mg): Ca is absorbed by plants as Ca^{2+} and its concentration ranges from 0.2 to 1 %. Ca^{2+} is generally considered to be an immobile element in the plant. Similarly, Mg is absorbed as Mg^{2+} and its concentration in crops varies between 0.1 to 0.4%. Mg is involved in a number of physiological and biochemical functions. Ca varies from 115.3 mg/kg to 2756 mg/kg with an average value of 563.03 mg/kg and highest value was found in the sample no. 2 in both the cases

Available sulphur (S): Sulfur deficiency is more frequent in sandy soils with little organic matter (less than 2%) and

Table 3. Chemical analysis of the samples

Code	pH	EC at 25°C	OC	P_2O_5	K_2O	Ca
Adequate range	6.3-8.3	0.01-1.0	0.75	10-25	61-120	>301
S1	5.6	0.67	0.49	6	101	779.2
S2	4.5	3.26	1.16	7	382	2756
S3	4.4	0.27	0.06	160	59	148.2
S4	6.9	0.05	0.11	26	12	157.0
S5	6.5	0.15	0.06	40	13	281.7
S6	4.8	0.13	0.06	5	72	219.7
S7	4.8	0.06	0.09	5	20	115.3
S8	5.4	0.05	0.37	9	40	396.5
S9	6.1	0.10	0.09	30	110	433.1
S10	6.1	0.06	0.63	20	58	343.6

Code	Mg	S	Zn	Fe	Cu	Mn	B
	>120.01	>10.01	>1	>4.51	>0.21	>2.01	>0.51
S1	148.4	62.44	0.30	15.45	0.58	3.58	0.46
S2	910.5	1928	2.57	118.7	1.25	49.60	3.05
S3	21.72	39.59	2.15	27.90	0.38	2.25	0.47
S4	18.35	0.57	28.04	8.18	0.13	0.19	0.08
S5	14.0	12.64	0.35	32.57	0.40	3.57	0.21
S6	29.74	9.01	10.39	13.80	0.21	2.93	0.38
S7	51.88	10.29	0.14	2.62	0.09	3.73	0.10
S8	70.52	24.77	0.09	5.81	0.31	1.88	0.27
S9	69.93	2.67	2.05	10.80	0.40	0.54	0.10
S10	25.75	6.08	5.1	8.04	0.24	0.26	0.07

during periods of heavy rainfall. S in the soil samples varied from 0.57 to 1928 mg/kg with an average value of 209.606 mg/kg.

Micronutrients in soils: Plants need very small quantities of micronutrients the so-called trace or minor elements for their nutrition among them are zinc (Zn), Iron (Fe), manganese (Mn), copper (Cu) and boron (B).

Zinc (Zn): Zinc in the soil samples varied from 0.09 mg/kg to 28.04 mg/kg with an average of 5.118 mg/kg. It is possible that such high levels of zinc may be exerting some toxic effect on the root zone or they may be responsible for creating nutrient imbalance.

Iron (Fe): In all drained red and lateritic soils, iron poisoning is ubiquitous. Under reducing conditions, the washings from adjacent upland lateritic and plinthites, deposits at low lands, and valley bottoms, cause toxicity. The values range between 2.62 mg/kg to 118.7 mg/kg with an average of 24.387 mg/kg.

Manganese (Mn): Mn in soils occurs as various oxides and hydroxides coated on soil particles, deposited in cracks and veins and mixed with Fe oxides and other soil constituents. Mn in the soils varied from 0.19 mg/kg to 49.60 mg/kg.

Copper (Cu): Cu concentration in soils ranged from 0.09 mg/kg to 1.25 mg/kg and averaged about 0.399 mg/kg. The amount of copper available to plants in the soil is determined by the pH of the soil. In the alkaline range, it is lower, while in the acid range, it is higher.

Boron (B): It was ranged between 0.07 mg/kg to 3.05 mg/kg and averaged about 0.519 mg/kg. It is possible that high levels of Zn, Cu, Mn, and Cu may be exerting some toxic effect on the root zone or may be responsible for creating nutrient imbalance.

Physical properties of soil: Specific gravity varied from 2.56 to 2.74. The liquid limit varied from 23 to 58. The plastic limit ranged between 19 to 43. Permeability varies from 0.15 to 2.41 m/d (Table 4). From the sieve analysis, most of the samples were SW and SC (Table 5). Figure 1 shows the grain size distribution of soil samples.

Compaction: For the most of the samples, the optimum moisture content has increased in the seawater treated soil

Table 4. Physical properties of the soil samples

Sample No.	Specific gravity	Permeability constant, K (m/d)	Liquid limit	Plastic limit	Plasticity index
S1	2.60	0.45	51	35	16
S2	2.74	0.36	42	25	17
S3	2.66	0.31	28	21	7
S4	2.63	2.18	25	20	5
S5	2.68	2.41	23	19	4
S6	2.56	1.82	26	22	4
S7	2.69	0.33	58	43	15
S8	2.62	0.22	38	24	14
S9	2.63	0.15	41	25	16
S10	2.59	0.20	48	35	13

Table 5. Classification of the soils

Sample code	Soil classification			IS Soil classification
	Gravels (%)	Sand (%)	Silt and clay (%)	
S1	22	52	26	SC
S2	3.6	37.68	58.72	OL
S3	17	66	17	SM
S4	1	89.20	9.8	SW
S5	4.4	88.31	7.5	SW
S6	3.2	92	4.8	SW
S7	23.9	62	14.1	SC
S8	14.6	58	27.4	SC
S9	6	28.8	65.20	CL
S10	20	59	21	SC

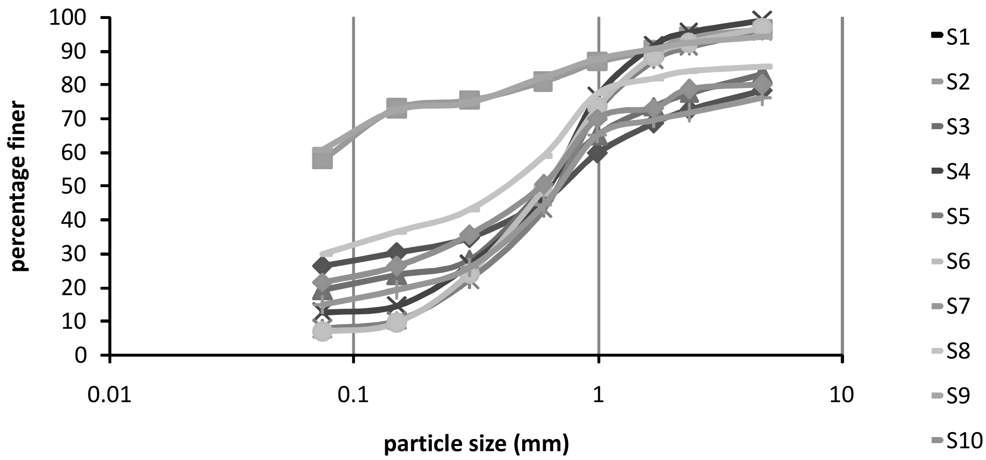

Fig. 1. Grain size distribution of soil samples

Table 6. Strength and compressibility of the soil samples in the presence of distilled water and seawater

Sample no.	MDD (g/cm^3)		OMC (%)		UCS (N/cm^2)	
	Distilled water	Seawater	Distilled water	Seawater	Distilled water	Seawater
S1	1.67	1.55	21	21.6	4.94	2.24
S2	1.44	1.41	24.7	24.2	4.93	3.1
S3	1.55	1.57	22.7	21.5	4.94	2.30
S4	1.59	1.62	22.35	21.6	4.10	2.5
S5	1.41	1.40	17.45	18.6	3.79	3.42
S6	1.62	1.49	23.5	24.2	3.83	2.06
S7	1.60	1.55	24.2	24.7	4.95	3.7
S8	1.48	1.39	20.08	22.1	4.81	2.36
S9	1.68	1.55	21.5	22.6	4.30	2.65
S10	1.52	1.42	24.12	24.8	4.45	2.3

compared to the distilled water treated soil and the maximum dry density decreased in seawater treated soil compared to the distilled water treated soil. This indicates that the situation has stabilized (Stabilized mixture has lower maximum dry density than that of unstabilized soil for a given degree of compaction). With more binders, the optimal moisture content rises.

Unconfined compression strength: UCS of the soil decreased in seawater treated soil compared to the distilled water treated soil. This can be contributed to increased size of the clay minerals (silt like behavior due to flocculation).

Material characterization of soil samples: SEM test indicate most of the samples have the crystalline texture. Average mean area of the particles was 0.6995 µm² with average minimum area of 0.0431 µm² and average maximum area of 30.25 µm². Particle sizes in the sample 4 were larger compared to the other collected samples. Similarly sample no. 8 has the smaller size particles when compared to other samples. From the EDX analysis it was concluded that, C, O, Al, Si, Fe and Hg were major elements abundantly found in the collected soil samples. XRD analysis shows that quartz, illite, kaolinite, orthoclase, mica, halloysite are the major mineral compounds found in the collected soil samples.

CONCLUSIONS

The most of the soil samples were coarse grained soils and Permeability of soils along the sea shores was high compared to the soils collected in Industrial area and towards the city center due to less silt and clay content. When soil samples undergo Compaction and UCS tests in the presence of seawater and distilled water, MDD, UCS values were decreased in the presence of seawater. Most of the samples were acidic in nature and were more or less not met the sufficient range for the agricultural activities. As a result, the anthropogenic activities occurring in and around the study area may be to blame for the chemical parameter deviations.

ACKNOWLEDGEMENTS

The authors are thankful to the Ministry of Earth Sciences, Government of India for supporting this work.

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Received 23 October, 2021; Accepted 22 March, 2022

Indian Journal of Ecology (2022) 49(2): 446-454
DOI: https://doi.org/10.55362/IJE/2022/3544

Manuscript Number: 3544
NAAS Rating: 5.79

Assessment of Drought Characteristics over Vindhyan Region through Different Drought Indices

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Abstract: The activities performed over a period of time by human induces circumstances that results in increasing the extreme events that causes severe impact to environment, agriculture, and livelihood relying on. One of the most devastating impacts can be seen as drought. Increased drought frequency with higher magnitude and intensity has severe implication to the water resources availability in the region. The aim of the present study was to evaluate the drought and its characteristics over Vindhyan region in Mirzapur and Sonbhadra district. The average annual rainfall over Vindhyan region is 934.75 mm with a coefficient of variation of 25.83. The rainfall in the region varies from 863.34 mm in Mirzapur district to 1003.26 mm in Sonbhadra district. The variation over Sonbhadra region is less in comparison with Mirzapur district. Identification of drought prone block indicates that in Mirzapur district 10 out of 12 blocks are drought prone whilein Sonbhadra district 3 out of 8 blocks are drought prone. In Vindhyan region there was widespread drought during 1982, 1988, 1992, 1997, 2002, 2004, 2009, 2015, and 2017. Relative departure index (RDI) indicates Chhanvey, Narainpur and Pahari blocks at highest priority with RDI=0.70 in Mirzapur district followed by Ghorawal blocks with RDI = 0.60 in Sonbhadra district. Standardized Precipitation Index (SPI) was adapted to evaluated meteorological drought characteristics. 1 month SPI and 3 month SPI was evaluated for assessing severity, duration, intensity, magnitude and extent of drought over the region. Based on the findings, drought preparedness and mitigation plan may be implemented, which will aid in reducing the influence of drought and its potentially dangerous consequences.

Keywords: Drought, Standard Precipitation Index (SPI), Vindhyan region, Relative Departure Index (RDI)

Droughts have drawn the attention of environmentalists, ecologists, hydrologists, meteorologists, geologists, and agricultural scientists as an environmental disaster which occurs in virtually all climatic zones (Belal et al 2014). It is mostly related to the reduction in the amount of precipitation received over an extended period. The reason for droughts occurrence includes strong temperatures, high winds, low relative humidity, and the timing and characteristics of rainfall, such as the distribution of rainy days during crop growing seasons, rain strength and length, and onset and termination. Due to the slow progress of its effects, it is still unclear and sometimes referred to as a creeping disaster. The frequency of drought unexpectedly increases worldwide as an outcome of global warming, which is induced due to anthropogenic activities coupled with climate change scenarios (Dai 2012, Frich et al 2002). Meteorological drought is simply the departure of meteorological variables from normal that induces drying of the surface. It is usually region-specific because the atmospheric conditions in different areas are highly variable in space and time. When meteorological drought is prolonged it subsequently leads to agricultural drought wherein the water quantity in the soil is unable to meet the demand of plants at various growth stages. The meteorological drought could also result in hydrological drought, which is indicated by the decline in streamflow, river discharge, and groundwater level. Insignificant rainfall marks the onset of meteorological drought, which is followed by hydrological drought as a decrease in the surface water and groundwater levels and thus has a direct effect on the crops resulting in agricultural drought (Mishra and Singh 2010, Thomas et al 2015, Aswathi et al 2018).

Most of the indexes used in drought assessment, by and large, involve a lot of datasets. But the most relevant and most comprehensive one which can serve the purpose of drought monitoring and detecting and which has also been recommended by WMO (2009) and WCRP (2010) is the Standardized Precipitation Index (SPI) and has been used in the present study. Soil moisture status can also be estimated using SPI and it is considered as a better indicator for estimating soil wetness. Keyantash and Dracup (2002) established the strength of SPI in drought analysis based on six weighted evaluation performance criteria viz, robustness, tractability, transparency, sophistication, extendibility, and dimensionality in comparison with other drought indexes (Thomas et al 2016).

The suitability and adaptability of SPI with other indicators through the development of meaningful relationships help in a more comprehensive evaluation of drought characteristics. Most of the studies performed by Gocic et al (2013), Basamma et al (2017), Rahman et al (2018) highlighted the suitability of SPI based on computation at different time scales in comparison with other drought indicators for meteorological, agricultural and hydrological drought evaluation. The present study mainly encompasses to evaluate the meteorological drought characteristics using SPI and other suitable drought indicators for a more comprehensive and more exhaustive assessment which help in revealing salient features of drought behaviors in the Vindhyan region comprising of Mirzapur and Sonbhadra district.

MATERIAL AND METHODS

Study area: The Vindhyan region of Uttar Pradesh lies between 82° 4' to 83°33' East longitude and 23° 52' to 25° 17' North latitude which includes the districts i.e., Mirzapur and Sonbhadra (Fig. 1). The region has a relatively subtropical climate with high variation between summer and winter temperatures. The average temperature is 32°C-42°C in the summer and 2°C-15°C in the winter. The study area has an area of 11,310 sq km. Most of the region has alluvial soil and the average elevation in the study area is 298.3m.

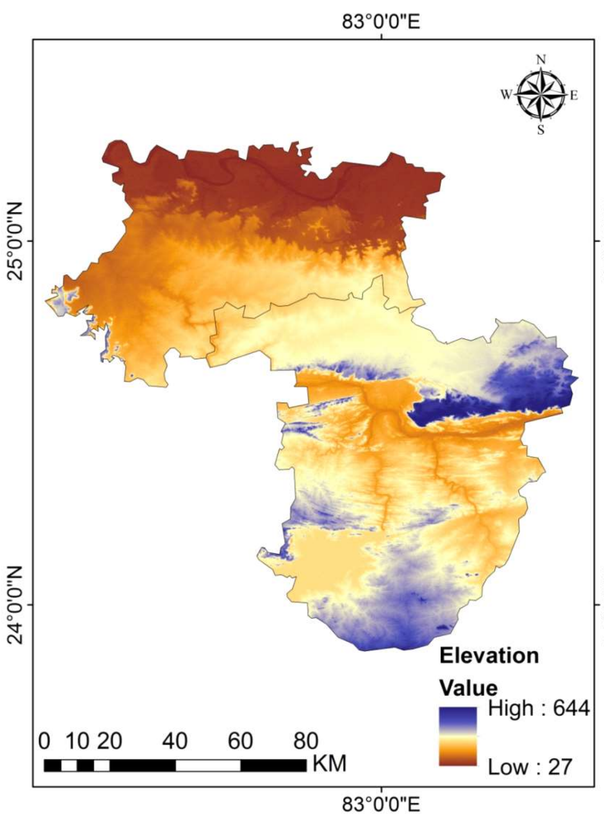

Fig. 1. Location and elevation map of Vindhyan region, U.P.

Data used: For assessment of drought characteristics in Vindhyan region, gridded daily rainfall data has been used and which was downloaded from Indian Meteorological Department (IMD), Pune. (https://www.imdpune.gov.in)

Identification of drought prone block: The drought-prone blocks in the study area have been identified based on the probability analysis of annual and seasonal rainfall (Thomas et al 2015, Sharma et al 2021). For computation the annual rainfall series sorted in the descending order and ranks has been assigned from 1, 2, 3, to N, up to the last record and thereafter Weibull's distribution fitted to the ranked data. An area will be considered to be drought prone if the probability of occurrence of 75 % of mean annual rainfall is less than 80 %. Kar et al (2016) adopted the similar technique for computing drought prone blocks in Bundelkhand region.

Identification of drought year and drought severity: The drought year has been identified based on the departure analysis of annual and seasonal rainfall. In the Indian context, since more than 90 % of the annual rainfall is received during the monsoon season, the seasonal rainfall departure has been adopted for computation as it better represents the drought conditions during the critical crop growth periods. The seasonal rainfall departure (Di) for the study area has been computed by subtracting the mean seasonal rainfall (Xm) from the seasonal rainfall series (Xi) as given below.

$Di = Xi - Xm$

Subsequently, the percentage departure (D %) is computed as:

$D\% = Di/Xm * 100$

IMD considers a season as drought affected, if the total seasonal rainfall is less than 75 % of the normal. Based on the seasonal rainfall departures and the prevailing climatic condition in the region, four drought classes have been defined for the study area viz., (a) mild drought (b) moderate drought (c) severe drought (d) extreme drought (Table 1.)

Relative departure index based prioritization of drought prone blocks: Relative departure index (RDI) is a ranking system, used to prioritize block based on departure analysis. This analysis helps for developing an initial drought mitigation plan for these affected blocks. For this purpose, weights have been assigned to various drought years as

Table 1. Seasonal rainfall departure based drought classification

Drought classes	Range (%)
Mild drought	-20 < D < -25
Moderate drought	-25 < D < -35
Severe drought	-35 < D < -50
Extreme drought	D > -50

follows, mild drought (1), moderate drought (2), severe drought (3) and extreme drought (4).

The relative departure index for the rain gauge stations will be divided by the total cumulative weights obtained for the study period during drought years with total number of years under consideration as given in equation below. Sharma et al (2021) had also used RDI based prioritization of drought prone blocks in Chambal basin falling in Madhya Pradesh and Rajasthan region.

$RDI = \frac{\sum_{i=1}^{n} W_i}{N}$ Where, N= Total number of year under consideration, W_i= Weight for the i[th] drought years.

SPI- based meteorological drought evaluation: The Standardized Precipitation Index is based on an equi-probability transformation of aggregated monthly precipitation into a standard normal variable. Assumed the aggregated precipitation to be gamma distributed and used a maximum likelihood method to estimate the parameters of the distribution. The computation of the SPI involves, (a) calculation of mean of the normalized precipitation of the lognormal (ln) rainfall series; (b) fitting a two-parameter gamma probability density function to a given frequency distribution of the precipitation and computation of shape and scale parameters β and α, for each time scale of interest (1, 3, 6 and 12 months), respectively, as given by the following equations (3)

$$Log\ mean\ (\overline{X}_{\ln}) = \frac{\Sigma \ln X}{N}$$

$$\text{Shape parameter } (\beta) = \frac{1}{4U}\left[1 + \sqrt{\frac{4U}{3}}\right]$$

$$\text{Scale parameter } (\alpha) = \frac{\overline{X}}{\beta}$$

Where U is the constant given by

$$U = \ln(\overline{X}) - \overline{X}_{\ln}$$

The resulting distribution parameters which have been estimated by the maximum likelihood approach are then used to find the cumulative probability of an observed precipitation event for the given month and time scale, for a particular station. The cumulative probability as given by gamma distribution (Kar et al 2018) is

$$G(x) = \frac{1}{\alpha^{\beta}\Gamma\beta}\int_0^x x^{\beta-1} e^{\frac{-x}{a}} dx$$

Letting $t = \frac{-x}{a}$, this equation becomes the incomplete gamma function

$$G(x) = \frac{1}{\Gamma\beta}\int_0^{t\alpha} t^{\beta-1} e^{-t} dt$$

Since the gamma function is undefined for x = 0 and a precipitation distribution may contain zero, the cumulative probability becomes

H(x) = q + (1 – q) G(x)

Where 'q' is the probability of a zero.

However, the three parameter gamma distribution is considered to produce more robust values of SPI. If m is the number of zeros in a precipitation time series, then q can be estimated by m/N and using the tables of incomplete gamma function to determine cumulative probability H(x) (Thomas et al 2015). The cumulative probability is then transformed to the standard normal random variable Z with mean zero and variance one, which is the value of the SPI. The Z or SPI values are more easily obtained computationally using an approximation that converts cumulative probability to the standard normal random variable Z (Abramowitz and Stegun, 1965).

$$SPI = -\left[t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right] For\ 0 < H(x) \le 0.5$$

$$SPI = +\left[t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right] For\ 0.5 < H(x) \le 1.0$$

Where,

$$t = \sqrt{\ln\left\{\frac{1}{(H(x))^2}\right\}} For\ 0 < H(x) \le 0.5$$

$$t = \sqrt{\ln\left\{\frac{1}{(1\text{-}H(x))^2}\right\}} For\ 0.5 < H(x) \le 1.0$$

c_0 = 2.515517, c_1 = 0.802853 and c_2 = 0.010328,

d_1 = 1.432788, d_2 = 0.189269 and d_3 = 0.001308

Classification of SPI-A drought event occurs during the period when SPI is continuously negative and reaches an intensity of -1.0 or less and ends when the SPI become positive. The frequency, duration and intensity of drought can be calculated with SPI. The positive sum of the SPI for all the months within a drought event is termed as drought magnitude. The division of the drought magnitude by its duration results in drought intensity. The drought severity has been evaluated using the classification used by Hayes et al. (1999) (Table 2).

A 1-month SPI (1m-SPI) and 3-month SPI (3m-SPI) has been adopted in the present study for assessing short-term or seasonal or meteorological drought. But it can also be used for assessing surface water drought and hydrological drought if investigated at 6 month and 12 month time scale.

RESULTS AND DISCUSSION

Statistical approaches based assessment of rainfall:

Evaluation based on statistical approach reveals that the area receives the average annual rainfall of 934.75 mm with an average coefficient of variation of 25.83. The region lying in the Mirzapur district receives minimal rainfalls in Jamalpur block (863.34 mm) whereas minimal rainfall amount occurs in Myorpur block (901.63 mm) in Sonbhadra district of Vindhyan region (Fig. 2). Higher variability in the rainfall amount signifies the irregularity in the rainfall pattern both spatially and temporally. This can be ascertained based on the variability in the annual rainfall amount in the region (Fig. 3). The highest coefficient of variation was observed at Kon blocks (33.14) followed by Chhanvey block in Mirzapur district of the study area whereas in Sonbhadra district highest coefficient of variation was obtained in Ghorawal block (26.70) followed by Dudhi blocks.

When comparing Vindhyan region in Mirzapur and Sonbhadra district it has been observed that the variation in average annual rainfall is low in Sonbhadra district and also the contribution of rainfall by the district to Vindhyan region is more. Trend analysis of annual rainfall indicated that blocks viz.Narainpur, Jamalpur and Hallia in Mirzapur district showed decreasing rainfall trend whereas in Sonbhadra district decrease in rainfall was observed in Chatra, Nagwa and Babhani blocks.

Drought prone blocks identification: In the present time prospect the frequency of drought occurrence increased certainly due to climate change scenario. The frequent drought resulted in inadequate water availability and water stress conditions in the region. Hence the drought prone (DP) blocks have been identified from non drought prone (NDP) blocks based on probability analysis using Weibull's formula so that region specific drought mitigation strategies can be implemented by the government agency to minimize the impact of drought (Table 3).

In Mirzapur district of the study area, 10 out of 12 blocks are drought prone except Majhawa and Sikhar blocks whereas in Sonbhadra district, 3 out of 8 blocks are drought prone. The distribution of rainfall was erratic and irregular coupled with the consequences of the climate change scenario there exists a situation where there was a drought in one region while in the close vicinity, the region remained unaffected. The study area is rain fed, therefore irregularity caused due to different climatic phenomenon viz. El-Nino, La Nina and ICZC affected the area to a large extent. Based on departure analysis of seasonal rainfall it was observed that most of the parts in Vindhyan region were under the grip of widespread drought during 1982, 1988, 1992, 1997, 2002, 2004, 2009, 2015, and 2017 (Table 4). Maximum drought years occurred in Narainpur block followed by Rajgarh in Mirzapur district and Robertsganj block in Sonbhadra district. The frequency of drought occurrence in Mirzapur district was more prominent in comparison with Sonbhabha district. The drought severity classes were also identified to examine the critical deficit rainfall region (Table 5).

The differences in the severity classes indicating the facts that there is high variability in the rainfall amount which resulting different drought severity classes in the region. Maximum extreme drought events occurred in Chhanvey block (4 events) followed by City, Kon, and Lalganj block (3 events) in Mirzapur district. The occurrence of extreme drought was less in Sonbhadra district as compared to Mirzapur district. Maximum severe drought events occurred

Table 2. SPI based drought severity classification

SPI range	Classification
≥2.0	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
0.0 to 0.99	Mild wet
0.0 to -0.99	Mild drought
-1.0 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
≤-2.0	Extreme drought

Table 3. Drought prone blocks in Mirzapur and Sonbhadra district of Vindhyan region

District	Block	Inferences
Mirzapur	Chhanvey	DP
	City	DP
	Hallia	DP
	Jamalpur	DP
	Kon	DP
	Lalganj	DP
	Marihan	DP
	Majhawa	NDP
	Narainpur	DP
	Pahari	DP
	Rajgarh	DP
	Sikhar	NDP
Sonbhadra	Robertsganj	DP
	Ghorawal	DP
	Chatra	NDP
	Nagwa	NDP
	Chopan	NDP
	Babhani	NDP
	Myorpur	DP
	Dudhi	NDP

Table 4. Drought year in Vindhyan region

Block name	Drought years														Drought frequency (In 40Yrs)
Chhanvey	1997	1998	2004	2005	2006	2007	2009	2014	2015	2017					10
Kon	1997	1998	2002	2004	2006	2007	2009	2014	2015	2017					10
Majhawa	1992	2004	2006	2007	2009	2010	2012	2014							8
Sikhar	1992	2004	2006	2007	2009	2010	2013	2014	2015						9
Narainpur	1982	1992	1997	1998	2002	2004	2006	2007	2009	2010	2013	2014	2015	2017	14
Jmalpur	1982	1992	1997	1998	2002	2004	2006	2009	2010	2014	2015				11
Lalganj	1997	1998	2004	2005	2006	2007	2009	2014	2015	2017					10
City	1992	1997	1998	2004	2006	2007	2009	2014	2015	2017					10
Pahari	1982	1988	1992	1997	1998	2004	2006	2009	2010	2013	2015				11
Rajgarh	1982	1988	1992	1997	1998	2004	2005	2009	2010	2013	2014	2015			12
Hallia	1982	1983	1998	2004	2007	2009	2010	2014	2015	2017					10
Marihan	1997	1998	2004	2005	2006	2007	2009	2014	2015	2017					10
Ghorawal	1982	1983	1997	1998	2004	2005	2007	2009	2010	2014	2015				11
Robertsganj	1982	1983	1992	1995	1997	2004	2005	2007	2009	2010	2014	2015			12
Chatra	1988	1992	2004	2009	2010	2014	2015								7
Nagwa	1988	1992	2002	2004	2005	2009	2010	2014	2017	2018					10
Chopan	1992	1998	2004	2005	2007	2009	2010	2014	2015						9
Myorpur	1992	1997	1998	2004	2007	2008	2009	2010	2015						9
Dudhi	1989	1992	2004	2009	2010	2015	2017								7
Babhani	1998	2004	2009	2010	2014	2015									6

Table 5. Block-wise drought severity classes and relative departure index

District	Block	Mild	Moderate	Severe	Extreme	RDI
Mirzapur	Chhanvey	1	4	1	4	0.7
	City	2	2	3	3	0.68
	Hallia	3	3	5	0	0.6
	Jamalpur	2	7	3	0	0.63
	Kon	2	2	3	3	0.68
	Lalganj	1	4	2	3	0.68
	Marihan	2	4	2	2	0.6
	Majhawa	2	4	1	1	0.43
	Narainpur	3	8	3	0	0.7
	Pahari	0	9	2	1	0.7
	Rajgarh	2	7	2	1	0.65
	Sikhar	3	4	1	1	0.45
Sonbhadra	Robertsganj	4	7	1	0	0.53
	Ghorawal	0	9	2	0	0.6
	Chatra	2	5	0	0	0.3
	Nagwa	4	5	1	0	0.43
	Chopan	2	4	3	0	0.48
	Babhani	1	3	1	1	0.35
	Myorpur	1	3	4	1	0.58
	Dudhi	1	2	3	1	0.45

in Hallia block (5 events) in Mirzapur district and Myorpur block (4 events) in Sonbhadra district. In the region severe drought events varies between 1 to 5 events. The Maximum number of moderate drought events (9 events) occurred in Pahari block in Mirzapur district and Ghorawal block in Sonbhadra district. The Maximum mild drought events occurred in Robertsganj and Nagwa block of Sonbhadra district (4 events) followed by Hallia, Narianpur, and Sikhar block (3 events) in Mirzapur district. Prioritization based on Relative departure index (RDI) indicates Chhanvey, Narainpur and Pahari blocks at highest priority with RDI=0.70 in Mirzapur district followed by Ghorawal blocks with RDI = 0.60 in Sonbhadra district.

Meteorological drought evaluation based on SPI: Meteorological drought characteristics have been evaluated at 1m-SPI and 3m-SPI time scales. The response of drought is depicted using rainfall data for the period spanning 40 years (1980-2019). 1m-SPI and 3m-SPI help to reveal drought characteristics with respect to available soil moisture. It depicts short term drought characteristics prevailing. Drought events evaluated using 1m-SPI and 3m-SPI are depicted in Table 6 and 7.

The number of drought events of different severity classes is different at different timescales. In 1m-SPI

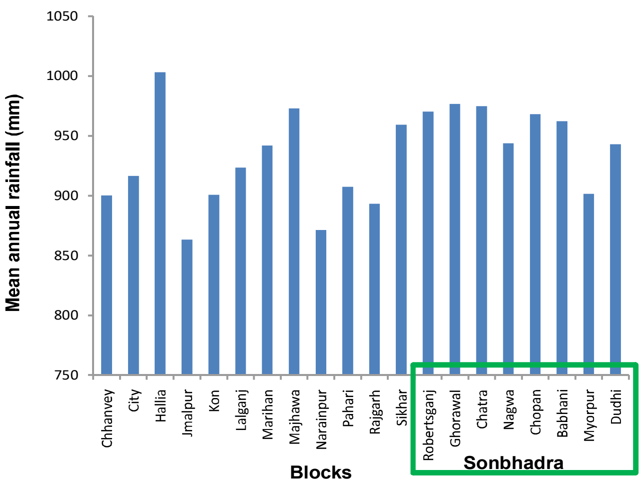

Fig. 2. Mean annual rainfall for different block in Vindhyan Region

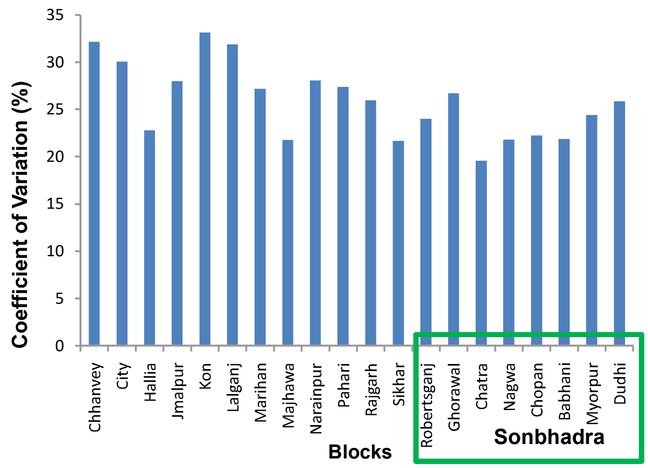

Fig. 3. Coefficient of variation for different block in Vindhyan Region

Table 6. 1m-SPI for the different blocks of Vindhyan region falling in Mirzapur and Sonbhadra district

Blocks	Extreme	Severe	Moderate	Drought duration (Months)	Drought magnitude	Drought intensity
Babhani	4	10	21	34	-50.85	-1.5
Chatra	5	13	26	44	-63.72	-1.45
Chopan	5	11	33	48	-68.48	-1.43
Chhanvey	8	5	29	41	-62.37	-1.52
City	7	4	35	46	-67.97	-1.48
Dudhi	4	12	22	38	-55.49	-1.46
Ghorawal	6	8	31	43	-62.4	-1.45
Hallia	4	8	33	44	-61.99	-1.41
Jmalpur	4	6	16	26	-42.69	-1.64
Kon	7	9	31	42	-62.96	-1.5
Lalganj	7	5	32	44	-64.07	-1.46
Marihan	5	11	24	39	-60.55	-1.55
Majhawa	5	9	32	45	-64.54	-1.43
Myorpur	5	8	32	45	-64.16	-1.43
Nagwa	3	14	25	42	-62.19	-1.48
Narainpur	5	4	33	42	-59.43	-1.42
Pahari	5	4	38	47	-66.02	-1.4
Rajgarh	5	7	27	38	-57.02	-1.5
Robertsganj	4	12	36	50	-68.84	-1.38
Sikhar	4	10	36	48	-68.17	-1.42

maximum extreme events occurred in Chhanvey blocks (8 events) followed by City, Kon and Lalganj block (7 events) in Mirzapur district and Sonbhadra district maximum of 6 extreme events occurred in Ghorawal blocks. The occurrence of severe events was maximum in Nagwa block (14 events) followed by Chatra block (13 events) in Sonabhadra district. In Pahari block maximum moderate drought events occurred (38 events) followed by Robertsganj and Sikhar blocks of the study area (36 events). Similar conclusions can be drawn for 3m-SPI using Table 7. Temporal variation of 1m-SPI and 3m- SPI of selected blocks are shown in Figure 4 to 7.

Temporal variation of 1m-SPI for Pahari block in Mirzapur district and Robertsganj block in Sonbhadra district. In case of Pahari block it can be observed that in 1986, 1997, 1998, 2009, and 2015 there is extreme soil moisture deficit condition wherein1m-SPI<-2.0. Drought of varying severities occurred in Robertsganj blocks of Sonbhadra district. In 1981, 1997, 2008, 2009 and 2016 extreme drought conditions existed in the region. This dissimilarity is due to the undulating topography of the region which resulting in maximum disposal of rainwater as runoff and thus causing water scarcity in the region along with prolonged dry spells and subsequent drought.

The temporal variation using 3m-SPI at Pahari blocks in Mirzapur district is given in Figure 6. The soil moisture deficit results due to prolonged dry spells for longer periods. The

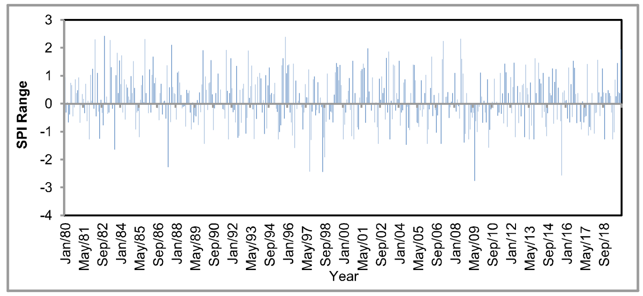

Fig. 4. 1m-SPI for Pahari block in Mirzapur district

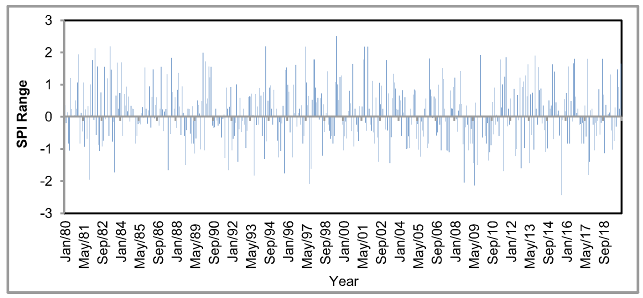

Fig. 5. 1m-SPI for Robertsganj block in Sonbhadra district

Table 7. 3m-SPI for different block in Mirzapur and Sonbhadra district of Vindhyan region

Blocks	Extreme	Severe	Moderate	Drought duration (Months)	Drought magnitude	Drought intensity
Babhani	7	19	50	75	-112.82	-1.5
Chatra	7	27	47	80	-117.49	-1.47
Chopan	9	26	46	81	-123.18	-1.52
Chhanvey	17	24	34	74	-124.44	-1.68
City	17	27	34	77	-127.39	-1.65
Dudhi	6	26	49	79	-118.62	-1.5
Ghorawal	10	21	53	81	-121.2	-1.5
Hallia	7	32	47	84	-125.73	-1.5
Jmalpur	5	21	51	76	-112.34	-1.48
Kon	16	27	33	75	-124.66	-1.66
Lalganj	13	24	36	73	-121.11	-1.66
Marihan	12	26	41	78	-125.61	-1.61
Majhawa	12	25	44	79	-121.78	-1.54
Myorpur	12	24	50	85	-129.61	-1.52
Nagwa	8	19	58	77	-112.5	-1.46
Narainpur	8	25	42	73	-113.97	-1.56
Pahari	13	18	48	79	-121.83	-1.54
Rajgarh	8	26	43	76	-118.6	-1.56
Robertsganj	10	21	49	77	-116.07	-1.51
Sikhar	12	24	44	77	-119.32	-1.55

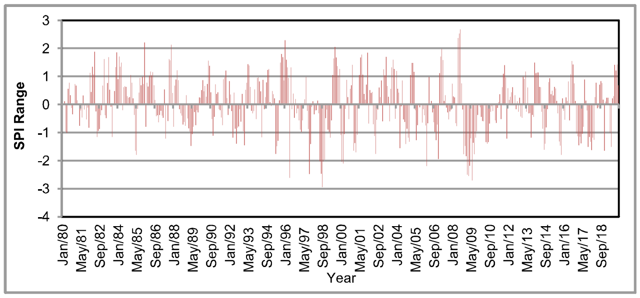

Fig. 6. 3m-SPI for Pahari block in Mirzapur district

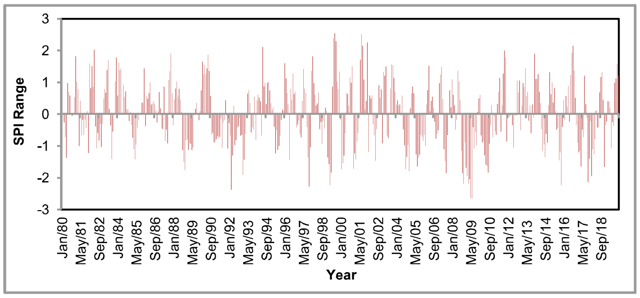

Fig. 7. 3m-SPI for Robertsganj block in Sonbhadra district

duration of the drought increase with the increase in the time scale of the SPI. 1996, 1997, 1998, 2005 and 2009 have been the predominant drought years. Extreme droughts which are observed in Pahari blocks are less as compared to the Robertsganj blocks in Sonbhadra district during 2008 and 2009.All the extreme soil moisture droughts were not translated into surface water drought probably due to favourable conditions in the intermittent years. Similarly, the severe soil moisture droughts are also fewer in both the blocks of Mirzapur and Sonbhadra district and the remaining years experienced moderate and mild soil moisture droughts.

CONCLUSION

The present study analysed the in-depth drought characteristics using indices and techniques which are suitable to analyse the drought scenario in Vindhyan region of Uttar Pradesh in Mirzapur and Sonbhadra district. The region due to water scarcity and undulating topography resulting in maximum disposal of rainwater as runoff causing water scarcity in the region. The region also experiences dry spells during the monsoon period, which, when prolonged, results in drought. The abnormal deficiencies in rainfall resulted in unfavourable conditions for agricultural production as well during the peak crop periods. Identification of drought prone block using Weibull's formula indicates that in Mirzapur district 10 out of 12 blocks are drought prone while in Sonbhadra district 3 out of 8 blocks are drought prone. In Vindhyan region there was widespread drought during 1982, 1988, 1992, 1997, 2002, 2004, 2009, 2015, and 2017. The assessment done helps to suggest suitable measures adopted to reduce drought impact and to cope under such devastating conditions. The focus of the mitigation strategy should be mainly diverted to accept the challenges that were put forward due to water stress conditions and which are having a negative impact on both crops and livestock.

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Received 22 December, 2021; Accepted 21 March, 2022

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Indian Journal of Ecology (2022) 49(2): 455-461
DOI: https://doi.org/10.55362/IJE/2022/3545

Manuscript Number: 3545
NAAS Rating: 5.79

Calibration, Validation and Evaluation of Temperature- and Radiation-based and Valiantzas' ET_0 Equations at Humid Dehradun District of Uttarakhand

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Abstract: The present study was undertaken to calibrate, validate and evaluate the performance of some temperature- & radiation-based and Valiantzas' ET_0 equations in comparison to standard FAO56-PM model in humid climatic conditions prevailing at Dehradun district of Uttarakhand (India). Prior to analysis, quality control of 31 years (1989-2019) daily meteorological dataset was ensured by omitting days with missing data and neglecting outliers. For calibration, 65% dataset (20 years, 1989-2008) was considered while, remaining 35% dataset (11 years, 2009-2019) was utilized for validation. The analysis showed that almost all calibrated equations performed well with higher value of Agreement index (D), reduced errors (RMSE, MAXE, PE) and nearby optimum value of ratio (R) of $ET_{0method}$ to $ET_{0FAO56\text{-}PM}$. The global performance indicator (GPI) analysis revealed that Valiantzas' V3 equation performed best among all considered equations.

Keywords: Calibration, Temperature-based, Radiation-based, Valiantzas', Reference evapotranspiration

Water is becoming a scarce commodity day-by-day due to increasing human population, urbanization, industrial development, severe negligence, and over-exploitation. It is estimated that per capita availability of water on annual basis in Indian conditions has been reduced from 1816 m^3 in 2001 to 1544 m^3 in 2011 (CWC 2015) which is expected to further drop down to 1140 m^3 in 2050 (Lal and Stewart 2012). Evapotranspiration (ET) being one of the basic elements of hydrological cycle is a very important and essential parameter for a large number of scientific and management studies including that of agriculture, crop simulation models, crop water requirement, environmental assessment, hydrology, irrigated areas, irrigation scheduling, watershed etc. (Bautista et al 2009, Sentelhas et al 2010, Vazquez and Hampel 2014). The most weather elements affecting evapotranspiration are air temperature, humidity, radiation, and wind speed (Nassif et al 2021). The calculated values of ET help in determining reference evapotranspiration (ET_0), which can be estimated either using lysimeters or meteorological data (Lopez-Urrea et al 2006) but as lysimeters are very expensive, takes more time to install and requires more maintenance, several equations were developed to indirectly estimate ET_0 from meteorological data causing confusion to select any specific equation as "standard". The Food and Agricultural Organization (FAO) of the United Nations proposed Penman-Monteith model in its Irrigation and Drainage Paper No. 56 (referred to as FAO56-PM model as "standard" and researchers have confirmed its superior performance over other ET_0 equations in different climatic conditions across the globe. A number of researchers recommended local calibration of existing empirical ET_0 equations before utilizing them due to their widely non-consistent performance as they optimally perform only under specific climatic conditions for which they were originally being developed. In order to use them at other places having less meteorological parameters and/or at different climatic condition, their local calibration is essentially required (Pereira et al 2006, Bautista et al 2009). The standard FAO56-PM model can be used to calibrate and validate empirical equations for new regions as per the recommendation of FAO Expert Consultation on Revision of FAO Methodologies for Crop Water Requirements. Some of existing ET_0 equations were calibrated, validated and evaluated by various researchers (Criestia et al 2013, Heydari and Heydari 2014, Tomar 2016) throughout the globe for different climatic conditions against standard FAO56-PM model. From above, it is evident that no information on calibration, validation, and evaluation of ET_0 equations for Indian humid locations is available. Therefore, an attempt has been made in the present study to calibrate, validate, and evaluate the performance of some existing ET_0 equations for humid Dehradun district of Uttarakhand considering standard FAO56-PM model as an index.

MATERIAL AND METHODS

The study was carried out for humid Dehradun district

(78°04'E longitude, 32°19'N latitude and 516.5 m above m.s.l.) of Uttarakhand state using 31 years (1989-2019) of daily dataset consisting of all required meteorological parameters. Prior to analysis, quality control of dataset was ensured by removing days with missing data and avoiding outliers. For calibration, 65% dataset (20 years, 199-2008) was utilized while remaining 35% dataset of 11 years (2009-2019) was used for validation.

Reference Evapotranspiration Estimation

FAO-56 PM model: The recommended form of FAO56-PM model consisting of aerodynamic and surface resistance terms (Allen et al. 1998) is presented as Equation 1:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)U_2(e_s - e_a)}{\Delta + \gamma(1+0.34U_2)} \quad (1)$$

Where ET_0 = reference evapotranspiration (mm/day), Δ = slope of vapour pressure curve (kPa/°C), R_n = net radiation at crop surface (MJ/m^2/day), G = soil heat influx density (MJ/m^2/day), γ = psychrometric constant (kPa/°C), T = mean daily air temperature (°C), U_2 = wind speed at 2 m height (m/sec), e_s = saturation vapour pressure (kPa), e_a = actual vapour pressure (kPa). The nature of climate system allows soil heat flux density (G) on daily timescale to be ignored as on daily basis, its value is nearly zero (Allen et al. 1998).

ET_0 equations considered: Pertinent details of ET_0 equations considered in this study are presented in Table 1.

Calibration coefficient determination: In this study, the procedure outlined in Tabari and Talaee (2011) for calculating calibration coefficient was adopted and its simplified procedure consists of two-steps as, (i) calculating ratio (R) as $ET_{0method}/ET_{0FAO56\text{-}PM}$, and (ii) multiplying inverse of this ratio (1/R) with original coefficient to get calibrated coefficient.

Statistical analysis and ranking: For comparing the performance of all considered ET_0 equations against standard FAO56-PM model, statistical analysis in terms of Agreement index (D), Root mean square error (RMSE), Maximum absolute error (MAXE), and Percent error of estimate (PE) was conducted while, Global performance indicator (GPI) was used for ranking purpose (Table 2) which extends combined normalized effect of all considered statistical indices between their minimum and maximum values of "0.00" and "1.00", respectively (Despotovic et al 2015).

RESULTS AND DISCUSSION

The performance of considered ET_0 equations against standard FAO56-PM model in terms of calibration coefficient and percent deviation from their corresponding original values, statistical indices (D, RMSE, MAXE, PE) and ratio (R) of $ET_{0method}$ to $ET_{0FAO56\text{-}PM}$ are presented in Table 3 and Table 4, respectively while, their overall ranking is presented in Table 5.

Calibration Coefficient

Temperature-based equations: The calibration coefficient of ALN and BR equations as 0.00186 and 0.09227 was lowered to 37.78 and 41.23% in comparison to their respective original values of 0.0030 and 0.157, respectively. At the study area, calibration coefficient of DA equation with 38.00% lower deviation in comparison to its original coefficient (0.0025) was obtained as 0.00155. Likewise, calibration coefficient for HAR and HH equations as 0.00151 and 0.00144, respectively was 34.35 and 37.39% lesser in comparison to their original coefficient of 0.0023. For KHA and SAM equations, calibration coefficient of 0.00780 was found lowered by 42.22% in comparison of its original coefficient of 0.0135. The calibration coefficient of TRA equation (0.00184) was f20.00% decreased in comparison to its original counterpart (0.0023). The calibrated temperature-based ET_0 equations extended decrement in value of calibration coefficient in between 20.00% (TRA) and 42.22% (SAM).

Radiation-based equations: The calibration coefficient of radiation-based equations was decreased in the range from 8.05% (MPT) to 42.62% (MB) while, 4.83% increment in its value was observed with SS equation (Table 3). For BG and CAP equations, calibration coefficient was obtained as 1.08490 and 4.23329 which was lower to the tune of 34.25% and 30.60% in comparison to their original coefficients of 1.65 and 6.1, respectively. At humid Dehradun district, calibration coefficient of HAN equation was found 18.09% lesser, yielding its value as 0.57334 in comparison to original coefficient of 0.70. Similarly, calibration coefficient of IRS and MB equations as 0.12627 and 0.00844 was 15.26 and 42.62% lower in comparison to their respective original coefficients of 0.149 and 0.01471. In comparison to original coefficient (1.18), calibrated MPT equation produced 8.05% lower value of coefficient as 1.08502 while, its value for SS equation (0.07338) was found 4.83% higher in comparison to its original coefficient of 0.07.

Valiantzas' equations: The calibrated Valiantzas' equations produced lower correlation coefficients in the range from 3.23% (V3) to 26.64% (V6). For V1 and V2 equations, calibration coefficients as 0.04673 and 0.04358 were found lower to the tune of 8.37 and 14.55%, respectively in comparison to their original coefficient (0.051) while, for V3, V4, V5 and V6 equations, in comparison to their original coefficient of 0.0393, lower values of calibration coefficients as 0.03803, 0.03006, 0.02976 and 0.02883 were obtained. Likewise, calibration coefficient for V7 equation as 0.01618 was found 24.39% lower in comparison to its original coefficient of 2.4.

Performance of calibrated ET_0 equations vs standard

FAO56-PM model: In almost all cases, calibrated equations produced higher D values, lower errors (RMSE, MAXE, PE) with value of ratio (R) near to 1.00 indicating closer ET_0 estimates to that of standard FAO56-PM model (Table 4). The pertinent details are discussed hereunder as:

Temperature-based equations: Except SAM equation, all calibrated ET_0 equations produced higher values of D (>0.95) and its highest value (0.9845) was obtained with TRA equation. The increment in D value was in the range from 11.67% (TRA) to 65.51% (SAM). The values of RMSE, MAXE, and PE with calibrated equations showed decrement ranging from 68.32% (SAM) to 85.79% (ALN), 62.71% (TRA) to 81.95% (DA), and 80.64% (TRA) to 91.21% (ALN), respectively. The TRA equation produced best ratio (R) of 1.1155 while, SAM equation produced worst result.

Radiation-based equations: For calibrated radiation-based

Table 1. Different ET_0 equations considered in the study

Equation (Notation)	Representative mathematical form	Reference	Eq. No.
Temperature-based equations			
Allen (ALN)	$ET_0 = 0.408 \times 0.0030R_a(T + 20.0)(T_{max} - T_{min})^{0.40}$	Allen (1993)	(3)
Baier-Robertson (BR)	$ET_0 = 0.157T_{max} + 0.158(T_{max} - T_{min}) + 0.109R_a - 5.39$	Baier and Robertson (1965)	(4)
Droogers-Allen (DA)	$ET_0 = 0.408 \times 0.0025R_a(T + 16.8)(T_{max} - T_{min})^{0.50}$	Droogers and Allen (2002)	(5)
Hargreaves (HAR)	$ET_0 = 0.408 \times 0.0023R_a(T + 17.8)(T_{max} - T_{min})^{0.50}$	Hargreaves (1994)	(6)
Heydari-Heydari (HH)	$ET_0 = 0.408 \times 0.0023R_a(T + 5.9519)(T_{max} - T_{min})^{0.611}$	Heydari and Heydari (2014)	(7)
Samani (SAM)	$ET_0 = 0.408 \times 0.0135R_a(T + 17.8)(T_{max} - T_{min})^{0.50}[0.00185(T_{max} - T_{min})^2 - 0.0433(T_{max} - T_{min}) + 0.4023]$	Samani (2004)	(8)
Trajkovic (TRA)	$ET_0 = 0.0023R_a(T + 17.8)(T_{max} - T_{min})^{0.424}$	Trajkovic (2005)	(9)
Radiation-based equations			
Berengena-Gavilan(BG)	$ET_0 = 0.408 \times 1.65\left(\frac{\Delta}{\Delta + \gamma}\right)(R_n - G)$	Berengena and Gavilan (2005)	(10)
Caprio (CAP)	$ET_0 = 6.1 \times 10^{-6}R_s(1.8\,T + 1.0)$	Caprio (1974)	(11)
Hansen (HAN)	$ET_0 = 0.408 \times 0.70\left(\frac{\Delta}{\Delta + \gamma}\right)R_s$	Hansen (1984)	(12)
Irmak-R_s (IRS)	$ET_0 = 0.149R_s + 0.079T - 0.611$	Irmak et al. (2003)	(13)
McGuinness-Bordne (MB)	$ET_0 = \left\{(0.0082T - 0.19)\left(\frac{R_s}{1500}\right)\right\} \times 2.54$	McGuinness and Bordne(1972)	(14)
Modified Priestley-Taylor (MPT)	$ET_0 = 0.408 \times 1.18\left(\frac{\Delta}{\Delta + \gamma}\right)(R_n - G)$	Abtew (1996)	(15)
Stephens-Stewart (SS)	$ET_0 = 0.408 \times (0.0148\,T + 0.07)R_s$	Stephens and Stewart (1963)	(16)
Valiantzas' equations			
Valiantzas 1 (V1)	$ET_0 = 0.051(1 - \alpha)R_s\sqrt{T + 9.5} - 2.4\left(\frac{R_s}{R_a}\right)^2 + 0.052(T + 20)(1 - 0.01RH)(a_u - 0.38 + 0.54U_2)$	Valiantzas (2006)	(17)
Valiantzas 2 (V2)	$ET_0 = 0.051(1 - \alpha)R_s\sqrt{T + 9.5} - 2.4\left(\frac{R_s}{R_a}\right)^2 + 0.048(T + 20)(1 - 0.01RH)(0.50 + 0.536U_2)$	Valiantzas (2006)	(18)
Valiantzas 3 (V3)	$ET_0 = 0.0393R_S\sqrt{T + 9.5} - 2.4\left(\frac{R_S}{R_a}\right)^2 - 0.024(T + 20)(1 - 0.01RH) + 0.066W_{aero}(T + 20)(1 - 0.01RH)U_2^{0.6}$ W_{aero} = 0.78, when RH > 65%; and W_{aero} = 1.067, when RH ≤ 65%.	Valiantzas (2013c)	(19)
Valiantzas 4 (V4)	$ET_0 = 0.0393R_s\sqrt{T + 9.5} - 2.4\left(\frac{R_s}{R_a}\right)^2 + C_u(T + 20)(1 - 0.01RH)$ C_u = 0.054 when RH > 65%; and C_u = 0.083 when RH ≤ 65%	Valiantzas (2015)	(20)
Valiantzas 5 (V5)	$ET_0 = 0.0393R_s\sqrt{T + 9.5} - 2.4\left(\frac{R_s}{R_a}\right)^2 + C_u(T + 20)(1 - 0.01RH)$ $C_u = 0.076–0.0119\,(RH-50)^{0.2}$, when RH >50%, and $C_u = 0.076+0.0084\,(50-RH)^{0.2}$, when RH ≤50%	Valiantzas (2015)	(21)
Valiantzas 6 (V6)	$ET_0 = 0.0393R_s\sqrt{T + 9.5} - 0.19R_s^{0.6}\varphi^{0.15} + 0.0061(T + 20)(1.12T - T_{min} - 2)^{0.7}$	Valiantzas (2013a)	(22)
Valiantzas 7 (V7)	$ET_0 = 0.051(1 - \alpha)R_s\sqrt{T + 9.5} - 2.4\left(\frac{R_s}{R_a}\right)^2 + 0.075(T + 20)(1 - 0.01RH)$	Valiantzas (2013b)	(23)

ET_0 = reference evapotranspiration (mm/day), R_s= solar radiation (MJ/m^2/day),R_a= extra-terrestrial radiation (MJ/m^2/day), T = mean air temperature (°C), RH = relative humidity (%), U_2= wind speed at 2 m height (m/sec), TR = temperature difference (°C), T_{dew}= dew point temperature (°C), T_{max}= maximum air temperature (°C), T_{min}= minimum air temperature (°C), equations, value of D was vary in between 0.9364 (HAN) and 0.9934 (CAP). The increment in D value was observed in between 0.58% (MPT) and 64.43% (MB) while, with HAN equation, its value was decreased to the tune of 2.76%. The values of RMSE, MAXE, and PE with calibrated equations varied in the range from 0.1961 mm/day (CAP) to 0.6312 mm/day (MB), 0.2700 mm/day (BG) to 1.8400 mm/day (MB), and 1.4769% (MPT) to 9.7139% (MB), respectively. The values of RMSE, MAXE, and PE were decreased in the range from 26.39 (MPT) to 85.49% (BG), 30.09 (IRS) to 89.16% (BG), and 13.52 (HAN) to 92.02% (BG), respectively while, highest increment in RMSE and PE were obtained with HAN and SS equations to the tune of 20.60 and 75.00%, respectively. The calibrated BG and MPT equations both yielded best result in terms of ratio (R) as 0.9851 with respective decrement of 34.24 and 8.05% while, IRS equation was adjudged worst with R value of 1.1129.

Valiantzas' equations: The calibrated Valiantzas equations produced higher D values [0.9489 (V6) to 0.9974 (V3)], lower RMSE values [0.1241 mm/day (V3) to 0.4682 mm/day (V6)], lower MAXE values [0.1600 mm/day (V1) to 0.6379 mm/day (V6)], and lower PE values [1.8982% (V3) to 5.6618% (V6)]. Except V1, all other equations produced higher D values in the range from 0.04% (V3) to 8.93% (V4) while, RMSE, MAXE, and PE values were lowered in the range from 8.07 (V3) to 65.39% (V4), 43.59 (V3) to 75.27% (V4), and 3.49 (V3) to 91.65% (V4), respectively. The calibrated V2 equation yielded best value of R as 0.9992.

Ranking of considered ET_0 equations: The normalized values of statistical indices and overall ranking of calibrated equations revealed that no temperature-based equation could make its place among top three positions, however, Valiantzas' V3 equation performed best, followed by two radiation-based (BG and MT) equations with corresponding GPI values of 0.3439, 0.2940, and 0.2916 while, temperature-based SAM equation with least GPI value of -

Table 3. Original and calibration coefficients of ET_0 equations

Equation (s)	Coefficient (s)		
	Original	Calibration	
Temperature-based equations			
ALN	0.0030	0.00186	(-37.78%)
BR	0.157	0.09227	(-41.23%)
DA	0.0025	0.00155	(-38.00%)
HAR	0.0023	0.00151	(-34.35%)
HH	0.0023	0.00144	(- 37.39%)
SAM	0.0135	0.00780	(-42.22%)
TRA	0.0023	0.00184	(- 20.00%)
Radiation-based equations			
BG	1.65	1.08490	(- 34.25%)
CAP	6.1	4.23329	(- 30.60%)
HAN	0.70	0.57334	(- 18.09%)
IRS	0.149	0.12627	(- 15.26%)
MB	0.01471	0.00844	(- 42.62%)
MPT	1.18	1.08502	(- 8.05%)
SS	0.07	0.07338	(+ 4.83%)
Valiantzas' equations			
V1	0.051	0.04673	(- 8.37%)
V2	0.051	0.04358	(- 14.55%)
V3	0.0393	0.03803	(- 3.23%)
V4	0.0393	0.03006	(- 23.51%)
V5	0.0393	0.02976	(- 24.27%)
V6	0.0393	0.02883	(- 26.64%)
V7	2.4	1.81469	(- 24.39%)

ALN = Allen, BR = Baier and Robertson, DA = Droogers and Allen, HAR = Hargreaves, HH = Heydari and Heydari, SAM = Samani, TRA = Trajkovic, BG = Berengen aand Gavilan, CAP = Caprio, HAN = Hansen, IRS = Irmak-R_s, MB = McGuinness and Bordne, MPT = Modified Priestley and Taylor, SS = Stephens and Stewart, V1 = Valiantzas 1, V2 = Valiantz as 2, V3 = Valiantz as 3, V4 = Valiantz as 4, V5 = Valiantz as 5, V6 = Valiantz as 6, V7 = Valiantz as 7.
Figures in parenthesis show percent deviation in comparison to original coefficient, (+) represents increment, and (-) shows decrement w.r.t. original coefficient.

Table 2. Computational form of considered statistical indices

Statistical index	Notation	Computational form	Eq. No.
Agreement index	D	$1-\frac{\sum_{i=1}^{n}(O_i-P_i)^2}{\sum_{i=1}^{n}(\lvert P_i-\bar{O}\rvert+\lvert O_i-\bar{O}\rvert)^2}$	(24)
Root mean square error	RMSE	$\sqrt{\frac{\sum_{i=1}^{n}(P_i-O_i)^2}{n}}$	(25)
Maximum absolute error	MAXE	$\mathrm{MAX}[\lvert O_i-P_i\rvert]_{i=1}^{n}$	(26)
Percent error of estimate	PE	$\left\lvert\frac{\bar{P}-\bar{O}}{\bar{O}}\right\rvert\times 100$	(27)
Global performance index	GPI	$\sum_{i=1}^{n}(\bar{X}_i-X_{ij})\times a_i$	(28)

$\bar{O}$ = mean of FAO56-PM ET_0 (mm/day), $\bar{P}$ = mean of ET_0 (mm/day) obtained with equations, O_i = FAO56-PM ET_0 (mm/day) value, P_i = predicted value of ET_0 (mm/day) obtained with equations, $\bar{X}_i$= median value of scaled indicator "i", X_{ij}= median value of indicator "i" for method "j", n = total number of observations, a_i is (-)1 for R^2 and (+)1 for all other individual statistical indices.

Table 4. Comparative performance of original and calibrated ET_0 equations vs FAO56-PM model along with their ratio during validation period (2009-2019)

Equation(s)	Features	Statistical indices				R
		D	RMSE	MAXE	PE	
Temperature-based equations						
ALN	Original	0.6794	2.0543	3.4546	71.4205	1.8034
	Calibrated	0.9840	0.2919	0.6374	6.2807	1.1181
	% variation	+44.83	-85.79	-81.55	-91.21	-38.00
BR	Original	0.6199	2.3722	3.6649	82.9789	1.9788
	Calibrated	0.9581	0.4513	1.0994	7.5380	1.1630
	% variation	+54.56	-80.98	-70.00	-90.92	-41.23
DA	Original	0.6743	2.1279	3.8217	72.8723	1.8118
	Calibrated	0.9811	0.3254	0.6899	7.1809	1.1233
	% variation	+45.50	-84.71	-81.95	-90.15	-38.00
HAR	Original	0.7196	1.8370	3.3288	63.0335	1.7119
	Calibrated	0.9808	0.3263	0.6709	7.0363	1.1239
	% variation	+36.30	-82.24	-79.85	-88.84	-34.35
HH	Original	0.6653	2.2718	4.4300	75.1687	1.8074
	Calibrated	0.9715	0.4237	1.1200	9.6821	1.1317
	% variation	+46.02	-81.35	-74.72	-87.12	-37.39
SAM	Original	0.5109	3.6425	10.6500	106.1499	2.1251
	Calibrated	0.8456	1.1539	3.9500	19.1117	1.2279
	% variation	+65.51	-68.32	-62.91	-82.00	-42.22
TRA	Original	0.8816	0.9534	1.7689	32.9825	1.3944
	Calibrated	0.9845	0.2904	0.6597	6.3860	1.1155
	% variation	+11.67	-69.54	-62.71	-80.64	-20.00
Radiation-based equations						
BG	Original	0.7933	1.4986	2.4900	49.8256	1.4981
	Calibrated	0.9916	0.2174	0.2700	1.4838	0.9851
	% variation	+25.00	-85.49	-89.16	-97.02	-34.24
CAP	Original	0.8537	1.2013	2.4900	38.9032	1.3813
	Calibrated	0.9934	0.1961	0.3200	3.6077	0.9585
	% variation	+16.36	-83.67	-87.15	-90.73	-30.61
HAN	Original	0.9630	0.4279	1.0793	10.7459	1.1927
	Calibrated	0.9364	0.5161	0.6778	9.2928	0.9769
	% variation	-2.76	+20.60	-37.21	-13.52	-18.09
IRS	Original	0.9183	0.6489	1.1300	20.6820	1.3133
	Calibrated	0.9541	0.4364	0.7900	2.2749	1.1129
	% variation	+3.90	-32.76	-30.09	-89.00	-15.26
MB	Original	0.5705	2.8577	5.2300	91.2124	1.9176
	Calibrated	0.9381	0.6312	1.8400	9.7139	1.1004
	% variation	+64.43	-77.91	-64.82	-89.35	-42.62
MPT	Original	0.9858	0.2954	0.6000	7.1497	1.0714
	Calibrated	0.9916	0.2174	0.2800	1.4769	0.9851
	% variation	+0.58	-26.39	-53.33	-79.34	-8.05
SS	Original	0.9750	0.3596	0.1600	10.0965	0.9116
	Calibrated	0.9882	0.2510	0.2800	5.7554	0.9556
	% variation	+1.36	-30.20	+75.00	-43.00	+4.83
Valiantzas' equations						
V1	Original	0.9945	0.1784	0.3300	5.5437	1.0809
	Calibrated	0.9940	0.1787	0.1600	3.2886	0.9905
	% variation	-0.05	+0.17	-51.52	-40.68	-8.36

Cont...

Table 4. Comparative performance of original and calibrated ET_0 equations vs FAO56-PM model along with their ratio during validation period (2009-2019)

Equation(s)	Features	Statistical indices				R
		D	RMSE	MAXE	PE	
V2	Original	0.9753	0.3915	0.7200	13.1188	1.1694
	Calibrated	0.9904	0.2243	0.2400	3.3453	0.9992
	% variation	+1.55	-42.71	-66.67	-74.50	-14.55
V3	Original	0.9970	0.1350	0.3900	1.9668	1.0207
	Calibrated	0.9974	0.1241	0.2200	1.8982	0.9791
	% variation	+0.04	-8.07	-43.59	-3.49	-4.08
V4	Original	0.9028	0.8757	1.8714	27.7146	1.3206
	Calibrated	0.9834	0.3031	0.4628	2.313	1.0101
	% variation	+8.93	-65.39	-75.27	-91.65	-23.51
V5	Original	0.9071	0.8272	1.9754	27.167	1.3314
	Calibrated	0.9794	0.3259	0.4957	3.7026	1.0082
	% variation	+7.97	-60.60	-74.91	-86.37	-24.28
V6	Original	0.8886	0.8397	1.4283	28.5984	1.3921
	Calibrated	0.9489	0.4682	0.6379	5.6618	1.0212
	% variation	+6.79	-44.24	-55.34	-80.20	-26.64
V7	Original	0.9033	0.8285	1.5234	27.9789	1.3536
	Calibrated	0.9772	0.3358	0.4455	3.2325	1.0235
	% variation	+8.18	-59.47	-70.76	-88.45	-24.39

See Table 3 for details

Table 5. Normalized value of statistical indices and overall ranking of calibrated ET_0 equations

Equation(s)	Statistical indices				GPI	Rank
	D	RMSE	MAXE	PE		
Temperature-based equations						
ALN	0.9117	0.1629	0.1260	0.1813	-0.0063	12
BR	0.7411	0.3177	0.2479	0.2287	-0.1598	17
DA	0.8926	0.1955	0.1398	0.2152	-0.0675	16
HAR	0.8906	0.1963	0.1348	0.2098	-0.0559	15
HH	0.8294	0.2909	0.2533	0.3096	-0.3076	18
SAM	0.0000	1.0000	1.0000	0.6654	-1.2898	21
TRA	0.9150	0.1615	0.1318	0.1852	-0.0180	13
Radiation-based equations						
BG	0.9618	0.0906	0.0290	0.0003	0.2940	2
CAP	0.9736	0.0699	0.0422	0.0804	0.2094	6
HAN	0.5982	0.3807	0.1366	0.2949	-0.0347	14
IRS	0.7148	0.3033	0.1662	0.0301	0.1613	8
MB	0.6094	0.4924	0.4433	0.3108	-0.4802	19
MPT	0.9618	0.0906	0.0317	0.0000	0.2916	3
SS	0.9394	0.1232	0.0317	0.1614	0.1199	10
Valiantzas' equations						
V1	0.9776	0.0530	0.0000	0.0684	0.2766	4
V2	0.9539	0.0973	0.0211	0.0705	0.2328	5
V3	1.0000	0.0000	0.0158	0.0159	0.3439	1
V4	0.9078	0.1738	0.0799	0.0315	0.1826	7
V5	0.8814	0.1960	0.0886	0.0840	0.1257	9
V6	0.6805	0.3341	0.1261	0.1579	0.0770	11
V7	0.3801	0.6840	0.3597	1.0000	-1.0482	20

See Table 3 for details

1.2898 was adjudged worst among all considered ET_0 equations (Table 5).

CONCLUSIONS

The present study revealed that except radiation-based HAN equation, all other calibrated equations produced higher values of D while, values of RMSE with calibrated temperature-based, radiation-based, and Valiantzas' equations decreased considerably and these equations yielded lowered values of MAXE and PE as well. The best value of ratio (R) of $ET_{0method}$ to $ET_{0FAO56M}$ was obtained with temperature-based TRA, radiation-based BG & MPT and Valiantzas' V2 equations. The overall ranking revealed that among all considered ET_0 equations, Valiantzas' V3 equation performed best, followed by two radiation-based equations (BG and MPT) while, temperature-based SAM equation showed worst performance.

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Indian Journal of Ecology (2022) 49(2): 462-469
DOI: https://doi.org/10.55362/IJE/2022/3546

Manuscript Number: 3546
NAAS Rating: 5.79

Precipitation Concentration Index and Rainfall Trend Analysis for South Western Districts of Karnataka, India

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***Abstract*:** A statistical analysis of the annual and seasonal (monsoon) rainfall was carried out for different stations located in south western districts of Karnataka state (adjoining to Western Ghats). The statistical methods such precipitation concentration index analysis (PCI), trend analysis using Sen's slope and Man-Kendall were employed for the observed data between 1960-2018. The findings show that the Spatiotemporal distribution of rainfall in these districts has changed during the later part of the data period, i.e., 1990-2018. There is no discernible upward trend in the region's rainfall. The erratic and increasing pattern of rainfall it these district may lead to the flash floods and at times drought situations. The results may of use to the water resources manager and planner of the region to devise an appropriate contingent plan to minimise the loss and for effective management of water resources.

Keywords: Precipitation concentration index, Mann-Kendell, Dry and wet periods. Soil erosion

In India, the majority of rainfall features are evaluated during the monsoon season, and the climate changes significantly due to unstable monsoon and other meteorological conditions due to variable topography and huge geographic extent in the tropics. During the monsoon months of June to September, around 80% of the yearly rainfall falls (In some localities, spanning mid-May to mid-October). Some areas face catastrophic floods and droughts as a result of the rain's uneven distribution. Therefore, Rainfall intensity and duration are important factors in rainfall variability in the research area. Rainfall levels and seasonal distribution have changed during the last few decades, owing to urbanisation and industrial expansion, both of which have resulted in environmental changes. (Kripalani and Kulkarni2001) There are several studies on evaluation of PCI e.g. Luis et al. (2011) of Spain, Xuemei et al (2011) over Xinjiang, China, Adegun et al (2012), Iskander et al (2014) over Bangladesh, Benhamrouche et al (2015) in Algeria, Milan Gocic et al (2016) of Serbia, Al-Shamarti (2016) of Iraq, Over south-eastern Brazil, Nery et al (2017). In India, however, there are just a few research on PCI, most of which are on a regional size (Patel and Shete 2015).

Precipitation Concentration Index Mann-Kendell test are the major tools which is the indicator of Uniform or Non-Uniform rainfall patterns over the region. Precipitation is one of the most significant components of the hydrological cycle since it assesses dry and wet periods and predicts drought or no drought. Although total precipitation is commonly used as a measure of the amount of water available to ecosystems and water resource schemes, the timing of seasonal precipitation is critical for many environmental processes (Weltzin and McPherson 2000, Pryor and Schoof 2008.) In hydrological processes, the distribution of precipitation throughout the year controls interception, evapotranspiration, infiltration rates, and snow accumulation, and these factors have significant implications for stream discharge and flood forecasting (Beniston 2003, 2006). Changes in the distribution of water inputs may result in a mismatch between water availability and demand when it comes to water resource management. Some poorly impounded systems can be managed in highly regulated basins (Lo'pezMoreno et al 2004). Using a 58-year database of monthly precipitation, the current study looks for monthly, seasonal, and annual distributions, changes, and trends in 10 rain gauge sites in the Mysore and Coorg districts.

MATERIAL AND METHODS

The Mysore district is spatially positioned between the latitudes of 12° 18′ 26″ north and 76° 38′ 59″ east in India's South-Western section of Karnataka state. It is situated at a height of 740 metres (2,427 ft) with Seven Taluk's which borders are shared with Chamarajanagar District, with Annual Average Rainfall of 776.6mm and Coorg District with three Taluk's and it has an area of 4120SqKm (1584 Sq. Mi) and it is located in Eastern slopes of Western Ghat, Karnataka. It is a hilly region with the highest Mean Sea level of 900m (3000Sq.Ft). The Major River of Kodagu is Kaveri. The average Rainfall of Kodagu is 3210mm and the Average maximum temperature is 25.6^{0}c. A total of 58 Years of Data is used for this study. The data was gathered from the KSNMDC and the Karnataka Department of Economics and Statistics in Bengaluru. For the analysis, three statistical methods were used. Specifically, the Precipitation Concentration Index and the Mann-Kendell test were used to determine Rainfall Trend.

For the period 1960-2018, the average monthly rainfall of 10 Meteorological (Fig. 1) was used to determine the Spatial and Temporal Distribution over the study period using GIS Tool, mean annual rainfall data, annual rainfall, seasonal (monsoon) June-September considered for seasonal, standard deviation (), and coefficient of variation. The rainfall data was subjected to a linear regression test to see if there was any sort of trend or consistency.

Index (PCI): The precipitation concentration index was proposed by Michiels et al (1992), Annually and seasonally. Oliver (1980)

Proposed the precipitation concentration index (PCI), Uniform Precipitation distribution was denoted if the PCI Values are less than or equal to 10 and Moderate Precipitation Distribution is considered as if the values are

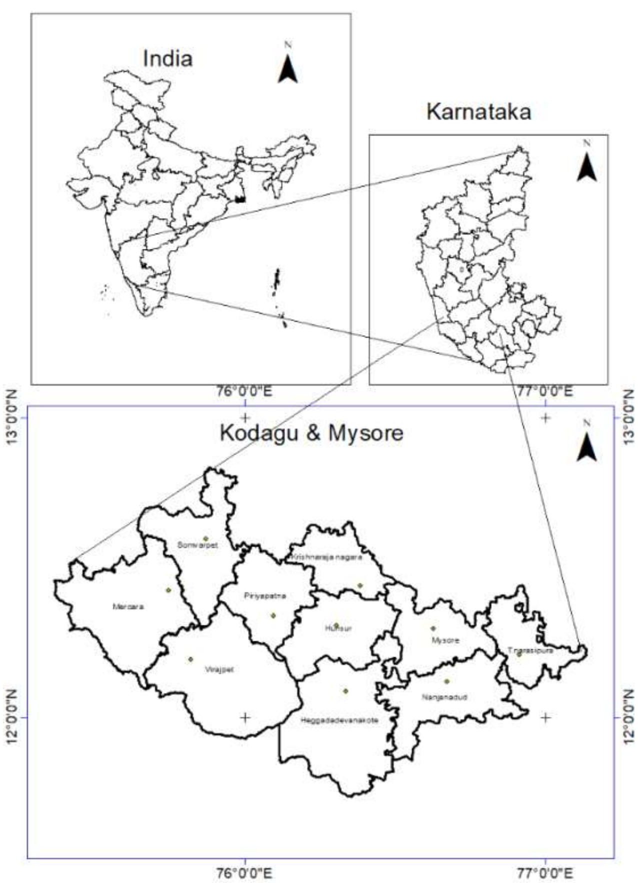


Fig. 1. The study area is depicted on a map

between 10 to 15, and irregular precipitation distribution is denoted as the PCI Values between 16 to 20 and strong Irregular precipitation distribution considered if the PCI Values are more than 20.Based on the equations of Oliver (1980), the PCI values were estimated on an annual basis using data from ten sites in the research area:

$$PCI_{annual} = \frac{\Sigma_{i=1}^{12} Pi^2}{(\Sigma_{i=1}^{12} Pi)^2} * 100 \; .....(eq.1)$$

where Pi is the total precipitation in a month I.

$$PCI_{Monsoon} = \frac{\Sigma_{i=1}^{4} Pi^2}{(\Sigma_{i=1}^{4} Pi)^2} * 33.33 \; .....(eq.2)$$

The monthly rainfall in month I is Pi. The number 100 in the formula for the annual PCI (Equation 1) represents the 12 months of the year, which equals 100%, and the numbers 33 percent in the formula for the seasonal PCI (Equation 2) represent the four monsoon months (June-September) in each season, which equals 33%.

Mann-Kendall Trend Test (MK): The study investigates Rainfall trend changes over the selected area by Mann-Kendall. Mann (1945), Kendall (1975), and Gilbert (1987) for identifying trends in the rainfall precipitation data. The MK test assesses “whether to reject the null hypothesis (H0)” or accept the alternative hypothesis (Ha), where H0 indicates no monotonic trend existed in the investigated time series, and Ha indicates the presence of monotonic trend in the investigated time series (Tatli 2015).

Where, $S = \Sigma_{i=1}^{n-1} \Sigma_{j=i+1}^{n} Sgn(x_j - x_i), ...(eq.3)$

$$Sgn(x_j - x_i) = \begin{cases} +1, & x_j > x_i \\ 0, & x_j = x_i \\ -1, & x_j < x_i \end{cases} ...(eq.4)$$

n = sample size; S = large positive value of S exhibits a strongly increasing trend, whereas the large negative value of S exhibits a strong decreasing trend. When the MK test is applied to a time series with many values, the Z test can be used to determine whether a trend is significant or not significant (Ahmad et al 2015).

$$Z = \begin{cases} \dfrac{s-1}{\dfrac{\sqrt{n(n-1)(2n+5) - \Sigma_{j=1}^{q} t_j (t_j - 1)(2t_j + 5)}}{18}} & \text{if S} > 0 \\ 0 & \text{if S} = 0 \\ \dfrac{s-1}{\dfrac{\sqrt{n(n-1)(2n+5) - \Sigma_{j=1}^{q} t_j (t_j - 1)(2t_j + 5)}}{18}} & \text{if S} < 0 \end{cases} \quad (eq..5)$$

n = sample size, q = number of zero difference groups in the data set, the p-value of 0.05 is used as the significance of a trend. Sen's Slope estimator of rainfall trend is a nonparametric technique applied to evaluate the trends in rainfall data. A positive and negative Sen Slope value indicates increasing and decreasing trends in the time series (Gocic and Trajkovic, 2013).

$$Q_i = \frac{x_j - x_k}{j - k} \; fori = 1,..., N ...(eq.6)$$

The converted yearly Precipitation Departure Z for Each Sub-station is used to calculate the number of wet and dry periods.

$$Z = \frac{X - \mu}{\sigma} ....(eq.7)$$

When x denotes annual precipitation, y denotes annual mean precipitation, and z denotes annual standard deviation. If z 0.5, there was a dry year, and if z 0.5, there was a wet year (Pnevmatikos and Katsoulis 2006).

RESULTS AND DISCUSSION

Descriptive statistics of rainfall data: Madikeri Taluk has the highest average rainfall and Somwarpete has the least in Kodagu District and Heggadadevanakotte recorded the highest T-Narsipura has got the least amount of average rainfall in Mysore District. The Skew values show the rainfall is positively Skewed distribution. The degree of Peakedness (kurtosis) of rainfall distribution indicates a peaked distribution (Nyatuame et al 2014).

Mann Kendall Test (MK): For rainfall series, a positive slope value indicates an upward or increasing trend. The slope with a negative value indicates a downward or decreasing trend in the time series. The positive and negative value implies increasing and declining rainfall trend. Most of the annual precipitation data show the Increasing trend and the Seasonal Precipitation Data also demonstrates an increasing trend. But when it comes to Sen's Slope station Madikeri, Virajapete and Somwarpete of Kodagu district and H.D.Kotte, Hunsur, Mysore Nanjangudu, T-Narsipura Periyapatna Stations of Mysore District exhibits the increasing trend in Sen's Slope for Annual Precipitation Data. The case of seasonal precipitation data which is done for June-Sept month shows the increasing trend for all the taluks, when it comes to Sen's slope Madikeri, Virajapete, Somwarpete of Kodagu, and Krishnarajapuram and Mysore shows the negative trend.

The highest Annual Rainfall was in Madikeri Taluk in the year 1960 and lowest in 2016 and in Somwarpete Taluk highest rainfall was in 2018 and the lowest was in 1987. For the Taluk Virajpete highest rainfall was in the Year 1961 and the lowest was in the year 2016 (Fig. 7).

Annual precipitation concentration index (PCI): Annual precipitation concentration index analysis is performed to calculate the rainfall distribution throughout28-years period for the first half (1961-1989) and the second half of 28 years (1990-2018) values more than 16 in most parts of the Study area especially in the Mysore Region (Nanjangudu, T-Narsipura, Mysore, H.D. Kotte, Hunsur, K.R. Nagara, Periyapatna). This region has got most irregular precipitation concentration and in Kodagu district, almost all the taluks have got strong irregular precipitation (Fig. 3) and for the second half the annual precipitation concentration index spatial patterns differ slightly Heggadadevankotte, Nanjangudu and few Regions of Hunsur got moderate precipitation concentration, whereas, the other than this region has got Irregular and Strong Irregular precipitation Distribution throughout the Study Area. In general, significant changes can be seen in most recent years, the moderate precipitation concentration is detected in the Mysore district and The Kodagu district has had more erratic precipitation distribution.

The seasonal precipitation concentration index: The precipitation concentration index, calculated on a seasonal

Table 2. Statistical tools of rainfall data at the selected stations

Station name	Mean	Std deviation	Skew	Kurtosis	CV
Madikeri	3212.922	707.1795	0.771963	2.045119	0.220105
Virajpete	2446.325	627.1679	1.506094	5.09944	0.256371
Somwarpete	2135.041	533.5571	0.418149	-0.4217	0.249905
H.D. Kotte	837.6356	196.8532	0.08414	-0.85792	0.235011
Hunsur	784.7842	221.6671	0.165828	1.524596	0.282456
Periyapatna	822.4305	203.1267	-0.52754	0.89604	0.246983
Krishnarajanagara	750.2932	240.8797	0.340604	0.530258	0.321047
Mysore	773.3932	220.0671	0.436964	-0.00937	0.284547
Nanjangudu	727.878	201.1097	0.222636	0.04219	0.276296
T-Narsipura	713.8008	187.7974	0.494726	0.358	0.263095

scale (Monsoon Season) from June to September, demonstrates the intricate spatial patterns of precipitation in Karnataka's southern areas. The PCI lower was10.59 and higher 12.28 (1961-1989) and lower value of PCI was10.01 to 11.52 (1990-2018). During the Monsoon (June-September), very few PCI Values is detected for the period (1961-1989) uniform precipitation concentration is detected in Madikeri and some regions of Virajapete (Fig. 3). The precipitation concentration index shows the uniform

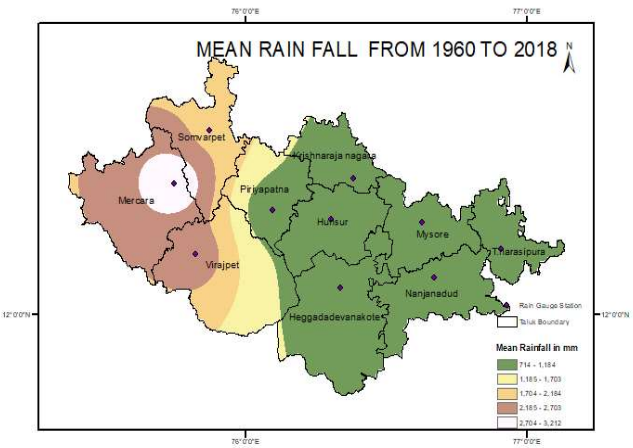


Fig. 2. District having highest average mean and lowest average mean rainfall

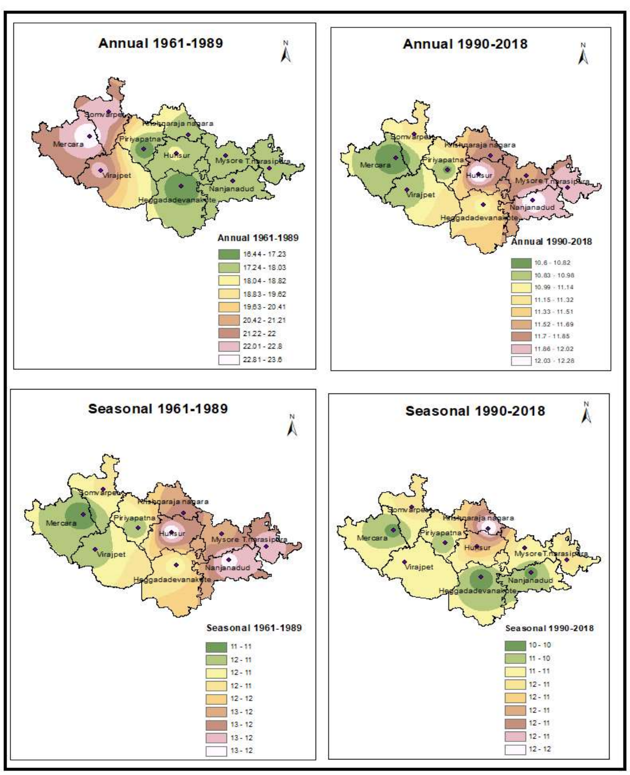


Fig. 3. Precipitation variation of annual 1961-1989 and 1990-2018 and seasonal precipitation variation June-September period (Monsoon month)

precipitation distribution and moderate precipitation distribution has been detected in most recent years. In this season the whole study shows only uniform and moderate precipitation distribution. Especially between 1961 and 1989 shows the Uniform precipitation (Low Precipitation) and in the Period 1990-2018, the Precipitation distribution is almost Moderate. Changes in the distribution of Precipitation is analysedas significant (Monsoon Season) and have uniform precipitation distribution over the study area.**T-Test significance:** The T-test has been conducted for the annual and seasonal (June-Sept) to detect the significance level. The T-Test has been carried out for a period total of 57 years. Statistically,a significant difference has been detected for 57 years period. The probability is categorised as follows exceptional likely (p<0.01); extremely likely (p<0.05); very likely (0.10); very low probability (p>0.10) (Fig. 4).**Dry and wet regions:** The dry and wet regions were decided on Z-Values, the total period of 58 years has divided into almost six decade. In the first decade (1960-1970) the very slight negative trend detected with half of the study area was dry

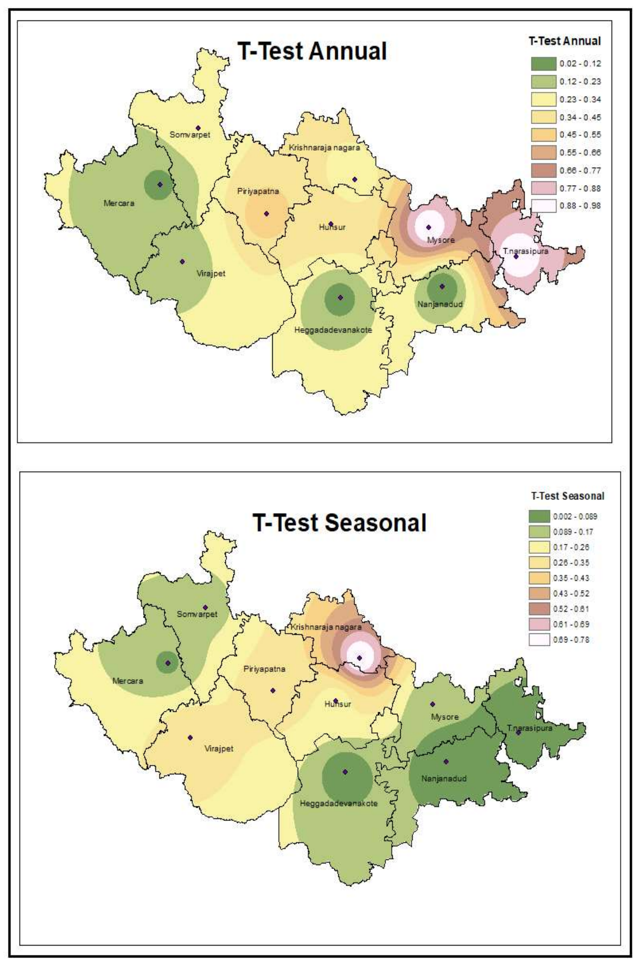


Fig. 4. T-Test significance level for annual and seasonal periods

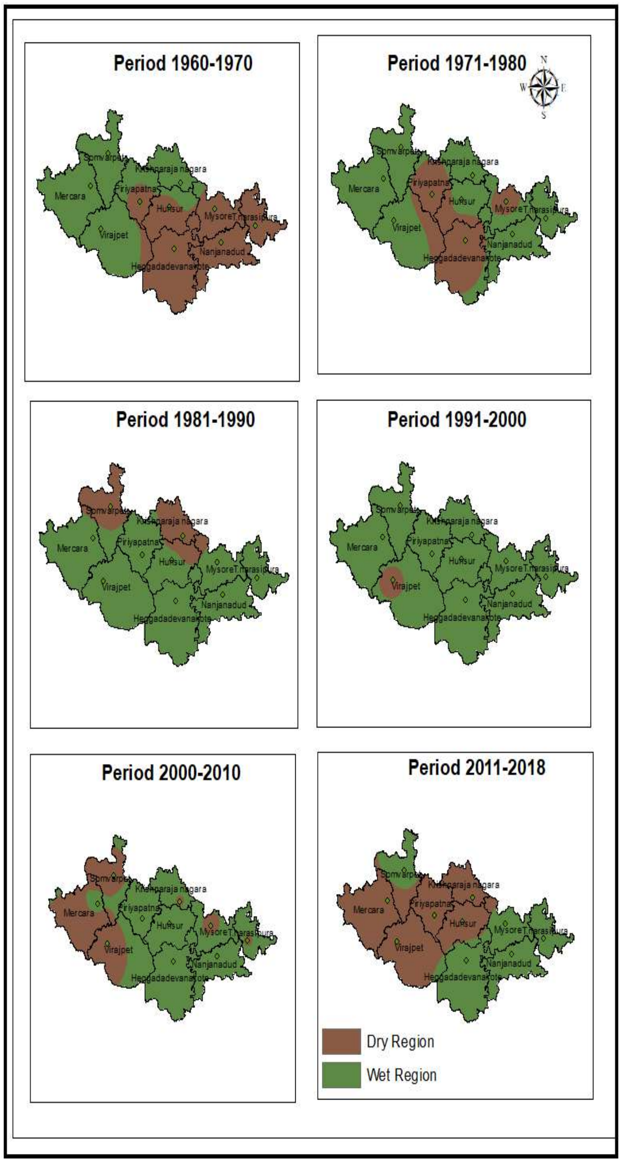
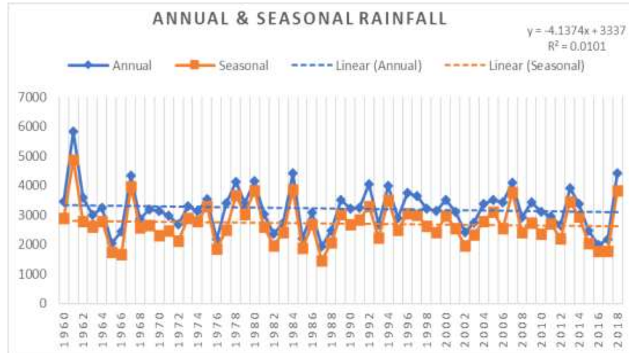
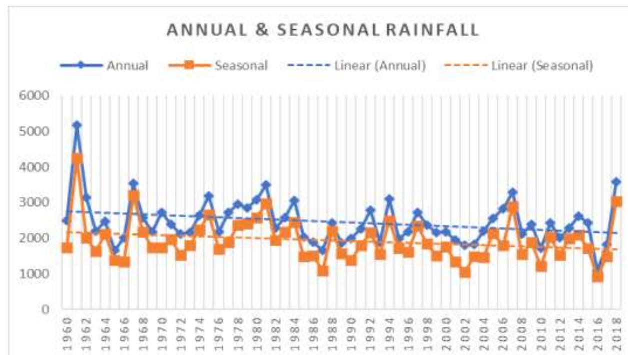


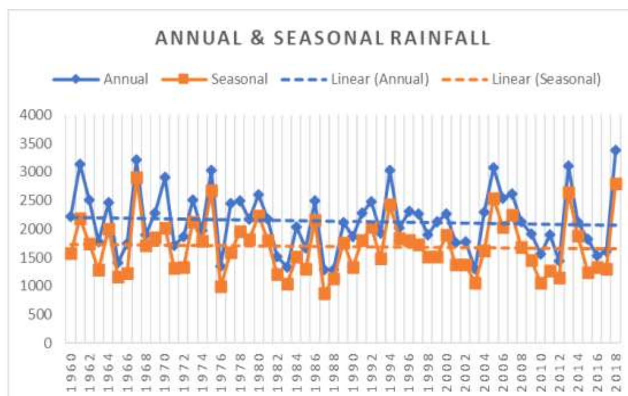
Fig. 5. Variation of rainfall departure (Z-values) dry and wet region over ten years of difference



a. Madikere Taluk



b. Somarwarpete Taluk

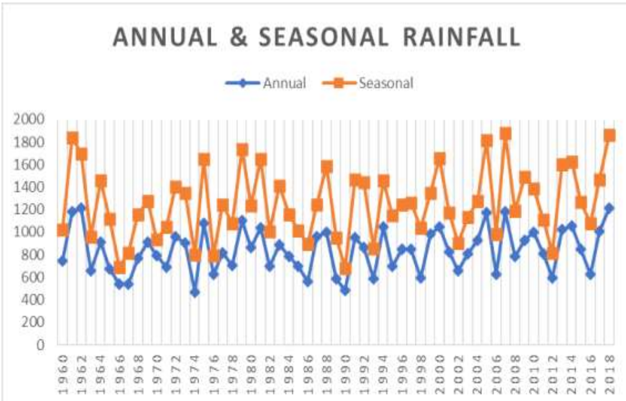


c. Virajapete Taluk

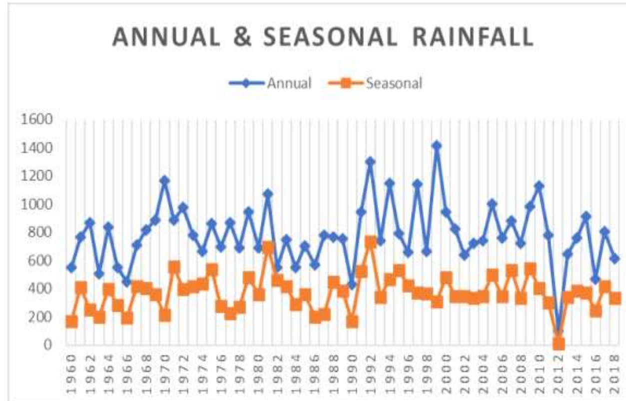
Fig. 6. Annual & seasonal rainfall during 1960-2018

Table 3. Trend analysis of annual and seasonal precipitation

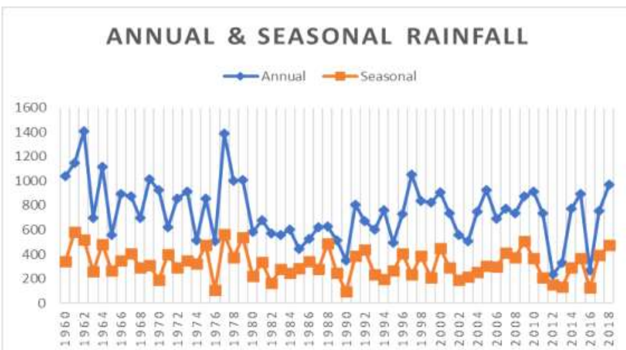
Station	Annual		Seasonal (Monsoon)	
	P value	Sen Slope	P value	Sen Slope
Madikeri	0.676	-1.687	0.008	-0.082
Virajpete	0.069	-7.511	0.132	-28.636
Somwarpete	0.185	-3.852	0.565	-7.433
H.D. Kotte	0.193	2.255	0.338	1.818
Hunsur	0.685	0.646	0.494	3.36
Periyapatna	0.559	0.921	0.460	2.708
Krishnarajanagara	0.089	-3.389	0.059	-5.1
Mysore	0.704	0.606	0.848	-0.504
Nanjangudu	0.031	3.837	0.180	4.715
T-Narsipura	0.468	1.305	0.305	1.153



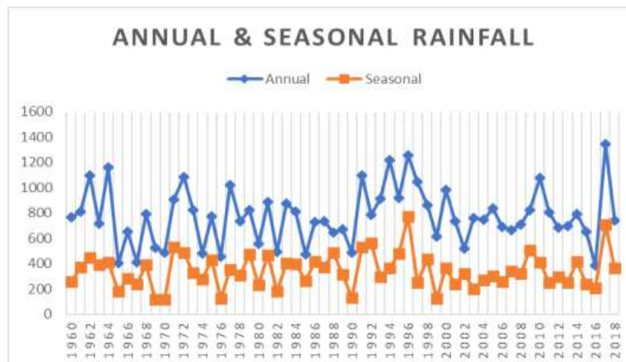
a. Hegaddadevakote



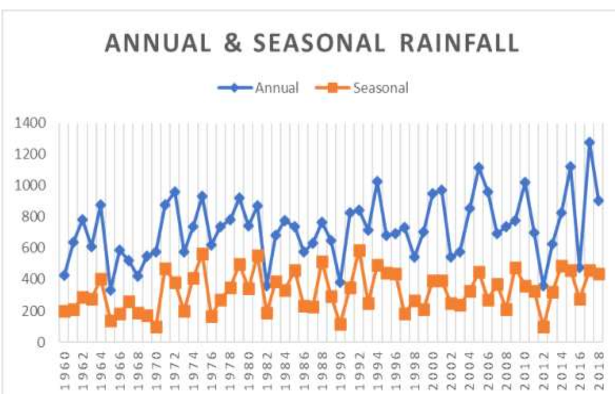
b. Hunsur



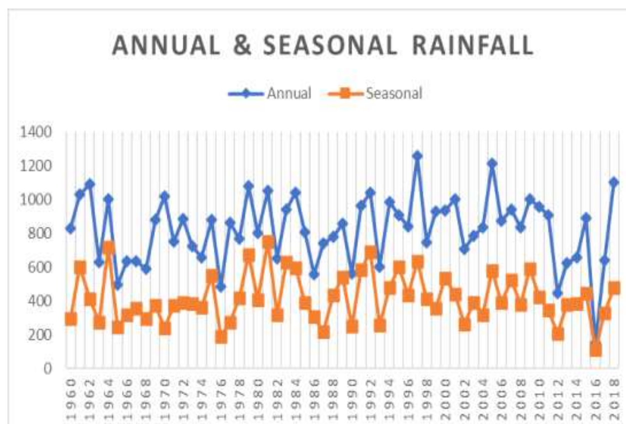
c. Krishnarajanagara



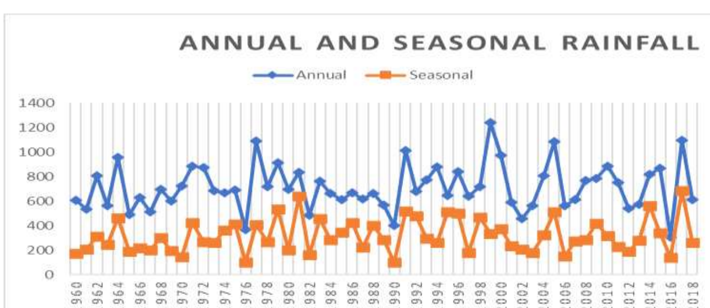
d. Mysore



e. Nanjangudu



f. Periyapatna



g. T-Narsipura.

Fig. 7. Annual & seasonal rainfall throughout 1960-2018

and another was wet. (Fig. 5, 8).The variation of rainfall in the period (1971-1980) was mostly the wet Periods (Fig. 8b). The period (1981-1990) was detected with all the taluk were dry and drought-prone area for this couple of years (Fig. 9) and next decade period of (1991-2000) were detected with full wet regions considering most Wet spell has taken place and the trend was be positive (Fig. 9b). In the period (2001-2010) detected to be almost all wet spell with some regions showed up with dry region also so the trend was decreasing when compared to last decade (Fig. 10a) and Last 8 years spell (2011-2018) were detected with decreasing trend of Rainfall variation (Fig. 10b).

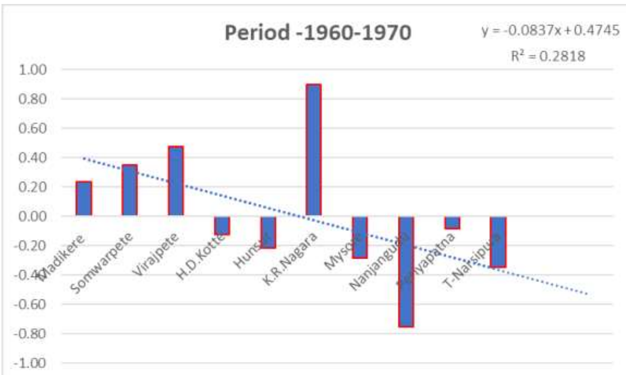


Fig. 8a. Dry and wet regions in period (1960-1970)

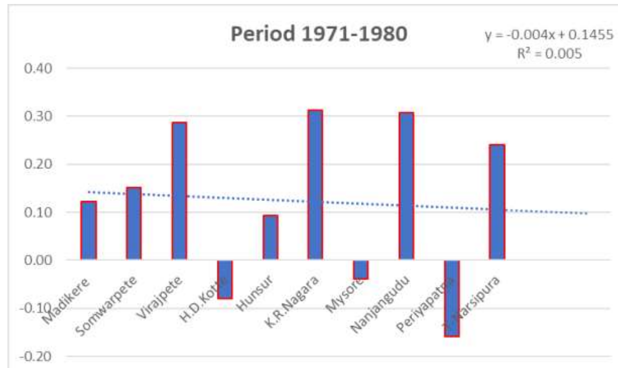


Fig. 8b. Dry and wet regions in period (1971-1980)

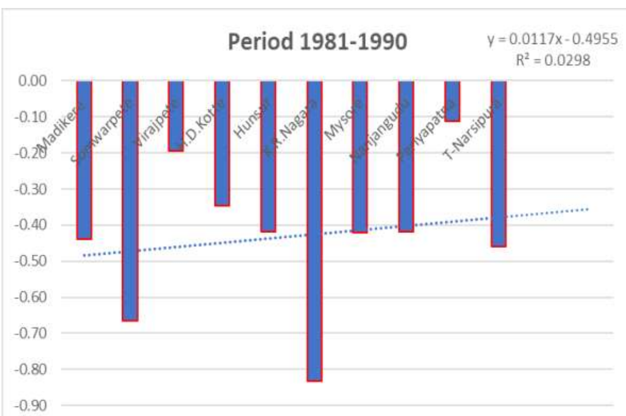


Fig. 9a. Dry and wet regions in period (1981-1990)

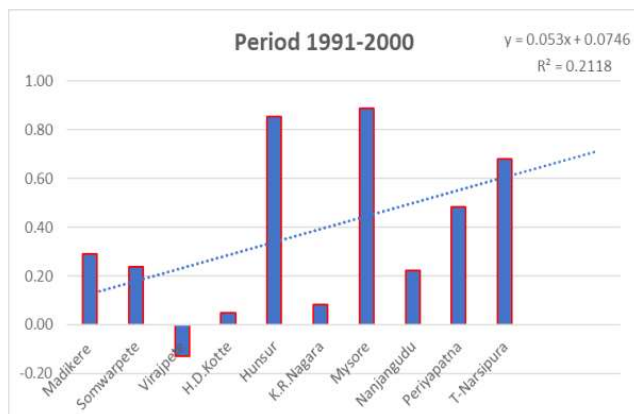


Fig. 9b. Dry and wet regions in period (1991-2000)

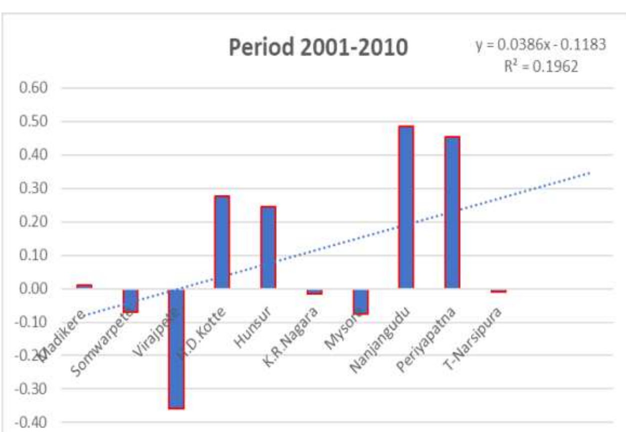


Fig. 10a. Dry and wet regions in period (2001-2010)

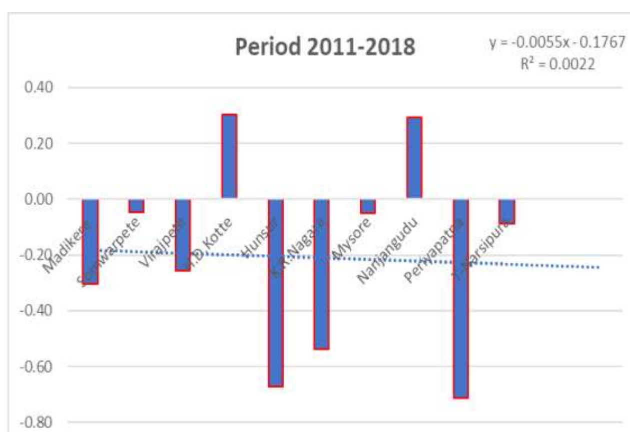


Fig. 10b. Dry and wet regions in period (2011-2018)

CONCLUSION

The study has used Precipitation Concentration Index and Non-Parametric Man-Kendell Trend analysis for Annual and Seasonal Periods of study Area from 1960 through 2018 total of 58 Years. The study was carried out for 10 Taluk's of Kodagu and Mysore District to detect the trends in Annual and Seasonal Precipitation Data.

Based on the discussion above, it may be concluded that

- The annual rainfall values seems to be increasing in part of study area adjoining to the Western Ghats and their magnitude is not significant.
- The seasonal precipitation Concentration Index (PCI) analysis for the period 1990-2018 indicate the rainfall pattern is lineating towards moderate non-uniform distribution.

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Received 22 October, 2021; Accepted 21 January, 2022

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Indian Journal of Ecology (2022) 49(2): 470-476
DOI: https://doi.org/10.55362/IJE/2022/3547

Manuscript Number: 3547
NAAS Rating: 5.79

Evaluation of Drought Tolerance Indices for Selection of High Yielding Fenugreek Genotypes under Moisture Regimes

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Abstract: Drought is the most severe production constraint for fenugreek worldwide. Identification and screening of drought tolerant genotype is necessary for mitigation the problem. This study aimed to find out the repeatability of drought tolerance indices for selection of high yielding fenugreek genotypes. Thirty genotypes of fenugreek were sown in RBD with three replications under two moisture regimes for two year during *Rabi* season. Rank correlation between seed yield and drought tolerant indices was highly correlated. PCA indicated that first and second PCA accounted for 97.10 and 93.70% of variations for proline content and seed yield. Consequently, GGE biplot showed that the genotypes RMt-305, GM-1, RMt-303, RMt-143, RMt-351 and GM-2 were ideal for un-predictable environments.

Keywords: Environment, Fenugreek, Moisture regimes, PCA

Fenugreek (*Trigonella foenum-graecum* L.) is a self pollinated crop which is used as leafy as well as seed spice purposes. The seeds and leaves are aromatic, carminative, tonic and anti-inflammatory in nature (Rathore et al 2013) and also possess numerous health properties. Drought is an emerging and serious concern globally. Thus, there is need of efficient use of water by the development of resilience crop cultivars which really sustain under moisture regimes. In India, Rajasthan is a dry state where annual average rainfall is around 550mm and often faces stress like situation. In the absence of an understanding of the special mechanisms of tolerance the quantification of drought tolerance should be based on the yield under moisture regimes. Several selection criteria have been proposed to select cultivar based on their performance in moisture regimes. Thus, drought tolerances indices which provide a measure of drought based on yield loss under drought conditions in comparison to normal conditions. However, the optimal selection criterion should distinguish genotypes that express uniform superiority in moisture regimes. Therefore, the present study aimed to identify drought tolerance cultivar of fenugreek.

MATERIAL AND METHODS

Thirty genotype of fenugreek were sown in a RBD with three replications in two moisture regimes, namely, (1) no water stress (E_1) and (2) water stress (E_2) for two cropping years (2018–2020) in the experimental field of the College of Horticulture and Forestry, Jhalawar during *Rabi* season (Table 1). Each genotype was sown in a double row plot of 4m length with row to row and plant to plant distance at 30 cm and 10 cm, respectively. Each year all recommended agronomic practices were adopted uniformly in order to ensure a healthy crop stand except irrigation in water stress condition (E_2). Irrigation was given at the time of seed sowing for establishing the crop in both the conditions every year. No water stress (E_1) condition was created by providing required irrigations sowing to maturity of the crop as per recommendation and water stress (E_2) condition was created by withholding irrigation at the time of pre flowering stage which commensurate with 40-45 days after sowing (DAS) and post flowering stage which commensurate with 70-80 days after sowing (DAS). Mean weekly meteorological data for the period of experiment are presented in Figure 1. Every year observation were recorded on five randomly selected plants in each genotype, each replication and each environment after eliminating border and unhealthy plants for proline content in leaves at maturity (mg/g) and seed yield per plant (g). Eighteen drought tolerance indices(DSI) were calculated based on pooled mean data of experiment for seed yield per plant under no water stress (Yp) and water stress (Ys) conditions and $\bar{Y}p$ and $\bar{Y}s$ are mean seed yield per plant (g) in Yp and Ys, respectively (for all genotypes).

1. Mean relative performance (MRP) = $(Ys / \bar{Y}s) + (Yp / \bar{Y}p)$ (Hossain et al 1999).
2. Stress susceptibility index (SSI) = $[1 - (Ys / Yp)] / [1 - (\bar{Y}s / \bar{Y}p)]$ (Clarke et al 1992).
3. Stress tolerance index (TOL) = Yp -Ys (Rosielle and Hamblin 1981).
4. Geometric mean productivity (GMP) = $\sqrt{Yp \times Ys}$ (Ramirez and Kelly 1998).

5. Harmonic mean (HM) = 2 × (Yp×Ys)/(Yp+Ys) (Dadbakhsh et al 2011).
6. Relative efficiency index (REI) = (Ys / $\bar{Y}$s) × (Yp / $\bar{Y}$p) (Hossain et al 1999).
7. Modified stress tolerance index (K1STI) = ($Y^{p2}/\bar{Y}^{p2}$) × [(Yp+Ys)/$\bar{Y}^{p2}$)] (Farshadfar and Sutka 2002).
8. Modified stress tolerance index (K2STI) = ($Ys^2/\bar{Y}s^2$) × [(Yp+Ys)/$\bar{Y}p^2$)] (Farshadfar and Sutka 2002).
9. Yield index (YI) = (Ys) / ($\bar{Y}$s) (Gavuzzi et al 1997).
10. Sensitivity drought index (SDI) = (Yp -Ys)/ Yp (Farshadfar and Javadinia 2011).
11. Relative drought index (RDI) = (Ys/Yp)/ ($\bar{Y}$s / $\bar{Y}$p) (Fisher and Wood 1979).
12. Drought resistance index (DI) = [Ys × (Ys /Yp)] / $\bar{Y}$s (Lan 1988).
13. Golden mean (GM) = (Yp + Ys) / (Yp - Ys) (Moradi et al 2012).
14. Abiotic tolerance index (ATI) = [(Yp–Ys)/ ($\bar{Y}$p / $\bar{Y}$s)] × [√Yp×Ys] (Moosavi et al 2008).
15. Stress susceptibility percentage index (SSPI) = [Yp– Ys / 2($\bar{Y}$p)] ×100 (Moosavi et al 2008).
16. Stress non-stress production index (SNPI) = 3√(Yp+Ys)/(Yp–Ys) × 3√Yp×Ys×Ys (Moosavi et al 2008).
17. Relative decrease in yield (RDY) = 100 – ((Ys / 100) ×Yp) (Farshadfar and Elyasi 2012).
18. Drought tolerance efficiency (DTE) = (Ys/ Yp) ×100 (Fischer and Wood 1981).

Statistical analysis: The spearman's rank correlation coefficients were calculated among indices, seed yield and proline content under moisture regimes using SPSS 2011. Finally, to identify ideal genotype, principal component analysis (PCA) and GGE biplot were performed for proline content and seed yield using PB Tools, IRRI (Yan et al 2000).

RESULTS AND DISCUSSION

Seed yield and proline content: The pooled mean data of seed yield of genotype under E_2 revealed a greater variation than E_1. Seed yield ranged from 6.61g (Nagour local-2) to 13.33g (RMt-143) and 9.46g (GM-2) to 17.60g (RMt-143) with mean values of 8.72 and 13.87 under E_2 and E_1, respectively (Table 2).The highest ranks were assigned in ascending order for RMt-143, RMt-305, RMt-303, GM-1 and RMt-351 and lowest ranks in descending order Nagour local-2, MP local-1, Jhalawar local and Karnataka local under E_2 and RMt-143, RMt-303, Rajendra Kranti, AFG-3 and GM-1 were assigned highest ranks in ascending order and lower ranks in descending order GM-2, Jaipur local, Nagour local and Sikar local under E_1. Mean seed yield of genotypes reduced by 73.68 percent under E_2 and similar result was confirmed by Choudhary et al (2017). Proline content in E_2 and E_1 ranged from 182.47 (AGF-2) to 364.54(GM-1) and

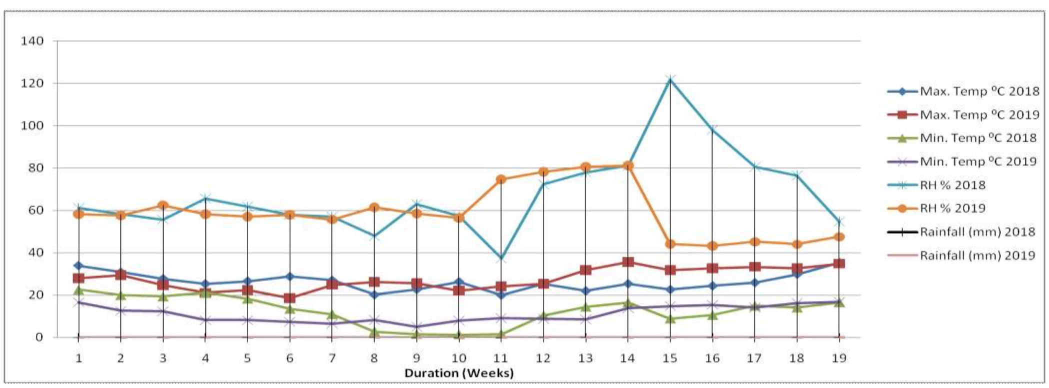

Fig. 1. Mean weekly meteorological data for the period of experiment

Table 1. Fenugreek genotype used under study

Notation	Genotype	Notation	Genotype	Notation	Genotype	Notation	Genotype	Notation	Genotype	Notation	Genotype
G1	RMt-305	G6	Karnataka local	G11	RMt-143	G16	Jhunjhunu local	G21	Hisar Sonali	G26	AFG-2
G2	GM-1	G7	Chittorgarh local	G12	Rajendra Kranti	G17	Azad Methi	G22	RMt-351	G27	Lam selection
G3	MP local-1	G8	Jhalawar local	G13	Hisar Suvarna	G18	Nagour local-1	G23	GM-2	G28	Sikar local
G4	MP local-2	G9	Nagour local-2	G14	AFG-1	G19	Hisar Mukta	G24	AFG-3	G29	AFG-4
G5	Jaipur local	G10	RMt-303	G15	Pant Ragini	G20	CO-2	G25	RMt-1	G30	Hisar Madhavi

150.94 (Lam selection) to 306.95(GM-1) (Table 2). The higher ranks were assigned for proline content in ascending order in GM-1, RMt-305, RMt-143, GM-2 and RMt-303 and lower ranks in descending order in AFG-2, Karnataka local, Lam selection and Azad methi under E_2. The highest rank were assigned in ascending order of GM-1, RMt-305, Rmt-143, GM-2 and AFG-3 and lowest ranks were assigned in descending order of Lam selection, AFG-2, Azad methi and Karnataka local under E_1, respectively. Proline content of genotypes was increase to 20.80% under water stress conditions and similar result was reported by Meena et al (2016).

Ranking of genotypes in response to drought tolerance indices: The significant differences were found in ranking of genotypes in each drought tolerance index (Table 3 and 4), indicating that the drought tolerance of genotypes is influenced by the moisture regimes. The higher ranks of MRP, GMP, HM, REI, MSTIK1, MSTIK2, YI, RDI, DI, GM,

Table 2. Pooled mean data of seed yield and proline content of the genotypes under moisture regimes

Genotype	Seed yield per plant						Proline content in leaves at maturity					
	Yp	Rank	Ys	Rank	Reduction (%)	Rank	PCMI	Rank	PCMS	Rank	Increase (%)	Rank
RMt-305	15.59	6	12.65	2	23.24	1	227.04	2	306.69	2	35.08	4
GM-1	15.62	5	12.13	4	28.81	3	306.95	1	364.54	1	18.76	17
MP local-1	13.65	16	6.7	29	103.71	29	184.31	16	209.11	21	13.46	28
MP local-2	13.4	17	7.49	23	79	24	183.29	18	209	23	14.03	27
Jaipur local	11.85	29	7.36	25	60.93	18	191.45	9	220.54	15	15.19	24
Karnataka local	14.5	11	7.21	27	101.06	28	159.28	27	183.06	29	14.93	26
Chittorgarh local	13.1	19	7.94	16	65.05	20	187.79	14	227.98	10	21.40	11
Jhalawar local	13.08	20	7.04	28	85.75	26	181.28	19	209.06	22	15.32	23
Nagour local-2	12	28	6.61	30	81.61	25	168.63	26	209.79	20	24.41	7
RMt-303	16.45	2	12.23	3	34.46	5	189.37	10	262.12	5	38.42	2
RMt-143	17.6	1	13.33	1	32	4	204.67	3	296	3	44.62	1
Rajendra Kranti	16.25	3	7.95	15	104.4	30	188.64	12	221.36	13	17.35	21
Hisar Suvarna	13.66	15	7.88	17	73.3	23	176.94	23	213.78	19	20.82	12
AFG-1	15.08	10	9.42	8	60.12	16	193.34	7	240.36	7	24.32	8
Pant Ragini	15.21	9	7.79	18	95.27	27	172.07	25	199.61	24	16.01	22
Jhunjhunu local	12.37	24	7.73	19	60	15	188.25	13	222.3	12	18.09	19
Azad Methi	12.64	22	7.43	24	70.04	22	158.36	28	188.44	27	18.99	16
Nagour local-1	12.23	25	7.22	26	69.53	21	180.65	20	196.48	26	8.76	30
Hisar Mukta	15.47	8	9.74	7	58.86	14	180.65	20	215.8	18	19.46	14
CO-2	14.45	12	9.27	9	55.88	12	183.4	17	224.5	11	22.41	10
Hisar Sonali	12.61	23	8.31	14	51.71	7	176.69	24	221.11	14	25.14	6
RMt-351	15.59	6	10.51	5	48.34	6	195.16	6	250.5	6	28.36	5
GM-2	9.46	30	7.64	21	23.9	2	203.26	4	279.8	4	37.66	3
AFG-3	15.71	4	10.08	6	55.77	11	200.36	5	238.73	8	19.15	15
RMt-1	12.83	21	8.33	13	54.15	8	179.83	22	198.24	25	10.24	29
AFG-2	12.09	26	7.73	19	56.41	13	154.81	29	182.47	30	17.87	20
Lam Selection	13.22	18	8.54	12	54.79	9	150.94	30	186.15	28	23.33	9
Sikar local	12.09	26	7.53	22	60.46	17	185.03	15	219.68	16	18.73	18
AFG-4	14.32	13	9.2	10	55.62	10	192.48	8	230.83	9	19.92	13
Hisar Madhavi	14.09	14	8.67	11	62.65	19	189.34	11	218.03	17	15.15	25
Mean	13.87		8.72		62.23		187.81		228.20		21.25	
Minimum	9.46		6.61		23.24		150.94		182.47		8.76	
Maximum	17.60		13.33		104.40		306.95		364.54		44.62	

Table 3. Drought tolerance indices of fenugreek genotype

Genotype	Drought tolerance indices																	
	MRP	SSI	TOL	GMP	HM	REI	MSTIK1	MSTIK2	YI	SDI	RDI	DI	GM	ATI	SSPI	SNPI	RDY	DTE
RMt-305	2.6	0.5	2.9	14.0	14.0	1.6	1.3	2.2	1.5	0.2	1.3	1.2	9.6	26.0	10.6	28.8	98.0	81.1
GM-1	2.5	0.6	3.5	13.8	13.7	1.6	1.2	1.9	1.4	0.2	1.2	1.1	7.9	30.2	12.6	26.3	98.1	77.6
MP local-1	1.8	1.4	7.0	9.6	9.0	0.8	0.5	0.3	0.8	0.5	0.8	0.4	2.9	41.8	25.0	12.2	99.1	49.1
MP local-2	1.8	1.2	5.9	10.0	9.6	0.8	0.5	0.4	0.9	0.4	0.9	0.5	3.5	37.2	21.3	13.8	99.0	55.9
Jaipur local	1.7	1.0	4.5	9.3	9.1	0.7	0.3	0.3	0.8	0.4	1.0	0.5	4.3	26.3	16.2	14.0	99.1	62.1
Karnataka local	1.9	1.4	7.3	10.2	9.6	0.9	0.6	0.4	0.8	0.5	0.8	0.4	3.0	46.9	26.3	13.1	99.0	49.7
Chittorgarh local	1.9	1.1	5.2	10.2	9.9	0.9	0.5	0.4	0.9	0.4	1.0	0.6	4.1	33.1	18.6	15.0	99.0	60.6
Jhalawar local	1.8	1.2	6.0	9.6	9.2	0.8	0.4	0.3	0.8	0.5	0.9	0.4	3.3	36.4	21.8	12.9	99.1	53.8
Nagour local-2	1.6	1.2	5.4	8.9	8.5	0.7	0.3	0.2	0.8	0.4	0.9	0.4	3.5	30.2	19.4	12.2	99.2	55.1
RMt-303	2.6	0.7	4.2	14.2	14.0	1.7	1.5	2.1	1.4	0.3	1.2	1.0	6.8	37.6	15.2	25.6	98.0	74.4
RMt-143	2.8	0.7	4.3	15.3	15.2	1.9	2.0	2.8	1.5	0.2	1.2	1.2	7.3	41.1	15.4	28.3	97.7	75.8
Rajendra Kranti	2.1	1.4	8.3	11.4	10.7	1.1	0.9	0.6	0.9	0.5	0.8	0.4	2.9	59.3	29.9	14.4	98.7	48.9
Hisar Suvarna	1.9	1.1	5.8	10.4	10.0	0.9	0.5	0.5	0.9	0.4	0.9	0.5	3.7	37.7	20.8	14.7	98.9	57.7
AFG-1	2.2	1.0	5.7	11.9	11.6	1.2	0.9	0.9	1.1	0.4	1.0	0.7	4.3	42.4	20.4	18.0	98.6	62.5
Pant Ragini	2.0	1.3	7.4	10.9	10.3	1.0	0.7	0.5	0.9	0.5	0.8	0.5	3.1	50.8	26.7	14.2	98.8	51.2
Jhunjhunu local	1.8	1.0	4.6	9.8	9.5	0.8	0.4	0.4	0.9	0.4	1.0	0.6	4.3	28.5	16.7	14.7	99.0	62.5
Azad Methi	1.8	1.1	5.2	9.7	9.4	0.8	0.4	0.4	0.9	0.4	0.9	0.5	3.9	31.7	18.8	13.9	99.1	58.8
Nagour local-1	1.7	1.1	5.0	9.4	9.1	0.7	0.4	0.3	0.8	0.4	0.9	0.5	3.9	29.6	18.1	13.5	99.1	59.0
Hisar Mukta	2.2	1.0	5.7	12.3	11.9	1.2	1.0	1.0	1.1	0.4	1.0	0.7	4.4	44.2	20.7	18.6	98.5	62.9
CO-2	2.1	1.0	5.2	11.6	11.3	1.1	0.8	0.8	1.1	0.4	1.0	0.7	4.6	37.7	18.7	17.8	98.7	64.2
Hisar Sonali	1.9	0.9	4.3	10.2	10.0	0.9	0.4	0.5	1.0	0.3	1.0	0.6	4.9	27.7	15.5	16.2	99.0	65.9
RMt-351	2.3	0.9	5.1	12.8	12.6	1.4	1.1	1.2	1.2	0.3	1.1	0.8	5.1	40.9	18.3	20.7	98.4	67.4
GM-2	1.6	0.5	1.8	8.5	8.5	0.6	0.2	0.3	0.9	0.2	1.3	0.7	9.4	9.8	6.6	17.3	99.3	80.7
AFG-3	2.3	1.0	5.6	12.6	12.3	1.3	1.1	1.1	1.2	0.4	1.0	0.7	4.6	44.5	20.3	19.4	98.4	64.2
RMt-1	1.9	0.9	4.5	10.3	10.1	0.9	0.5	0.5	1.0	0.4	1.0	0.6	4.7	29.3	16.2	16.1	98.9	64.9
AFG-2	1.8	1.0	4.4	9.7	9.4	0.8	0.4	0.4	0.9	0.4	1.0	0.6	4.5	26.5	15.7	14.9	99.1	63.9
Lam selection	1.9	1.0	4.7	10.6	10.4	0.9	0.5	0.6	1.0	0.4	1.0	0.6	4.7	31.2	16.9	16.5	98.9	64.6
Sikar local	1.7	1.0	4.6	9.5	9.3	0.8	0.4	0.4	0.9	0.4	1.0	0.5	4.3	27.3	16.4	14.3	99.1	62.3
AFG-4	2.1	1.0	5.1	11.5	11.2	1.1	0.7	0.8	1.1	0.4	1.0	0.7	4.6	36.9	18.4	17.7	98.7	64.3
Hisar Madhavi	2.0	1.0	5.4	11.1	10.7	1.0	0.7	0.6	1.0	0.4	1.0	0.6	4.2	37.7	19.6	16.4	98.8	61.5

DTE and SNPI in descending order of RMt-143, RMt-303, RMt-305, GM-1 and RMt-351 and lowest ranks observed in Nagour local-2, MP local-1, Jhalawar local and Karnataka local. According to SSI and TOL index, the greater value of SSI and TOL, means the higher yield reduction under E_2. The lowest rank of SSI, TOL, SDI, ATI, SSPI and RDY in RMt-305, GM-2, GM-1, RMt-143 and RMt-303 and highest ranks observed in Rajendra Kranti, MP local-1, Karnataka local and Pant Ragni. The genotypes RMt-305, GM-1, RMt-143, RMt-303 and RMt-351 determined lower and genotypes Nagour local-2, MP local-1, Jhalawar local, Karnataka local and Nagour local-1 were observed higher total ranks (Table 4). The results showed a great deal of inconsistency in ranking of genotypes as tolerant based on each one of the indices. The similar findings were reported by Pour-Siahbidi and Pour-Aboughadareh (2014) in chickpea, Sahar et al (2016) in bread wheat and Choudhary et al (2017) in fenugreek.

Drought tolerance indices: Spearman's rank correlation

Table 4. Rank of drought tolerance indices of fenugreek genotype

Genotype	Drought tolerance indices																		
	MRP	SSI	TOL	GMP	HM	REI	MSTIK1	MSTIK2	YI	SDI	RDI	DI	GM	ATI	SSPI	SNPI	RDY	DTE	Total
RMt-305	3	1	2	3	3	3	3	2	2	1	1	1	1	2	2	1	3	1	35
GM-1	4	3	3	4	4	4	4	4	4	3	3	3	3	11	3	3	4	3	70
MP local-1	24	29	27	25	28	25	20	29	29	29	29	30	29	24	27	30	25	29	488
MP local-2	20	24	25	20	20	20	17	20	23	24	24	24	24	17	25	25	20	24	396
Jaipur local	28	18	8	28	26	28	28	25	25	18	18	20	18	3	8	23	28	18	368
Karnataka local	17	28	28	18	19	18	14	22	27	28	28	29	28	28	28	27	18	28	433
Chittorgarh local	19	20	16	19	18	19	18	18	16	20	20	18	20	14	16	16	19	20	326
Jhalawar local	25	26	26	24	25	24	22	27	28	26	26	27	26	15	26	28	24	26	451
Nagour local-2	29	25	19	29	29	29	29	30	30	25	25	28	25	10	19	29	29	25	464
RMt-303	2	5	4	2	2	2	2	3	3	5	5	4	5	18	4	4	2	5	77
RMt-143	1	4	5	1	1	1	1	1	1	4	4	2	4	23	5	2	1	4	65
Rajendra Kranti	11	30	30	11	12	11	8	13	15	30	30	26	30	30	30	20	11	30	378
Hisar Suvarna	15	23	24	15	17	15	15	17	17	23	23	21	23	20	24	19	15	23	349
AFG-1	8	16	22	8	8	8	9	8	8	16	16	11	16	25	22	8	8	16	233
Pant Ragini	13	27	29	13	14	13	11	16	18	27	27	25	27	29	29	22	13	27	380
Jhunjhunu local	21	15	11	21	21	21	24	19	19	15	15	17	15	7	11	18	21	15	306
Azad Methi	22	22	18	22	23	22	23	23	24	22	22	22	22	13	18	24	22	22	386
Nagour local-1	27	21	13	27	27	27	27	26	26	21	21	23	21	9	13	26	27	21	403
Hisar Mukta	7	14	23	7	7	7	7	7	7	14	14	8	14	26	23	7	7	14	213
CO-2	9	12	17	9	9	9	10	9	9	12	12	9	12	19	17	9	9	12	204
Hisar Sonali	18	7	6	17	16	17	21	15	14	7	7	13	7	6	6	14	17	7	215
RMt-351	5	6	14	5	5	5	5	5	5	6	6	5	6	22	14	5	5	6	130
GM-2	30	2	1	30	30	30	30	28	21	2	2	7	2	1	1	11	30	2	260
AFG-3	6	11	21	6	6	6	6	6	6	11	11	6	11	27	21	6	6	11	184
RMt-1	16	8	9	16	15	16	19	14	13	8	8	14	8	8	9	15	16	8	220
AFG-2	23	13	7	23	22	23	25	21	20	13	13	16	13	4	7	17	23	13	296
Lam Selection	14	9	12	14	13	14	16	12	12	9	9	12	9	12	12	12	14	9	214
Sikar local	26	17	10	26	24	26	26	24	22	17	17	19	17	5	10	21	26	17	350
AFG-4	10	10	15	10	10	10	12	10	10	10	10	10	10	16	15	10	10	10	198
Hisar Madhavi	12	19	20	12	11	12	13	11	11	19	19	15	19	21	20	13	12	19	278

coefficients among the drought tolerance indices, proline content and seed yield were calculated (Table 5). The relationship between seed yield under moisture regimes was significant positively, indicating that relationship between genotype seed yield is moisture regimes and year effect. Yp was positive and significant with Ys, GMP, REI, RDY, HM, MSTIK1, MSTIK2, YI and SNPI indicating that selecting genotypes for these indices will not always improve seed yield under E_2. Ys indicated positive significant correlation with the indices MRP, SSI, SDI, RDI, GM, DTE, GMP, REI, RDY, HM, MSTIK1 MSTIK2, YI, DI and SNPI indicating that selecting genotypes for these indices will improve the seed yield under E_2water stress condition. These results can be supported by other works (Farshadfar and Sutka, 2002 and Mohammadi et al 2011). The indices MRP, GMP, HM, REI, MSTIK1, MSTIK2, YI, SNPI and RDY had a significantly positive correlation with seed yield under E_1 and E_2, indicating that these indices are able to discriminate group a genotype (genotypes with high yield in E_1 and E_2). Proline content was found positive and significant with SSI, SDI, RDI, GM and

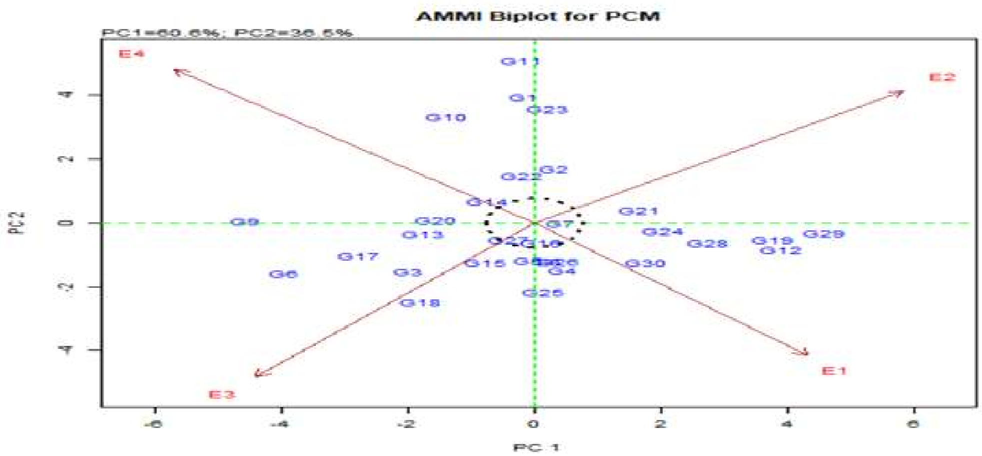

Fig. 2. GGE Biplotwith the first two principal axes of the interaction (PC1 and PC2) for proline content

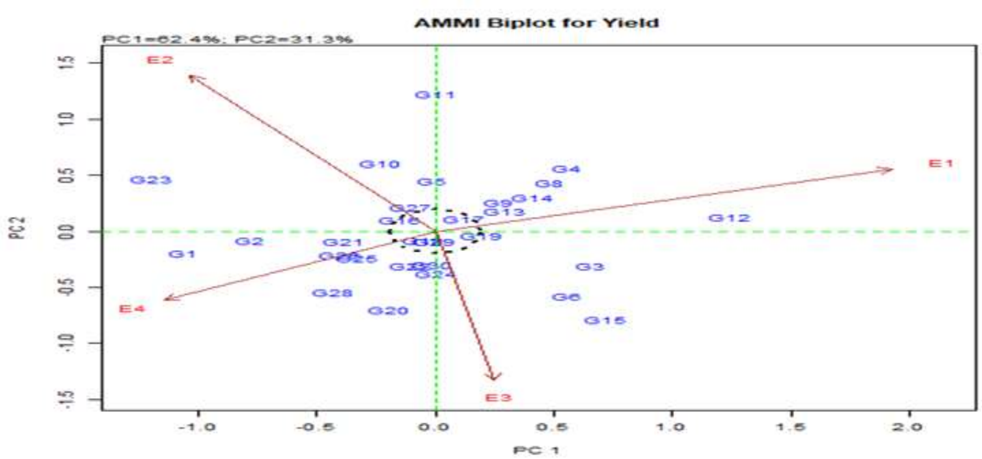

Fig. 3. GGE Biplotwith the first two principal axes of the interaction(PC1 and PC2) for the seed yield

Table 5. Spearman's rank correlation coefficient among seed yield, proline content and drought tolerance indices

Characters	Drought tolerance indices																				
	Yp	Ys	PCMI	PCMS	MRP	SSI	TOL	GMP	HM	REI	MSTIK1	MSTIK2	YI	SDI	RDI	DI	GM	ATI	SSPI	SNPI	RDY	DTE
Yp	-	.734**	.436*	.459*	.922**	.187	-.191	.914**	.875**	.914**	.976**	.823**	.734**	.187	.187	.440*	.187	-.711	-.191	.590**	.914**	.187
Ys		-	.567**	.677**	.921**	.727**	.371*	.927**	.951**	.927**	.844**	.977**	1000*	.727**	.727**	.890**	.727**	-.209	.371*	.960**	.927**	.727**
PCMI			-	.906**	.461*	.509**	.367*	.461*	.473**	.461*	.469**	.500**	.567**	.509**	.509**	.624**	.509**	-.010	.367*	.627**	.461*	.509**
PCMS				-	.544**	.622**	.454*	.551**	.564**	.551**	.520**	.593**	.677**	.622**	.622**	.728**	.622**	.022	.454*	.742**	.551**	.622**

DTE indicating that selecting genotypes for these indices will improve the seed yield under E_2. Repeatable relationships were observed between seed yield with MRP, GMP, HM, REI, MSTIK1, MSTIK2, YI, SNPI and RDY suggesting that one of them can be used as alternative to others for the evaluation of drought tolerant genotypes. These results are in agreement with the previous studied by Sahar et al (2016) and Choudhary et al (2017).

Ideal genotypes: The analysis revealed that the first two PCA of proline content in leave at maturity and seed yield per plant explained 97.10 and 93.70% of the total variation. An ideal genotype should have invariably high average proline content and seed yield in the entire environment. This ideal genotype is graphically defined by the longest vector in PC1 and without projections in PC2 (Costa De Mattos et al 2013). G1(RMt-305), G2(GM-1), G10(RMt-303), G11(RMt-143), G22(RMt-351) and G23(GM-2) genotypes were located between E_2 and E_4 concentric circles away from centre (Figure 2 and 3). These genotypes are closest to the ideal and can be considered desirable in terms of yield and stability of the seed yield. The similar findings were reported by Pour-Siahbidi and Pour- Aboughadareh (2014) in chickpea and Meena et al (2016) in fenugreek..

CONCLUSION

The seed yields were influenced by the year effect under moisture regimes and differences in ranking of genotypes based on each drought tolerant index. MRP, GMP, HM, REI, MSTIK1, MSTIK2, YI, SNPI and RDY indices highly correlated with seed yield in moisture regimes are introduced as the best indices. Consequently, genotypes RMt-305, GM-1, RMt-303, RMt-143, RMt-351 and GM-2 were more droughts tolerant and can be used as parents for developing the drought tolerance varieties in fenugreek.

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Received 15 October, 2021; Accepted 22 February, 2022

Indian Journal of Ecology (2022) 49(2): 477-482
DOI: https://doi.org/10.55362/IJE/2022/3548

Manuscript Number: 3548
NAAS Rating: 5.79

Assessment of Climate Change on Crop Water Requirement of Different Crops using CROPWAT model in Bapatla Region

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Abstract: This study investigated possible implications of climate change (in terms of temperature, wind speed, relative humidity) on crop water requirements (CWRs) by 2050s using CROPWAT 8.0 model in Bapatla region. On an average, 1^0C rise in temperature may increase the overall CWR by 2-3% in this region. Increase in CWR due to 3^0C increase in temperature is observed as 16.59, 0.54 and 1.59 MCM for the crops rice, maize and pulses respectively. For rice crop, the CWR showed 2.3, 6.52 and 8.75% increase from the average CWR (1375.1 mm) due to increase in 1, 2 and 3^0C respectively. Similar trend was observed in the case of other major crops in this region such as chillies, maize, cotton, pulses, tomato and vegetables. Similarly change in the wind speed and relative humidity has the demonstrative effects on crop water requirements. This study might be useful in explaining the negative effects of climate change on CWR in Bapatla region and better planning for water resources management.

Keywords: Climate change, Crop water requirement, CROPWAT 8.0 model, Water demand

Water is an important natural resource for all forms of life and it is becoming scarce natural resource in the future owing to climate change, which aggravates the present situation. Water resources are inextricably linked with climate (Rao et al 2011). The population of India is expected to stabilize around 1640 million by the year 2050. The gross per capita water availability in India will decline from ~1820 m^3/yr in 2001 to as low as ~1140m^3/yr in 2050 (IPCC, 2007). Total water requirement of the country for various activities around the year 2050 has been assessed to be 1450 km^3/yr. This is significantly more than the current estimate of utilizable water resource potential (1122 km^3/yr) through conventional development strategies. Therefore, when compared with the availability of ~500 km^3/year at present the water availability around 2050 needs to be almost trebled (Gupta and Deshpande 2004, Babu et al 2014). Almost 60% of India's agriculture is rain-fed, making the country highly dependent on groundwater. In India average temperature may increase 2^0C with 1.0 - 4.0^0C at extreme ranges by the 2050s. Under 2^0C warming, the country may need to import more than twice the amount of food-grain than would be required without climate change. Crop water requirement (CWR) is the depth of water needed to meet the water loss through evapotranspiration of a disease-free crop growing in large fields under non restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment. The amount of water needed by the various crops to grow optimally. The potential evapotranspiration (ET_p) of a crop is the volume of water required by it to meet its evapotranspiration requirements (Raju et al 2016).

Climate change may impose further stress on the availability of water and agricultural productions. Past studies reported that the negative effects from climate change can affect agricultural sector (Ziad and Sireen 2010, Chowdhury and Al-Zahrani 2013, Falguni and Pramodchandra 2013). Increase in temperature, change in relative humidity and wind speed, variable rainfall patterns and interactions of other meteorological parameters may have negative effects on crop water requirements. Increase in temperature by 1^0C may change the thermal limits of the crop, which may lead to 5-25% decrease in crop productions (Al Zawad and Aksakal 2010). For better management of available natural water resources and agricultural productions, it is essential to understand CWR, present level of water supplies and possible effects of climate change in future. To apply irrigation water efficiently, the water requirement of the crops is to be estimated accurately. Past studies indicated that CROPWAT software could be a reliable tool to better understand Crop Water Requirement, irrigation planning and manage irrigation scheduling (Kang et al 2009). Keeping in view of the above facts, the present study is planned to evaluate the impacts of climate change on crop water requirements of different crops for the Bapatla region.

MATERIAL AND METHODS

Study area: The study area is Bapatla lies between the coordinates of 15°54′16″N latitude and 80°28′3″E longitude with an average altitude of 6 m above the mean sea level (MSL). It is one of the 57 mandals in Guntur district.

Agro-Climatic conditions: Bapatla comes under humid sub-tropical area and is very close to the coast with very hot summer and cool winter**.** The maximum and minimum temperatures are 38.6^{0}C during May month and 17.6^{0}C during January month respectively with an average air temperature is 28.4^{0}C. The mean relative humidity ranged from 62 to 80 % with an average of 75%. The average wind speed is equal to 8.68 km/hr, while the annual precipitation ranges from 666-1392 mm with normal rainfall 1120mm. The soils in the study area are broadly classified as Black cotton, Red loamy and sandy loamy. The predominant crops grown in the study area are paddy and maize among cereals, blackgram, green gram and red gram among pulses, cotton and chillies among non-food and commercial crops and vegetables including tomato crop. The meteorological data collected from the meteorological station at College Farm, Bapatla and analyzed for the finding variation in meteorological factors.

Estimation of crop water requirements due to impact of climate change: CWRs were influenced mainly by climate factors and change trends. Changes in the water requirement of different crops affected mainly by meteorological factors, such as temperature, average relative humidity and wind speed. Estimation of the CWR was carried out by the appropriate climate and rainfall data sets, together with soil and crop data files and the corresponding planting dates. Based on the climate data, rainfall data, crop data, cropping pattern data and soil data fed to the CROPWAT 8.0 model, the CWRs were estimated for Bapatla region. The changes in temperature are positive and the temperature will be increased by year 2050s is to be expected 2.0^{0}C. Similarly, the changes in the relative humidity and wind speed expected in the range of 5 to 10% and the CWRs of different crop were estimated under different climate scenarios to find out the impact of climate change on CWR.

RESULTS AND DISCUSSION

Rainfall: The annual average rainfall of Bapatla over 10 years (2006 - 2015) is 1120 mm with the maximum rainfall occurred during the year of 2010 was 1898.4mm and minimum rainfall occurred in the year of 2009 was 666.6 mm (Fig. 1). The effective rainfall was computed using the average annual rainfall data and the average effective rainfall over 10 years is estimated as 839.9 mm with the maximum effective rainfall was 1100.7 mm during 2010 and minimum effective rainfall was 480.7 mm during 2009 (Table 1 and Fig. 2).

Changing trends of meteorological factors: The trend of average temperature increased sharply with the change in the decade is 1.2^{0}C at the rate of 0.12^{0}C per year. It was increased continuously from 32.6^{0}C in the 2006 to 33.8^{0}C in the 2015 (Table 2). Average temperature was the meteorological factor that showed a marked change. The

Table 1. Annual rainfall and their effective rainfall of the study area

Year	Rainfall (mm)	Effective rainfall (mm)
2006	1195.6	760.8
2007	1392.5	805.3
2008	1074.2	817.8
2009	666.6	480.7
2010	1898.4	1100.7
2011	791.2	632.5
2012	1066.9	771.1
2013	1553.5	889.3
2014	676.8	552.9
2015	891.3	587.5
Average	1120.0	839.9

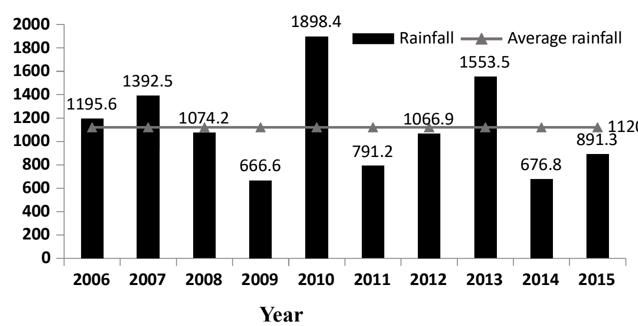

Fig. 1. Rainfall data of Bapatla region from (2006-2015)

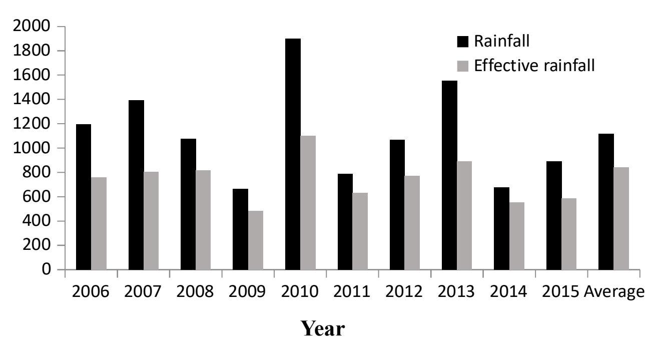

Fig. 2. Rainfall and effective rainfall data of Bapatla region (2006-2015)

effective rainfall was 1100.7 mm during 2010 and minimum effective rainfall was 480.7 mm during 2009 (Table 1 and Fig. 2).

Changing trends of meteorological factors: The trend of average temperature increased sharply with the change in the decade is 1.2^{0}C at the rate of 0.12^{0}C per year. It was increased continuously from 32.6^{0}C in the 2006 to 33.8^{0}C in the 2015 (Table 2). Average temperature was the meteorological factor that showed a marked change. The trend of average wind speeds have many variations with no definite trend during the period 2006 to 2015 and it was decreased from 233 km/hr in the 2006 to 196 km/hr in the 2015 with 10 to 20 % change. Similarly a descending trend in overall average humidity was detected from 78% to 73% with the change in the decade is 5 % and the decline in average relative humidity was consistent with the rise in the temperature. Reference evapotranspiration (ET_o) varies in range of 5.70 to 6.00 mm/day (Table 2). The ET_o increases gradually from 2006 to 2015 approximately at the rate of 0.03 mm/day per year.

Estimation of crop water requirement: Based on the climate data, rainfall data, crop data, cropping pattern data and soil data fed to the CROPWAT 8.0 model, the crop water requirements were estimated for Bapatla region. The CWR for the cotton, chillies, maize, rice, pulses, tomato and vegetables of the Bapatla region were estimated as 984.3, 604.1, 491.3, 1375.1, 384.6, 868.7 and 617.8 mm respectively (Table 3).

Effect of change in temperature on CWR: Temperature has the demonstrative effects on crop water requirements. The CWR was calculated under different temperatures with increment of 1^{0}C from the average temperature. The effect of change in every 1^{0}C rise in the temperature on the CWR for different crops (Table 4 and Fig. 3). As the temperature increases, the CWR of various crops increases this is due to increasing in the evapotranspiration from soil and crop. For cotton, the CWR increased 2.83, 5.89 and 8.94% increase from the average CWR (984.3 mm) due to increase in temperature was 1, 2 and 3^{0}C respectively. Similar trend was observed in the case of other major crops in the study area such as chillies, maize, rice, pulses, tomato and vegetables.

Effect of Change in relative humidity on CWR: The decreased RH increases the rate of evapotranspiration from soil and crop which leads to decrease in CWR of the crops. The effect of change in every 5 and 10% reduction in RH on the CWR for different crops in the study area shown in Table 5. The decreased RH increases and increased RH decreases the crop water requirements of various crops (Table 5). The 5% decrease in the RH, increased the CWR about 2.79% for the cotton. Similar trend has been identified for other major crops in the study area.

Effect of Change in wind speed on CWR: The higher wind speeds carried away the moisture content from the soil, increases the crop water requirements (Table 6). As the wind speed increases, the crop water requirements of various

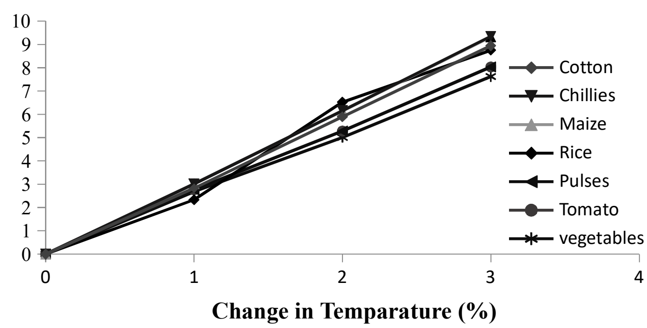

Fig. 3. Effect of increase in temperature on crop water requirement (CWR)

Table 2. Change trends for different meteorological factor means in the study area

Year	Average temperature (^{0}C)		Humidity (%)	Wind speed (Km hr^{-1})	ETO (mm day^{-1})
	Min temp	Max temp			
2006	22.2	32.6	78	233	5.70
2007	22.6	32.7	78	226	5.73
2008	23.3	33.4	75	205	5.93
2009	23.6	34.2	72	228	6.29
2010	23.9	32.5	80	208	5.64
2011	23.1	33.6	76	195	5.92
2012	23.4	33.7	77	204	5.88
2013	23.3	33.2	76	199	5.81
2014	23.4	33.7	72	204	6.12
2015	23.3	33.8	73	196	6.00

Table 3. Monthly crop water requirement of different crops during their crop season

Crop	Crop Water Requirement (ETc) in mm												
	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Total
Cotton	-	-	-	-	-	80.7	134.2	216.0	212.6	189.6	117.8	33.7	984.3
Chillies	127.3	123.7	88.1	-	-	-	-	-	-	27.2	107.6	130.3	604.1
Maize	167.5	127.7	14.9	-	-	-	-	-	-	-	50.5	130.7	491.3
Rice	-	-	-	-	410.2	262.8	265.4	242.1	194.1	-	-	-	1375.1
Pulses	143.5	60.4	-	-	-	-	-	-	-	-	57.8	122.8	384.6
Tomato	-	-	-	-	-	138.1	180.9	225.9	205.0	118.6	-	-	868.7
Vegetables	-	-	-	-	-	165.2	219.1	209.8	23.7	-	-	-	617.8

Table 4. Response of crop water requirement to change in mean temperature (T^0C)

Crop	Crop Water Requirement (ETc)						
	Avg. Temp.	ΔT = 1^0C		ΔT = 2^0C		ΔT = 3^0C	
	CWR (mm)	CWR (mm)	Change (%)	CWR (mm)	Change (%)	CWR (mm)	Change (%)
Cotton	984.3	1012.2	2.83	1042.3	5.89	1072.3	8.94
Chillies	604.1	622.3	3.01	641.3	6.16	660.5	9.34
Maize	436.4	449.6	3.02	463.2	6.14	477.1	9.32
Rice	1375.1	1407.2	2.33	1464.8	6.52	1495.5	8.75
Pulses	384.6	396.4	3.06	406.4	5.66	417.8	8.63
Tomato	868.7	892.7	2.76	914.6	5.28	938.5	8.03
Vegetables	617.8	634.4	2.68	648.8	5.01	664.9	7.62

Table 5. Response of crop water requirement to change in relative humidity (RH)

Crop	Crop Water Requirement (ETc)				
	Avg. RH	ΔRH = -10%		ΔRH = -5%	
	CWR (mm)	CWR (mm)	Change (%)	CWR (mm)	Change (%)
Cotton	984.3	1038.8	5.53	1011.8	2.79
Chillies	604.1	631.4	4.52	617.9	2.28
Maize	436.4	455.7	4.42	446.1	2.22
Rice	1375.1	1482.7	7.82	1444.6	5.05
Pulses	384.6	401.5	4.39	393.2	2.23
Tomato	868.7	921.4	6.06	895.3	3.06
Vegetables	617.8	659.6	6.76	638.9	3.41

Table 6. Response of crop water requirement to change in wind speed (W)

Crop	Crop Water Requirement (ETc)				
	Avg. RH	ΔW = +5%		ΔW = +10%	
	CWR (mm)	CWR (mm)	Change (%)	CWR (mm)	Change (%)
Cotton	984.3	991.3	0.71	998.3	1.42
Chillies	604.1	608.3	0.70	613.3	1.52
Maize	436.4	439.5	0.71	443.3	1.58
Rice	1375.1	1383.6	0.62	1392.0	1.23
Pulses	384.6	387.2	0.68	390.2	1.45
Tomato	868.7	874.4	0.66	880.0	1.30
Vegetables	617.8	622.2	0.71	626.6	1.42

Table 7. Excess water demand in Bapatla region due to increase in temperature

Crops	Avg.CWR (mm)	CWR (mm) at 3^{o}C temp. raise	Increase in CWR (mm)	Area under crops (ha)	Increased water demand (MCM)
Rice	1375.1	1495.5	120.4	13782	16.59
Maize	436.4	477.1	40.7	1326	0.54
Pulses	384.6	417.8	33.2	4790	1.59

Table 8. Excess water demand in Bapatla region due to decrease in relative humidity

Crops	Avg.CWR (mm)	CWR (mm) at decreasing 10% relative humidity	Increase in CWR (mm)	Area under crops (ha)	Increased water demand (MCM)
Rice	1375.1	1482.7	107.6	13782	14.83
Maize	436.4	455.7	19.3	1326	0.26
Pulses	384.6	401.5	16.9	4790	0.81

Table 9. Excess water demand in Bapatla region due to increase in wind speed

Crops	Avg.CWR (mm)	CWR (mm) at increasing 10% relative humidity	Increase in CWR (mm)	Area under crops (ha)	Increased water demand (MCM)
Rice	1375.1	1392.0	16.9	13782	2.33
Maize	436.4	443.3	6.9	1326	0.09
Pulses	384.6	390.2	5.6	4790	0.27

crops increases. For cotton, the CWR increased about 0.71 and 1.42% with increase in wind speed was 5 and 10% respectively. Similar trend was observed in the case of other major crops in the study area.

Increase in water demand: The effect of climate change on the CWR is observed and increase in temperature, decrease in relative humidity and increase in wind speed and interactions of other meteorological parameters may have negative effects on CWR and higher crop water requirements is observed in the study area. Increased CWR leads to high water demand for the agriculture. Excess water demand for some of the crops in the study area is given in (Table 7). Excess water demand due to decrease in relative humidity and increase in wind speed (Table 8, 9). Similarly the other crops also have the excess water demand due to climate change and the excess water demand can be met from the groundwater exploration which leads another problem i.e. the ground water depletion.

CONCLUSIONS

The major findings of the present research had clearly demonstrated that the estimation of CWR for various crops for different changes in climatic parameters. In order to save water resources and efficient use of water resources for future generations, keeping in view of this climate changes there is a need to improve the water use efficiency through estimation of the accurate CWR. The change in every 1ºC rise in the temperature has 2 to 3 % increases in the CWR in the study area. Similarly change in the wind speed and relative humidity has the demonstrative effects on crop water requirements. Excess water demand due to 3^{o}C increase in temperature observed as 16.59, 0.54 and 1.59 MCM for the crops rice, maize and pulses respectively. Similarly the other crops also have the excess water demand due to climate change. Due to climate change there is a necessity to apply efficient water management practices at the field level, so therefore there is a need to create the awareness on the effective utilization of available water resources to the farmers.

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Received 25 September, 2021; Accepted 21 February, 2022

Indian Journal of Ecology (2022) 49(2): 483-490
DOI: https://doi.org/10.55362/IJE/2022/3549

Manuscript Number: 3549
NAAS Rating: 5.79

Constraints in Mango Export from India

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***Abstract*:** Indian Economy is facing various constraints in exporting horticulture goods relating to production practices, post-harvest technologies and issues relating to supply chain, market access, Non-Tariff Measures and government policies. The present paper aims to analyse the constraints in the export of Indian mango in terms of tariff and non-tariff barriers imposed by developed countries and the constraints faced by the exporters at domestic level. The findings depicts that countries like Russia, Japan, Turkey and EU countries imposed tariff on agricultural products more than or equal to bound rate while rate while USA rejects IMPORT OF Indian mango due to Sanitary reasons. Besides, the tariff rates of other countries are also beyond the bound rate as decided by the WTO. Also, out of the total refusals, around 58 per cent were on the grounds of adulteration and 42 per cent on account of inadequate labelling/misbranding & insanitary conditions. Although, the government has taken various efforts to remove these aforementioned hurdles, but a lot more is needed to boost mango export at national and international level.

Keywords: Pre & Post-harvest, Supply chain, Non-tariff measures, Market access

India is the second largest producer of fruits in the world just behind China. It's diverse climatic and geographical conditions support production of wide variety of fruits, vegetables, nuts and spices etc. Horticulture production has increased in the country by 30 per cent in the last 5 years and is estimated to be nearly 46 million tons (10 per cent of the world production) (APEDA 2014).In spite of being the largest producer of fruits and vegetables in the world, the export competitiveness of Indian producers remains low with only 1 percent share of export earnings from agricultural products. It is only after the Uruguay Round Agreement on Agriculture, the agricultural exports got increased and new opportunities have emerged. Its main reasons are rising income level of the people, focus on healthy diet pattern and improved transportation that has promoted the globalization of fruit trade (Chandra and Kar 2008). But despite these changes, Indian economy is still facing various constraints in export of horticulture goods that are related to production practices, post-harvest technologies, issues relating to supply chain, market access, NTB, and government policies. Among horticultural crops in India, 'Mango 'enjoys a place of pride. The Indian government has also taken various measures to boost mango production and exports in collaboration with APEDA, NHB, Export Promotion Board, Ministry of Commerce, and Government of India. In this context, the paper analyses the current global trade environment for horticultural exports and the restrictions that Indian mangoes are facing at domestic and international level, despite its competitiveness. Uttar Pradesh and Andhra Pradesh, combined together have a share of more than 50 per cent production of mango in the country. Dashehari, which is cultivated in the plains of Uttar Pradesh, is an important export variety of mango for its attractive appearance, excellent taste and pleasing flavour (Kishor et al 2019). Also, a large number of export varieties of mango are produced in these two states. For this reason, these two states have been selected to find out the major constraints in mango export from India.

The present paper aims to analyse the constraints in the export of Indian mango in terms of tariff and non-tariff barriers imposed by developed countries and the constraints faced by the exporters at domestic level. Further, the paper critically examines the Government policies for export promotion of horticultural products and its impact on export of mangoes with suggested measures to enhance its export from the country as well as from the selected states.

MATERIAL AND METHODS

The paper is mainly based on secondary and primary data. The secondary data on export was compiled from the publications of APEDA, Agricultural Marketing Board, Food and Agriculture Organization (FAO) and Monthly Statistics on Foreign Trade published by Directorate General of Commerce, Intelligence and Statistics, Ministry of Commerce, Government of India. Apart from secondary data, 20 traders/exporters were interviewed to collect detailed information regarding major constraints in mango export at National and International level. Besides, discussions were also held with the officials from *Mandi Samiti;* mango pack houses, agriculture marketing board of both the states and APEDA to know existing government policies to promote export of mango and constraints faced in this context.

Ten exporters were purposively selected from Uttar Pradesh and Andhra Pradesh, 5 from each State as they are the leading producer of mango in the country (appendix table 1).This represent different agro-climatic and geographical conditions. Moreover, Uttar Pradesh is a land locked state, while Andhra Pradesh has a long coastal belt. Dashehari mango of Lucknow in UP has been granted Geographical Indication. Another ten exporters were randomly selected from national level who exports from different states and particularly via Delhi and Mumbai (list of exporters were collected from the APEDA).

Compound annual growth rate (CAGR): The study used time series analysis to analyze the production and export performance of Indian mangoes and mango pulps. The exponential compound annual growth rates are estimated by using time series data on area, production, yield and export of mango.

Growth estimation: The following exponential model has been fitted to the time series data for estimating the compound annual growth rates (CAGR) of area, production, yield and export of mango from 1985-86 to 2015-16 in India;

$$y = ab^t e^u$$

The logarithmic form of this function is given by

$$\ln(y) = \ln(a) + t\ln(b) + u$$

Where y is a dependent variable whose growth rate is to be estimated, t is an Independent variable (time) and u is a disturbance or error term. The coefficients 'a' and 'b' are the parameters to be estimated from the time series observations. The regression co-efficient b is estimated by ordinary least squares (OLS) technique. The Compound Average Growth Rate (CAGR) in per cent is estimated as:

$$CAGR = \{Antilog(b) - 1\}*100$$

RESULTS AND DISCUSSION

Trends in mango production and exports: The area and output of mango has shown growth over the years but its share in total fruit area and production has declined sharply in the last two decades. The share of mango in total area under fruit crops declined from 43.5 per cent in 1987-88 to 34.4 percent in 2019-20 and over the same period its share in fruit production dropped from 37.4 per cent to 20.7 per cent. However, its production in absolute term increased from 8.7 MT in 1991-92 to 20.4MT in 2019-20, registering an annual compound growth rate of around 3 per cent. Although, the productivity has increased in the recent years (2014-19) but still CAGR is only 0.26 per cent. Thus, when area is expanding, productivity per hectare is likely to decline initially as new plantations start bearing fruits only after four-five years.

The mango export has increased at a CAGR of 9.4 per cent but the share of exports in mango production is still nominal (Table 2). In 1985, mango export was only 0.18 per

Table 1. Trends in area, production and productivity of mango in India

Year	Area under mango (M ha^{-1})	Per cent of total fruit area	Production of mango (Million MT)	Per cent of total fruit production	Productivity (t ha^{-1})
1987-88	1.24	43.5	10.35	37.4	8.4
1991-92	1.08	37.5	8.72	30.4	8.1
1994-95	1.23	28.5	10.99	28.5	9.0
1999-00	1.49	37.3	10.50	23.0	7.1
2004-05	1.97	39.7	11.83	24.0	6.0
2009-10	2.31	36.5	15.03	21.0	6.5
2013-14	2.55	35.7	18.68	22.1	7.3
2014-15	2.16	35.40	18.53	21.39	8.6
2015-16	2.20	35.50	19.52	21.92	8.9
2016-17	2.21	34.71	19.51	20.99	8.82
2017-18	2.26	34.71	21.82	22.41	9.66
2018-19	2.30	34.80	21.38	21.82	9.31
2019-20*	2.29	34.38	20.44	20.64	8.92
CAGR (%)	3.00		3.27		0.26

Source: Indian Horticulture Database, various years, sources www.nhb.gov.in, http://nhb.gov.in/Statistics.aspx?enc=WkegdyuHokljEtehnJoq0KWLU79sOQCy+W4MfOk01GFOWQSEvtp9tNHHoiv3p49g#; *= Second estimates cent of the total production and improved to 1.55 in 2001-03 followed by 1.92 percent in 2006-08 after 10 years of WTO. This improvement may be because after 1986, US lifted the ban from Indian mango export in 2006. This trend declined in 2012-14 by 1.31 followed by 0.57 percent in 2018-20. The major reasons of this decline are strict non-tariff measure imposed by the developed countries and massive decline of Indian export to Bangladesh (Table 3). Further, the neighboring country, Pakistan, produces around one million tons of mango, but exports 40,000 tons annually (4 per cent of its total production) (Hegde, 2006) which indicates that there is a huge possibility for promoting mango exports from India.

Table 2. Trends in mango export from India

Year	Production ('000 tons)	Export ('000 tons)	Export as per cent of production
1985-87	9774	18	0.18
1988-90	8359	20	0.24
1991-93	9362	24	0.26
1994-96	10976	26	0.24
1997-99	10337	43	0.42
2000-02	10194	42	0.42
2003-05	12018	186	1.55
2006-08	13465	258	1.92
2009-11	14322	259	1.83
2012-14	17543	230	1.31
2015-17	20167	179.9	0.89
2018-20	25115	142.8	0.57
CAGR	2.95	9.35	

Source: FAOSTAT (1961-2016)

Major destination of Indian fresh mango export: The major importing countries of Indian mango are Gulf countries like Bahrain, Qatar, UAE, Saudi Arabia; United Kingdom, USA, and Bangladesh. In 2000-01, India exported 39.9 million tons of mango that increased to around 50 tonnes in 2019-20. In terms of value, during 2004-05, the total export of fresh mango on constant price was Rs.9545 lakh that increased to Rs. 11977 lakhs in 2019-20 (Table 3). In value terms, the Gulf countries accounted for around 51 per cent of total mango export followed by the Bangladesh (26 percent) in 2001-03(the other major country was United Kingdom). On the other hand, during 2019-20, the share of Bangladesh reduced to 2.4 per cent. Out of the total mango exports from India to Bangladesh, around 70 per cent of export used to be from West Bengal. But due to the rising import duty on the fruit by the neighbouring country coupled with increase in the area of the mango cultivation there, the export of mango from West Bengal to Bangladesh declined. However, over the period, the share of UAE in total mango export has increased due to decreased share of Bangladesh (though in absolute terms, it has declined). Nvertheless, the export of Indian mango was impressive in case of UK, USA, and other

Table 3. Mango fresh export from India (2004-05 constant price)

Country/year	Quantity (000 Tones)			Value in Rs Lakhs		
	2001-03	2011-2013	2017-20	2001-03	2011-2013	2017-20
Baharain IS	636 (1.6)	701 (1.2)	918 (1.9)	236 (2.5)	142 (1.4)	240 (2.0)
Bangladesh PR	18618 (46.7)	18433 (31.1)	2983 (6.1)	2491 (26.1)	1012 (10.3)	290 (2.4)
Kuwait	911 (2.3)	712 (1.2)	1176 (2.4)	401 (4.2)	271 (2.8)	484 (4.0)
Qatar	204 (0.5)	905 (1.5)	2648 (5.4)	78 (0.8)	216 (2.2)	755 (6.3)
Saudi Arab	2380 (6.0)	1879 (3.2)	1942 (4.0)	744 (7.8)	454 (4.6)	502 (4.2)
U Arab EMTS	11234 (28.2)	28362 (47.8)	18836 (38.5)	3445 (36.1)	5776 (58.7)	4878 (40.7)
U K	1148 (2.9)	2853 (4.8)	4033 (8.2)	543 (5.7)	977 (9.9)	1773 (14.8)
U S A	638 (1.6)	232 (0.4)	949 (1.9)	188 (2.0)	147 (1.5)	722 (6.0)
Other countries	4079 (10.2)	5219 (8.8)	12272 (25.1)	1418 (14.9)	838 (8.5)	1603 (13.4)
Total	39847 (100.0)	59297 (100.0)	48919 (100.0)	9545 (100.0)	9834 (100.0)	11977 (100.0)

Source: Compiled from Monthly Statistics on Foreign Trade published by Directorate General of Commerce, Intelligence and Statistics, Ministry of Commerce, Government of India; Figures in parentheses are percentage share.

countries. Namrata et al (2019) also reported that after WTO period, UAE again became the largest importer followed by Bangladesh due to the shrunken export to Bangladesh.

Table 4 depicts the growth of Mango fresh exports from India from 2000-01 to 2019-20 in terms of quantity and value. During the overall period of study, the growth rate of Mango fresh export, in value terms stood at 1.5 percent but was significant only at 10 percent while the growth rate of quantity for the same period was insignificant. During 2000-2010, the total mango export registered a positive growth rate of 8.6 and 4.6 percent for quantity and value respectively .However, during the last decade, it got slumped to -1.9 & 3.0 per cent for quantity and value respectively (Table 4).

During the recent period, the growth rate of Bangladesh and UAE slumped but that of Qatar, USA and Kuwait surged up. This is due to the lifting of ban on mango export by USA in 2006. Moreover, UK and Saudi Arabia showed positive growth rates. UAE registered a modest growth rate of 3.3 per cent during the overall period while UK and Quarter registered significantly higher growth rate. Besides, higher growth rates were also posted by relatively smaller importers (Baliyan et al 2015). Though the rate of growth of total quantity of mango exported from India for the overall period was negative (-1.9), but in value terms, exports increased at the rate of 1.5 per annum and was not significant.

Constraints in mango export: This section shows the major constraints in mango export that India faced at international level due to trade policies of different countries and which adversely affected Indian agricultural exports. The major constraints at the international level include market access and non- tariff barriers (NTM).

Tariff Barriers: After the formation of WTO and implementation of Agreement on Agriculture, low growth rate of agriculture exports, especially mango exports, is not only due to high rate of tariff barriers but also due to many non-tariff barriers imposed by the developed countries. The WTO has defined the specific bound rate of tariff for all member countries and the member countries are directed not to charge the tariff more than the bound rate. However, Russia, Japan, Turkey and EU countries imposed tariff on agricultural products more than or equal to bound rate while the tariff rate of other countries are far away from bound rate as decided by the WTO (Table 5). Similarly, non-tariff measures also very strict in developed countries as compared to other countries.

Non-Tariff Barriers (NTB): Non-tariff barriers are extensively applied by the developed countries to restrict imports from developing countries. They have the potential to cause/create an economic effect on international trade in goods, causing change in quantities traded, or prices or both (UNCTAD 2015). The basic aim of the TBT Agreement was to ensure that technical regulations and procedures used for assessing conformity with such regulations are not formulated and applied which disrupts the smooth functioning of trade. Both the agreements have a provision that depicts disparity for developing countries (WTO, 2007). There exist 8 different types of NTMs (1) packaging and labeling guidelines, (2) pesticide residue limit guidelines, (3) chemical content restrictions, (4) fruit fly related rules, (5) uniformity requirements, (6) labour standards, (7) documentation procedures and (8) company and product registration. Developed countries like USA, EU and Japan impose sophisticated regulations like registration, packaging and labelling, pesticide residue and aflatoxin content, fruit fly regulations and labour standards. The problems faced by

Table 4. Growth of export of mango fresh from India (2004-05 constant price)

Country/year	Quantity (000 Tones)			Value in Rs Lakhs		
	2001-03	2011-2013	2017-20	2001-03	2011-2013	2017-20
Baharain IS	6.1***	3.0***	1.9**	-0.1 NS	6.8***	0.4 NS
Bangladesh PR	7.8***	-26.5***	-19.1***	-0.9 NS	-21.7***	-20.8***
Kuwait	-5.5***	8.1***	4.6***	-2.6**	9.6***	4.6***
Qatar	2.1**	21.4***	20.1***	3.8***	24.1***	18.0***
Saudi Arab	-2.3**	-0.1 NS	-1.4*	-2.6**	1.4*	-1.4*
U Arab EMTS	12.8***	-4.7***	3.3***	10.4***	-2.3**	3.3***
U K	12.5***	5.8***	5.7***	12.6***	10.2***	5.9***
U S A	-28.4***	25.3***	9.2***	-14.9***	28.2***	16.3***
Other countries	8.8***	15.0***	4.3***	-1.5*	10.4***	0.2 NS
Total	8.6***	-1.9**	-0.4 NS	4.6***	3.0***	1.5*

Source: Compiled and calculated from Monthly Statistics on Foreign Trade published by Directorate General of Commerce, Intelligence and Statistics, Ministry of Commerce, Government of India.

***, ** and * Significant at 1, 5 and 10 per cent levels: Non-significant.

firms in Gulf countries are mostly caused by uniformity in size and documentation procedures (WTO 2015). The compliance costs were not uniform across NTMs but seemed to be more severe on smaller firms than large ones[1]. Some of the major NTMs that are maintained against Indian exports are given Table 6.

Adherence to safe export norms is very important to have credible sustainable export. SPS Codex brings nations together to evaluate agricultural, processing and handling methods and bring out commonly accepted guidelines for the international food safety. It becomes essential to generate knowledge by scientific research for structuring food safety norms and policy alignment according to the changing global regulations (Baliyan et al.2015). During the period 2002 to 2019, there were 303 cases of refusals of Indian mango and mango products by USA accounting for 30.1 per cent of total world mango export refusals by USA (Table 7).

The refusal of mango products was highest in 2006 i.e.

Table 5. Average rate of tariff imposed by the selected countries on mango & agricultural products (in percent)

Country	Fresh or dried guavas, mangoes and mangosteens		Tariff on agricultural products	
	1996-2020		1996-2015	2006-2020
	Bound	MFN applied	Bound	MFN applied
Bahrain	35.0	0.25	31.1	5.7
Bangladesh	200.0	25.05	134.1	10.3
Canada	0.0	0.00	14.6	13.5
EU Countries	0.0	0.55*	12.6	12.5
Japan	3.0	3.01	20.0	18.1
Kuwait	100.0	0.00	80.0	4.0
Nepal	30.0	10.00	37.3	12.8
Oman	46.7	0.00	22.3	6.0
Qatar	15.0	0.00	20.7	5.5
Russia	4.0	4.20	3.4	12.0
Saudi Arab	7.3	1.42	14.4	5.1
Singapore	10.0	0.00	24.7	0.5
Sri Lanka	50.0	28.65	40.0	19.9
Turkey	58.5	45.00	42.4	30.1
U Arab Emirates	15.0	0.00	20.3	5.1
USA		0.00	4.4	4.6
Yemen Republic	100.0	25.00	2.5	5.2

Source: WTO, World Tariff Profile, different years, accessed from http://tariffdata.wto.org/TariffList.aspx dated 28.2.2022,

Table 6. Non-tariff measures imposed by selected countries on Indian mango export

Name of country	Details of NTM
Australia	Australia continues ban on the alleged reason of the presence of fruit flies and stone weevils.
United States	Detailed labelling requirements with extensive product and content description. Presently, USA imports Mangoes from India after irradiation treatment. The inspectors from USDA, APHIS supervise the all preclearance activity.
European Union	European Commission (EC) has placed a ban w.e.f. 1st May, 2014 on the ground of interception of high no. of harmful pests and organisms in the exported consignments but now, it has lifted the ban.
New Zealand	Ban on import of Indian mangoes and other fruits due to presence of fruit flies and weevil and high food safety standards and bio security[2] Issue. Without Approval of Vapor Heat Treatment (VHT) facility, New Zealand is not ready to import mango from India.
South Africa	Market access for mangoes is denied due to approval of pests risk analysis (PRA) management system.
South Korea	Indian mangoes cannot be exported to South Korea because of pests management system from farm to treatment is yet to be approved by Animal and Plant Quarantine Agency of South Korea.

[1] http://www.tradeportalofindia.com/usrdata/webadmin/Section3.9/Mult_NonTariffMeasures_1201.html) 23.04.2014
[2] Biosecurity, as defined by FAO, offers a strategic and integrated approach to analyses and manage risks in food safety, animal and ... to biosecurity, and discusses the characteristics, requirements and benefits of a more harmonized approach

around 38 consignment and lowest in 2018 (only 8 consignment). Out of the total refusals, about 58 per cent were on the grounds of adulteration and 42 per cent on account of inadequate labelling/misbranding & insanitary conditions (Table 7). Indian mangoes must undergo several treatments and inspections before they enter United States, including an irradiation treatment with a minimum absorbed dose of 400 grays to treat insect pests, inspection and fungicidal treatments for fungal pests and preclearance inspection within India for bacterial pests (Ferrier et al 2012).

Findings Based on Field Survey

Constraints at domestic level: The exporters reported that several domestic factors have constrained the export of mango from the country as well as from the states. At domestic level, the major constraints can be divided into two parts i.e. Supply chain and technological constraints.

Supply chain constraints: Most of the exporters in both the states reported that despite high mango production, they did not get the sufficient good quality mangoes for exports. The major problems in the supply chain constraints related with pre & post-harvest management of crops and marketing and constraints like lack of gradation and quality control, transport problems; inadequate storage facility, poor packaging, marketing problems, fluctuations in output due to weather conditions were also reported. These findings are also supported by the findings of earlier workers (Adhiguru and Ramasamy 2003, Mittal 2007, Kishore et al 2019). These factors restrict mango export from India and also affect mango growers, who do not get a fair value of their crops. Another major issue in the supply chain is the inefficient post-harvest management which include proper cooling and packaging facility, quick and efficient transportation, careful handling and proper management of the environment like temperature, humidity and cleanliness. Besides, inadequate knowledge of pest control, inadequate sea freight facilities and high air freight costs are other major constraints in exports. The similar findings are also mentioned by earlier workers (Badatya 2007, Mittal 2007, Banerjee 2011, Menaka et al 2016).

Technological constraints: The exporters as well as the government officials reported that major technological constraints in mango export from India are unavailability quality mango grafts, lack of knowledge regarding improved technology, poor rates offered by middlemen to the farmers

Table 7. Share of Indian mango and mango products in world mango export consignment refusals by USA

Year	Total world mango refusals	Mango and mango products related refusals	Percent share of Indian mango refusals in world mango refusals	Reason for refusals (Multiple reasons for rejection of one consignment)	
				Adulteration	Inadequate labelling/ misbranding and insanitary conditions
2002	59	7	11.86	25.0	75.0
2003	52	13	25.00	50.0	50.0
2004	57	9	15.79	76.2	23.8
2005	63	31	49.21	62.9	37.1
2006	58	38	65.52	63.0	37.0
2007	77	21	27.27	54.5	45.5
2008	75	32	42.67	39.1	60.9
2009	48	12	25.00	44.0	56.0
2010	55	16	29.09	63.0	37.0
2011	44	12	27.27	76.5	23.5
2012	110	26	23.64	40.4	59.6
2013	48	9	18.75	71.4	28.6
2014	42	17	40.48	53.1	46.9
2015	33	12	36.36	93.8	6.3
2016	55	15	27.27	73.3	26.7
2017	46	15	32.61	93.3	6.7
2018	49	8	16.33	100.0	0.0
2019	35	10	28.57	70.0	30.0
Total	1006	303	30.12	57.9	42.1

Source: http://www.accessdata.fda.gov/scripts/importrefusals/.

and lack of knowledge in exporting of fruits as size & variety of mango. The inferior quality of genetic stocks, high incidence of diseases and excess use of pesticides increases the cost of farmers and also increases the chance of rejection of export consignment. The present findings of the study are supported by the findings of Hegde, (2006) and Reddy and Kumar (2010). Besides, the export of mango requires proper post-harvest management techniques such as hot water treatment, vapor heat treatment and irradiation technique. Japan, UK and other EU countries do not allow import of mango without vapor heat treatment (APEDA 2007). There are only six VHT centers operating in India and out of these, two are not working properly i.e. one in Uttar Pradesh and one in Andhra Pradesh. However, both-pack houses and VHT centers were on lease by the big exporters which acts as a hurdle for small exporters for exporting their product. Exporters further reported that they cannot export mango to USA without irradiation treatment, and the country's only irradiation center is at Lasalgaon, about 70 km from Nasik in Maharashtra which started working from 16 March, 2007. Another two centers located in Karnataka and Vashi (Mumbai) have starting working only recently (2016 onwards).The major hurdles that are restricting exports from India are availability of fewer varieties for exports, high shipping charges, limited cargo space, poor labelling and costly packaging (specific packaging for each produce made of bio-degradable materials only).Main constraints faced by mango exporters in Andhra Pradesh and Uttar Pradesh is lack of sufficient VHT canters. Besides, Uttar Pradesh lacks processing units, as such it's unable to export processing mango products .As far as Andhra Pradesh is concerned, and it lacks exportable variety of fresh mango.

Problems faced by the exporters at international level: The exporters reported that they have to bear 100 percent risk in case of rejection of consignment, due to any reason, as the help from the government side is negligible. High freight charges increases the price of mango, thereby decreasing its competitiveness in the international market. Baliyan (2017) has found that India has a very high comparative advantage in mango export but is unable to enjoy competitiveness at international level .the reason being the high domestic prices of mango as compared to prices at international level. The exporters reported that they are facing the refusals of exports consignments, particularly from the developed countries, as there is a lack of international standard in branding and packaging, not only in fresh mango but in processed products also.

Suggestions given by the exporters to improve mango export: It was suggested that to tackle sophisticated regulations like registration, packaging &labeling, pesticide residue & aflatoxin content, fruit fly regulations and labour standards involved in exporting products, adequate number of pack houses and VHT centers are required to be established near the production area. The costly freight charges, restricted cargo space and high packaging cost needs to be removed. Since the importing countries demand specific packaging for each produce, the use of bio-degradable materials should be taken care off.

To bridge these gaps and improve competitiveness of mango in the world markets, India has taken several significant steps such as setting-up of National Horticulture Mission (NHM), mango pack houses and Codex Committee and broadening of export basket by APEDA. These reforms have enhanced the access of Indian exports to international markets. APEDA has also been organizing mango promotion programs in different countries. The Government of India is also taking steps to encourage exports of agro products, including mangoes through measures and incentives under planned schemes through Export Promotion Councils & APEDA. Besides ,various schemes namely Market Development Assistance (MDA), Market Assistance Initiative (MAI), Assistance to States for Developing Export Infrastructure and Allied Activities (ASIDE), Vishesh Krishi and Gram UpajYojana, Focus Product Scheme, Focus Market Scheme, Town of Export Excellence, etc. are there to provide assistance to encourage exports. The Government also established mango pack houses, VHT centers, Hot Water treatment and Irradiation technique plant during 2005-06 to meet the International Standards and to increase the mango export from India. This had a positive impact on the value of exports especially to developed countries like USA, Japan, UK, etc. these efforts led to the increase of exports at 5.8 per cent annum in value terms of 5.8 per annum (Table 4).

CONCLUSION

India's export of mango is going up but not proportionately to total production. At domestic level, a number of factors have affected export of mango from the country like, fluctuations in output due to weather conditions, costly transportation, lack of gradation and quality control, excessive use of pesticides & insecticides, marketing problems. Besides, other issues like inefficient post-harvest management i.e., proper cooling and packing facility, careful handling, and proper management of environment like temperature, humidity, proper ventilation and sanitation apart from storage facilities. Further, constraints like suitability of few varieties for exports, high freight charges, limited cargo space, high packaging cost and poor labeling also restricts the expansion of mango exports from India. At international level, incidences of NTMs in mangoes are also hindering mango exports. Though, to remove these aforementioned hurdles, the government has taken many efforts. But a lot more is needed to be done to boost export of mango at national as well as international level.

ACKNOWLEDGEMENT

This paper is based on the project "Impact of WTO Provisions on Horticultural Exports: The Case of Indian Mango" Sponsored by Indian Council of Social Science Research (ICSSR), New Delhi. Author is Thankful to the ICSSR for providing the Financial Support for the project.

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Received 25 October, 2021; Accepted 21 January, 2022

Indian Journal of Ecology (2022) 49(2): 491-495
DOI: https://doi.org/10.55362/IJE/2022/3550

Manuscript Number: 3550
NAAS Rating: 5.79

Pre-harvest Application of Calcium Maintained Fruit Quality in Cold Stored Plum

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Abstract: An experiment was conducted to study the influence of pre-harvest applications of different concentrations of calcium nitrate on various physico-chemical parameters of plum (*Prunus salicina* L.) *cv.* Satluj Purple under cold storage conditions. Uniform and healthy plants of plum *cv.* Satluj Purple were sprayed with calcium nitrate (1.0, 1.5 and 2.0 %) in 2[nd] and 3[rd] week of April and control plants were water sprayed only. Fruits from both treated and control plants were harvested at colour break stage, and then stored at low temperature conditions (0–1 °C and 90–95 % RH) for 35 days. Evaluation of different physico-chemical parameters were made on 0 day and after 7, 14, 21, 28 and 35 days of storage. The results revealed that two sprays of $Ca(NO_3)_2$ @ 2.0 % retained maximum pulp: stone (15.37), total soluble solids (12.93 %), titratable acidity (0.69 %), reducing (6.52 %) & non-reducing sugars (2.64 %) and total phenolics content (101.19 mg $100g^{-1}$) at the end of storage. The fruits treated with two sprays of $Ca(NO_3)_2$ @ 2.0 % were effective in maintaining the quality of fruits without any spoilage up to 35 days under low temperature storage conditions.

Keywords: Calcium nitrate, Plum, Titratable acidity, Spoilage, Total phenolics content

Plum is an important stone fruit grown in north-western provinces of India. Amongst different varieties of Japanese plum, 'Satluj Purple' has gained a special importance among plum growers of north western India, due to its early ripening behavior, low chilling requirement, high yield, attractive colour, excellent flavour and better size. The fruit is rich in vitamins and minerals which makes them highly nutritious and contains certain phytochemical compounds like polyphenols and anthocyanins which imparts them anti-oxidative, anti-carcinogenic, anti-microbial, anti-allergic, anti-mutagenic and anti-inflammatory properties (Thanaa et al 2017). But its keeping quality under ambient conditions is poor due to the climacteric nature of ripening which ensues fruit softening and susceptibility to post-harvest spoilage, thus lowering its marketing value. The harvesting time of this fruit coincides with very hot and dry conditions in the region which further reduces the shelf-life of fruits. Thus, to overcome these post-harvest losses several pre- and post-harvest methods have been employed to enhance the storage life of plum fruits, by minimizing the spoilage, reducing the rate of respiration, ethylene emissions & transpiration losses. Calcium is considered as an important essential nutrient involved in various physiological processes in plant concerning the maintenance of membrane structure & function and various enzymatic activities (Sinha et al 2019b).It is a chief constituent of cell wall, involved in forming cross-bridges and therefore strengthens & maintains the rigidity of the cell wall and prevent fruit spoilage (Ayon-Reyna et al 2015). It effectively reduces the hydrolytic activities of enzymes thus delaying the degradation, softening and senescence of fruits and also inhibits the polygalacturonase and pectin methylesterase activity (Madani et al 2014). Pre-harvest treatment of guava fruits with calcium nitrate resulted in an increase in calcium concentration of the cell wall, maintained the fruit firmness & quality and effectively delayed the senescence (Bisen et al 2014). Calcium treatments efficiently retained the phenolic compounds and minimized decay percentage in pear (Khalaj et al 2017) and peach (Gayed et al 2017) fruits. Calcium application can be incorporated in the production system so as to improve the quality attributes of fruit as well to minimize the usage of chemical fungicides (Moradinezhad et al 2019). Keeping in view the concern of food safety among consumers and harmful effect of chemical residues, calcium nitrate has been found as a safe and effective method to reduce fruit spoilage and preserve its quality parameters. Hence, the aim of study was to determine the effect of application of calcium nitrate on fruit quality of plum fruits during low temperature storage.

MATERIAL AND METHODS

For the experiment, twenty eight uniform and healthy plants of plum *cv.* Satluj Purple were selected at the Fruit Research Farm, Department of Fruit Science, Punjab Agricultural University, Ludhiana (India) in the year 2017.

Twenty four plants were sprayed with calcium nitrate (1.0, 1.5 and 2.0 %) in 2nd and 3rd week of April and four were kept untreated. Fruits from treated and untreated plants were harvested at colour break stage. The fruits of uniform size, free from diseases and bruises were selected, washed and air dried under shade before packaging. The experiment comprised of seven treatments with four replications in each treatment. One kg of fruit from every replication of each treatment was packed in 5% perforated corrugated fibreboard (CFB) boxes lined with paper and stored at low temperature conditions (0-1°C and 90-95 % RH) for 35 days. For study of storage behaviour, fruit samples were analysed on 0 day and after 7, 14, 21, 28 and 35 days of storage period for various physico-chemical characteristics. After each interval of cold storage, pulp to stone ratio was calculated by separating and weighing the pulp and stone of individual fruits. The per cent of spoiled fruits was calculated by counting the spoiled fruits on the number basis and expressed in percentage. Total soluble solids (TSS) in fruit juice were determined by hand refractometer while titratable acidity was determined as malic acid percentage. Total phenolic content was estimated as per the method followed by Sinha et al (2019a), using folin-ciocalteu phenol reagent and the absorbance of resultant blue colour was determined in 'Spectronic-20 D+' colorimeter at 760nm wavelength against blank reagent. Methods followed by Kaur et al (2015) were used to determine the reducing and non-reducing sugars.

The data were statistically analyzed using using statistical package SAS 9.3 (The SAS system for Windows, Version 9.3, SAS Institute, Cary, NC)and significant effects ($P \leq 0.05$) were noted.

RESULTS AND DISCUSSION

Pulp: stone: Pulp: stone in fruits decreased with the advancement of storage period (Table 1) due to the loss of moisture irrespective of the treatments. However, this decrease was slower in calcium treated fruits as compared to untreated fruits. From the day of harvesting to 35 days of storage, fruits treated with two sprays of $Ca(NO_3)_2$ @ 2.0% recorded minimum decline (13.75%) in pulp-stone ratio as compared to control fruits (20.31%), followed by fruits received one spray of $Ca(NO_3)_2$ @ 1.0%. Similar view was shared by Raja et al (2015) in peachfruits.

Total soluble solids: During storage, TSS contents varied significantly with different calcium treatments. The data evidently shows that TSS content increased in fruits treated with two sprays of $Ca(NO_3)_2$ up to 28 days, whereas in untreated fruits TSS content increased only up to 21 days of storage period and, thereafter a sharp decline in the TSS content was recorded (Table 1). From the day of harvesting to 21 days of storage period, fruits treated with two sprays of $Ca(NO_3)_2$ (2.0%) registered minimum (11.39 %) increase in TSS content, whereas this increase was found maximum (12.38%) in control fruits. This slow increase in TSS content in calcium treated fruit at the initial stage of the storage period might be due to the formation of thin layer of calcium on the fruit surface which delays the solubilisation of polysaccharides. However, after 35 days of storage period TSS content recorded in fruits treated with two sprays of $Ca(NO_3)_2$ @ 2.0% was 6.5% higher as compared to untreated fruits. Maintenance of higher TSS content in fruits received two sprays of $Ca(NO_3)_2$ (2.0%) at the end of storage period may be attributed to the slower dehydration processes as well as the conversion of complex polysaccharides (like starches and pectins) into simple sugars. Similar results were reported by Khalaj et al (2017) in pears where higher TSS was retained in calcium treated fruit.

Titratable acidity: Titratable acidity registered an overall decreasing trend during the storage period irrespective of the treatments due to the breakdown of organic acids into sugars during respiration process (Table 1). However, the pace of decline of acidity in fruits treated with calcium was less as compared to control fruits. Titratable acidity is directly related to the concentration of principle organic acids, which is an important attribute in the maintenance of fruit quality. From the day of harvesting to 35 days of storage, fruits subjected to two sprays Ca $(NO_3)_2$ @ 2.0% registered lowest decline (40.52%) in acidity against 57.95% in control fruits. The reason for delayed reduction in acidity in calcium treated fruits may be due to suppression in the metabolic activities which in turn delay the organic acids utilization in the pyruvate decarboxylation pathway, during the ripening process (Wang et al 2014). Similar finding in view of slow decline in acidity was reported in calcium treated papaya fruits by Madani et al (2014).

Fruit spoilage: The spoilage of plum fruits increased with the progression of storage period (Table 1). However, fruits treated with calcium did not show any spoilage up to 21 days of storage, whereas control fruits started deteriorating after 14 days of storage period. Moreover, no spoilage was observed in fruits treated with two sprays of Ca $(NO_3)_2$ (1 %, 1.5 % and 2.0 %) till the end of storage period (35 days). Reduced spoilage percentage of calcium treated plum fruits may be due to increased deposition of calcium pectate resulting into thickening of middle lamella of the cell wall thus inhibiting the penetration and accessibility of hydrolase enzymes of pathogens in fruits (Ayon-Reyna et al2015). Calcium also accelerates the synthesis of phytoalexin and phenolic compounds which further inhibits the activity of enzymes secreted by the fungus (Awanget al 2011), thus preventing fruit spoilage. Similar results were reported earlier by Gayed et al (2017) in peach where pre-harvest application of calcium effectively minimized the fruit spoilage during low temperature storage conditions.

Total phenolics content: A declining trend in the phenolics content with storage was observed in all fruits regardless of the treatments (Table 2). However, this decline was slower in fruits treated with calcium as compared to control depicting the suppression of polyphenol oxidase activity with the application of calcium nitrate. From the day of harvesting to 35 days of storage, fruits subjected to two sprays $Ca(NO_3)_2$ @ 2.0 % recorded minimum decline in phenolics content by 46.94% in contrast to control fruits where maximum decline (52.22 %) in total phenolics content was recorded. At the end of 35 days of storage period fruits received two sprays $Ca(NO_3)_2$ @ 2.0 % recorded 8.38 % higher phenolics content in comparison to control fruits. This signifies the efficacy of two sprays $Ca(NO_3)_2$ @ 2.0 % in maintaining the phenolics content as calcium compounds strengthen the cell walls, maintains the selective exchange of ions and gases (Zeraatgar et al 2018), prevents the leaching of polyphenol compounds, therefore causing reduction in the oxidation of phenols (Turmanidze et al 2016).

Table 1. Pulp: stone, TSS, (B.) titratable acidity and (C.) fruit spoilagein plum *cv*. Satluj Purple during cold storage (0-1°C, 90-95% RH) in relation to pre-harvest treatment with different concentration of calcium nitrate

Parameter	Treatments	Storage time (days)					
		0	7	14	21	28	35
Pulp: stone	T1	17.08^{d}	15.25^{c}	14.81^{d}	14.50^{d}	14.29^{b}	13.95^{d}
	T2	17.19^{cd}	15.42^{c}	15.04^{c}	14.75^{cd}	14.54^{b}	14.26^{cd}
	T3	17.24^{cd}	15.49^{bc}	15.13^{c}	14.87^{c}	14.66^{b}	14.38^{c}
	T4	17.49^{bc}	15.83^{ab}	15.57^{b}	15.36^{b}	15.25^{a}	15.01^{b}
	T5	17.74^{ab}	16.11^{a}	15.89^{a}	15.70^{ab}	15.52^{a}	15.33^{ab}
	T6	17.82^{a}	16.17^{a}	15.94^{a}	15.76^{a}	15.59^{a}	15.37^{a}
	T7	16.69^{e}	14.79^{d}	14.30^{e}	13.81^{e}	13.48^{c}	13.13^{e}
TSS (%)	T1	11.89^{a}	12.85^{a}	13.23^{ab}	13.51^{ab}	12.75^{c}	12.43^{ab}
	T2	11.73^{ab}	12.67^{ab}	13.03^{abc}	13.28^{ab}	12.89^{bc}	12.61^{ab}
	T3	11.67^{ab}	12.62^{ab}	12.97^{abcd}	13.22^{abc}	12.97^{bc}	12.68^{ab}
	T4	11.38^{ab}	12.30^{ab}	12.62^{bcd}	12.85^{bcd}	13.50^{ab}	12.76^{ab}
	T5	11.09^{b}	12.01^{b}	12.32^{cd}	12.53^{cd}	13.78^{a}	12.91^{a}
	T6	11.04^{b}	11.94^{b}	12.24^{d}	12.46^{d}	13.85^{a}	12.93^{a}
	T7	12.03^{a}	13.03^{a}	13.45^{a}	13.73^{a}	12.52^{c}	12.09^{b}
Titratable acidity (%)	T1	0.94^{de}	0.81^{d}	0.71^{de}	0.62^{c}	0.56c^{d}	0.45^{bc}
	T2	0.97^{cde}	0.86^{cd}	0.77^{cd}	0.65^{c}	0.61b^{c}	0.48^{bc}
	T3	1.02^{bcd}	0.90^{c}	0.81^{bc}	0.68^{c}	0.64^{abc}	0.51^{bc}
	T4	1.07^{abc}	0.99^{b}	0.87^{ab}	0.79^{b}	0.69^{ab}	0.57^{ab}
	T5	1.12^{ab}	1.05^{ab}	0.91^{a}	0.85^{ab}	0.72^{ab}	0.65^{a}
	T6	1.16^{a}	1.08^{a}	0.94^{a}	0.89^{a}	0.75^{a}	0.69^{a}
	T7	0.88^{e}	0.71^{e}	0.63^{e}	0.52^{d}	0.43^{d}	0.37^{c}
Spoilage (%)	T1	0.00^{f}	0.00^{f}	0.00^{f}	0.00^{f}	1.76^{d}	3.82^{b}
	T2	0.00^{f}	0.00^{f}	0.00^{f}	0.00^{f}	1.11^{e}	3.19^{c}
	T3	0.00^{f}	0.00^{f}	0.00^{f}	0.00^{f}	0.98^{e}	3.08^{c}
	T4	0.00^{f}	0.00^{f}	0.00^{f}	0.00^{f}	0.00^{f}	0.00^{f}
	T5	0.00^{f}	0.00^{f}	0.00^{f}	0.00^{f}	0.00^{f}	0.00^{f}
	T6	0.00^{f}	0.00^{f}	0.00^{f}	0.00^{f}	0.00^{f}	0.00^{f}
	T7	0.00^{f}	0.00^{f}	1.97^{d}	3.91^{b}	4.26^{b}	6.34^{a}

T-1: one spray $Ca(NO_3)_2$(1.0 %), T-2: one spray $Ca(NO_3)_2$(1.5 %), T-3: one spray $Ca(NO_3)_2$(2.0%), T-4: two sprays $Ca(NO_3)_2$(1.0 %), T-5: two sprays $Ca(NO_3)_2$(1.5 %), T-6: two sprays $Ca(NO_3)_2$(2.0%), T-7: control. Means in the columns and rows with the same letter are not significantly different at ($p \le 0.05$) according to LSD.

Table 2. Total phenolics content, reducing sugars and non-reducing sugarsin plum *cv*. Satluj Purple during cold storage (0-1^{o}C, 90-95% RH) in relation to pre-harvest treatment with different concentration of calcium nitrate

Parameter	Treatments	Storage time (days)					
		0	7	14	21	28	35
Total phenolics content (mg 100g^{-1})	T1	182.31^d	151.79^d	137.53^d	110.56^b	95.83^e	92.62^c
	T2	184.17^{cd}	154.56^{cd}	140.69^c	114.48^b	98.65^d	94.37^c
	T3	185.54^{bc}	155.73^{bcd}	142.65^c	115.72^b	99.84^c	95.56^c
	T4	186.65^b	158.82^{abc}	145.58^b	120.81^a	105.47^b	97.29^b
	T5	190.19^a	160.27^{ab}	147.79^{ab}	122.45^b	108.32^a	100.65^a
	T6	190.71^a	161.43^a	148.82^a	124.09^a	109.76^a	101.19^a
	T7	178.32^e	146.15^e	133.74^e	105.43^c	89.54^f	85.21^d
Reducing sugars (%)	T1	11.89^b	12.85^b	13.23^{ab}	13.51^{ab}	12.75^d	12.43^c
	T2	6.75^c	6.87^c	7.06^{bc}	7.20^{bc}	6.51^c	6.03^{bc}
	T3	6.57^c	6.66^c	6.82^{bc}	6.94^{bc}	6.68^c	6.12^{bc}
	T4	6.53^d	6.62^d	6.76^{cd}	6.89^c	6.73^b	6.15^{ab}
	T5	6.37^d	6.46^{de}	6.57^{cd}	6.68^c	6.93^a	6.31^a
	T6	6.31^d	6.37^e	6.50^d	6.57^c	7.02^a	6.49^a
	T7	6.26^a	6.32^a	6.43^a	6.51^a	7.08^e	6.52^c
Non-reducing sugars (%)	T1	2.73^{abc}	2.78^{abc}	2.86^{abc}	2.92^{ab}	2.64^{ab}	2.44^{bc}
	T2	2.66^{ab}	2.70^{ab}	2.76^{ab}	2.81^{ab}	2.71^{ab}	2.48^c
	T3	2.64^{ab}	2.68^a	2.74^a	2.79^{ab}	2.73^b	2.49^c
	T4	2.58^c	2.62^c	2.66^d	2.70^c	2.81^{ab}	2.56^a
	T5	2.56^{bc}	2.58^c	2.63^{cd}	2.66^{bc}	2.84^{ab}	2.63^{ab}
	T6	2.54^{abc}	2.56^{bc}	2.60^{bcd}	2.64^{abc}	2.87^{ab}	2.64^{ab}
	T7	2.79^a	2.85^a	2.94^a	3.01^a	2.56^b	2.39^c

See Table 1 for details.

Reducing and non-reducing sugars: Sugars have a critical role in determining the palatability of the fruits. The reducing and non-reducing sugars followed similar trend during storage studies (Table 2). Fruits treated with two sprays of $Ca(NO_3)_2$ showed an increase in both reducing and non-reducing sugars up to 28 days, whereas in untreated fruits this increase was recorded only up to 21 days of storage period and, thereafter it declined gradually. The initial increase in sugars is due to the breakdown of complex polysaccharides into simple sugars, which at later stages get utilized in the respiration process, thus resulting into decline of sugars (Adhikary et al 2021). From the day of harvesting to 21 days of storage period fruits subjected to two sprays $Ca(NO_3)_2$ @ 2.0% recorded minimum rate of increase (3.99 and 3.79%, respectively) in reducing and non-reducing sugars in fruits against 7.27% and 14.34% in control fruits. This might be due to slow conversion of starch into sugars and the gradual build up of sugars in calcium treated fruit may be associated with delayed ripening. These results are in line with the findings of Kaur et al (2015) in plum and Sidhu et al (2020) strawberries where calcium application effectively maintained reducing and non-reducing sugars in fruit.

CONCLUSION

In conclusion two sprays of $Ca(NO_3)_2$ @ 2.0% inhibited the spoilage of plum fruits up to 35 days of storage and was most effective in extending the storage life and maintaining the quality of plum fruits during cold storage.

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Received 05 January, 2022; Accepted 02 April, 2022

Indian Journal of Ecology (2022) 49(2): 496-501
DOI: https://doi.org/10.55362/IJE/2022/3551

Manuscript Number: 3551
NAAS Rating: 5.79

Effect of Girdling on Yield and Quality of Kiwifruit (*Actinidia deliciosa* Chev.) Raised through Different Propagation Methods

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Abstract: The present investigation entitled "Effect of girdling on yield and quality of kiwifruit (*Actinidia deliciosa* Chev.) raised through different propagation methods was carried out during 2019-20 at Dr. YS Parmar University of Horticulture and Forestry, Nauni-Solan, Himachal Pradesh. Ten years old vines of uniform size and vigour, planted at 4.0 m × 6.0 m spacing were selected for the study. There were twelve treatment combinations. The experimental plants were raised through three different modes of propagation *viz.*, *in situ*, grafting and own rooted (cuttings) which were planted in different sections of experimental orchard. Four different girdling levels namely; full (100% girdling), 1/2 (50% girdling), 1/4 (25% girdling) and no girdling were applied to the experimental vines. The grafted kiwifruit vines girdled upto 1/4 (25%) trunk girth by removing 2 mm bark in the last week of March exhibited best performance in terms of improvement in flower and yield parameters namely; number of flowers per shoot, per cent fruit set, number of fruits per shoot, total yield and graded yield.

Keywords: Kiwifruit, Girdling, Propagation, Quality, Yield

The kiwifruit (*Actinidia deliciosa* Chev.) belonging to the family, Actinidiaceae is the most recent fruit crop grown and marketed successfully in the world (Shastri et al 2012) and native to Yangtze River valley of northern China and Zhejiang Province on the coast of eastern China. In the World, the major kiwifruit producing countries are China, Italy, New Zealand and Chile. China is the leading kiwifruit producing country with an annual production of 1.39 million tonnes, followed by Italy with 0.41 million metric tonnes and New Zealand with 0.32 million tonnes (FAO 2020). In India, this fruit is successfully grown in Arunachal Pradesh, Nagaland, Mizoram, Sikkim, Himachal Pradesh and Uttrakhand. The area under kiwifruit in India is reported to be 5,000 ha with the production of 13,000 MT (NHB 2019). Himachal Pradesh produced 254 MT of kiwifruit from an area of 145 ha (Anonymous 2018).

The kiwifruit is propagated either through grafting onto the seedling rootstock or semi-hardwood or hardwood cutting to ensure production of true type plants (Hamdi et al 2006). *In situ* propagation technique ascertain the purity of the variety and gives certainty of quality planting material and also minimizes other problems like transportation, wastage of time and mental stress of the farmers. Cutting is very useful method of propagation for production of kiwifruit and it is more quick and cheap because plants grown on their own roots and eliminate the rootstock for grafting (Baber et al 2018).

Girdling involves removal of a strip of bark from the trunk or major limbs of a fruit tree, thereby blocking the downward translocation of photosynthates and other metabolites through the phloem. Trunk girdling temporarily increases the availability of carbohydrates to the developing fruit through disruption in the source sink relationship (Black et al 2012). Mineral elements namely; nitrogen, phosphorus, potassium, calcium, and magnesium are stored in the leaves through girdling which can break off the phloematic flow. The positive effect of girdling on the fruit size and yield via improvement of photosynthates supply towards developing fruits has been well documented for grape, peach, nectarine, citrus, mango, avocado, olive, and persimmon (Assar et al 2009). The objective of the present study is to elucidate the comparative performance of kiwifruit plants raised through different propagation methods and to elucidate the effect of girdling on the yield and quality of kiwifruit.

MATERIAL AND METHODS

The present investigation entitled "Effect of girdling on yield and quality of kiwifruit (*Actinidia deliciosa* Chev.) raised through different propagation methods" was carried out at Dr Y S Parmar UHF, Nauni, Solan, (HP) during the year 2019-2020. The experiment was conducted at an elevation of 1260 m above mean sea level with latitude of 30º 50' North and longitude of 77º11'30" East. The experiment was conducted on 10 years old vines of kiwifruit cv. Allison. The vines were maintained under uniform cultural practices and planted at a spacing of 4m × 6m. The vines were trained on T- bar system. The experiment was laid out according to Randomized Block

Design with 12 treatment combinations (Table 1). In the present study, the experimental plants were raised through three different modes of propagation *viz*., *in situ*, grafting and own rooted (cuttings) which were planted in different sections of experimental orchard. In all, the experimental vines, four different girdling levels namely; full (100% girdling), 1/2 (50% girdling), 1/4 (25% girdling) and no girdling were applied. Girdling of trunk was done during the last week of March at the base with the help of girdling knife. A 2mm of bark was removed in the form of full (100% girdling), 1/2 (50% girdling) and 1/4 (25% girdling).

Leaf area index was calculated as the ratio of the leaf surface (one side only) of a plant to the ground area occupied by the plant (Chen and Cihlar 1995). Leaf area measured in the field using LP-80 PAR/LAI ceptometer in the month of July to first week of August. The girth of experimental kiwifruit vines was measured in cm above the ground level by using measuring tape before start of the experiment and then at the end of growing period. The carbohydrate contents of leaf and shoot were determined as per the method described by Thimmaiah (2006). Carbohydrate content was estimated by drying samples and weighing 100 mg then crushed in pestle and mortar, and taken in boiling tube. It was then hydrolyzed by keeping it on boiling water bath for 3 hours with an addition of 5 ml of 2.5 N HCL. The sample solution was cooled to room temperature. After cooling, it was neutralized by adding solid sodium carbonate until effervescence ceased. Then, the final volume was made to 100 ml by adding distilled water and centrifuged. One ml of supernatant was taken in the test tube for analysis and 4 ml of the anthrone reagent was added to it and mixed well by vortexing. The mixture was heated for 8 minutes in boiling water bath. The contents were cooled rapidly and the intensity of green to dark green colour was measured at 630 nm using UV-VIS spectrophotometer. The yield of fruits under each treatment was determined on the basis of weight of crop load removed from each vine at the time of harvest and expressed as kilogram per vine (kg/vine).The fruits harvested from vines were categorized into three grades on the basis of fruit weight. These grades were A grade (> 80 g), B grade (50-80 g) and C grade (< 50 g). The per cent of different grade fruits per vine was calculated by using the following formula:

$$\text{Per cent yield of grade 'X'} = \frac{\text{Yield of grade X (kg/vine)}}{\text{Total yield (kg/vine)}} \times 100$$

Where, 'X' = Grade A or B or C

The fruit samples were collected for physico-chemical analysis when the fruits had attained optimum maturity (TSS > 6.5%). The size of fruit was measured in terms of fruit length and fruit breadth and expressed in millimeters. The total soluble solids content in fruit were determined by Erma hand Refractometer (0-32^0 Brix). The total soluble solids were expressed as per cent. Total sugars and ascorbic acid were estimated by using the standard methods (AOAC 1984). The sugar acid ratio was calculated by dividing per cent total sugars by per cent titratable acidity.

Leaf sampling was done in the second fortnight of August, according to guidelines of Cresswell (1989). From each experimental vine, 30 healthy leaves along with petioles were collected from middle of 5-6 months old new shoots in all the directions. After sampling, leaves were gently washed in running tap water to remove the dirt, soil particles, spray residues and then the leaves were washed with distilled

Table 1. Effect of girdling on the vegetative growth parameters of kiwifruit raised through different propagation methods

Treatment code	Treatment details	Leaf area index	Per cent increase in trunk girth	Number of shoots/cane	Shoot carbohydrate content (%)
T_1	*In situ* + full girdling	2.59	7.12	4.55	2.92
T_2	*In situ* + 1/2 girdling	2.78	7.29	4.75	2.86
T_3	*In situ* + 1/4 girdling	3.11	7.81	5.06	2.65
T_4	*In situ* without girdling	3.90	7.73	5.60	2.33
T_5	Grafted + full girdling	2.61	7.81	4.63	3.25
T_6	Grafted + 1/2 girdling	2.90	8.00	4.96	3.99
T_7	Grafted + 1/4 girdling	3.49	8.16	5.21	4.22
T_8	Grafted without girdling	3.98	8.38	5.66	2.01
T_9	Own rooted + full girdling	2.63	8.58	4.60	4.02
T_{10}	Own rooted + 1/2 girdling	2.97	9.26	4.68	2.86
T_{11}	Own rooted + 1/4 girdling	3.76	9.70	5.50	3.24
T_{12}	Own rooted without girdling	4.10	8.53	5.88	1.94
CD (p=0.05)		0.12	0.54	NS	0.35

water. The washed leaves were put in brown paper bags. The samples were dried in an oven at 60 ± 5°C for nearly 48 hours until reaching at constant dry weight. After drying, samples were ground and sieved to obtain finely ground samples. The samples were analyzed for macro nutrients. For nitrogen estimation, 0.5g dried samples were taken in Kjeldahl flask and digested in 10 ml of concentrated H_2SO_4 in the presence of 1 g digestion accelerator which was prepared by mixing 2.5 g SeO2, 100 g K_2SO_4 and 20 g of $CuSO_4.5H_2O$. In case of phosphorus and potassium one gram of dried leaf sample was digested with 10 ml Di-acid mixture prepared by mixing nitric acid and per chloric acid in a ratio of 4:1 (v/v) (Jackson 1973). The data obtained from these observations were appropriately computed, tabulated and analyzed by applying Randomized Block Design (RBD) as given by (Panse and Sukhatme 2000). The level of significance was tested for different variable at 5 per cent level of significance (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Vegetative growth paramerters: The leaf area index (LAI) was significantly influenced by different levels of girdling in kiwifruit vines, raised through different propagation methods (Table 1). The highest leaf area index (4.10) was noticed in the ungirdled own rooted vines which was statistically at par with ungirdled grafted vines whereas, the lowest leaf area index (2.59) was in fully girdled *in situ* vines. The possible reason for reduction in leaf area index with full girdling might be due to the low photosynthetic rate. The results of present study are supported by earlier findings of Richardson et al (2021) who reported that the girdling might create imbalance in the source-sink ratios, transpiration rates and structural properties of the leaves. The decline in photosynthetic rate was also achieved by a decline in photosynthetic capacity under full girdling (Asao and Ryan 2015). Cheng et al (2008) reported that the decrease in the photosynthesis rate after girdling is mainly caused by closing of the stomatal aperture and reduction in RuBP activity per leaf area.

The highest (9.70%) increase in trunk girth was in own rooted vines subjected to 1/4 girdling treatment which was statistically at par with 1/2 girdled own rooted vines. The lowest increase in vine girth (7.12%) was in fully girdled grafted vines. The highest carbohydrate content (4.22%) was observed in shoots of 1/4 girdled grafted vines which was statistically at par with 1/2 girdled grafted and fully girdled own rooted exhibiting 3.99 per cent and 4.02 per cent shoot carbohydrate contents, respectively. The lowest shoot carbohydrate content (1.94%) was observed in ungirdled own rooted vines shown in (Table 1). Girdling expressed a significant accumulation of carbohydrate contents in bearing shoots.

Yield parameters: The highest yield (43.29 kg/vine) was recorded in 1/4 girdled grafted vines which was statistically at par with 1/2 girdled grafted vines. Whereas, the lowest yield (30.38 kg/vine) was recorded in ungirdled own rooted vines depicted in Table 2. The highest proportion of grade 'A' fruits had significantly improved with all the girdling treatments, but more noticeable effect was observed in 1/4 girdled grafted vines which yielded highest proportion (24.24 kg/vine) of 'A' grade fruits, contributing 56 per cent towards total yield. This treatment was closely followed by treatment 1/2 girdled grafted and 1/4 girdled own rooted. The lowest (9.31 kg/vine)

Table 2. Effect of girdling on yield and physical characteristics of kiwifruit raised through different propagation methods

Treatment code	Fruit yield (kg/vine)	Graded yield (kg/vine)			Fruit size (mm)		Fruit weight (g)
		A	B	C	Length	Diameter	
T_1	32.11	9.31	11.24	11.56	61.98	42.27	68.52
T_2	34.10	11.94	9.89	12.28	65.90	41.88	67.36
T_3	36.29	14.15	11.98	10.16	62.46	41.78	67.75
T_4	32.54	13.99	10.09	8.46	65.64	41.39	65.04
T_5	40.05	17.82	12.96	9.72	63.65	42.35	68.86
T_6	42.00	20.58	11.76	9.66	66.58	42.50	68.75
T_7	43.29	24.24	12.99	6.06	66.87	42.87	68.98
T_8	32.49	17.54	8.77	6.17	63.25	41.14	67.62
T_9	31.33	16.60	8.15	6.58	62.62	41.16	63.45
T_{10}	31.65	16.46	7.91	7.28	64.79	41.88	67.36
T_{11}	36.70	18.72	8.81	9.18	65.90	42.28	67.75
T_{12}	30.38	15.19	8.51	6.68	60.46	40.10	61.52
CD (p=0.05)	1.85	0.44	0.52	0.17	1.30	1.06	1.53

yield of 'A' grade fruits was observed with fully girdled *in situ* treatment, which was significantly lower than all other treatments. Highest proportion of 'B' grade fruits (12.99 kg/vine) comprising 30 per cent of the total yield was observed in treatment grafted plants with 1/4 girdling. The minimum yield of 'B' grade fruits (7.91 kg/vine) was recorded in 1/2 girdled own rooted vines. The yield of 'C' grade fruits was reduced significantly with different treatments of girdling. The highest 'C' grade fruits (12.28 kg/vine) contributing 36 per cent of total fruit yield were obtained in 1/2 girdled *in situ*. The lowest yield of 'C' grade fruits (6.06 kg/vine) was with 1/4 girdled grafted treatment. The data on different grade fruits are presented in (Table 2). The results of present study are supported by the earlier findings of Rivas et al (2006) who reported that girdling increased the yield by 28 per cent in 'Fortune' mandarin and 'Clausellina' Satsuma mandarin. Fayek et al (2011) on Le Conte pear found that girdling significantly increased yield comparing with the control. Girdling disrupts basipetal transport in the phloem, which results in the removal of apical dominance and an increase in root-derived cytokinins.

Fruit quality parameters: Different levels of girdling in kiwifruit vines raised through different propagation methods significantly influenced the fruit quality parameters (Table 2. The highest fruit length (66.87 mm) and diameter (42.87 mm) were in the 1/4 girdled grafted vines. whereas, the lowest fruit length (60.46 mm) and diameter (40.10 mm) was with ungirdled own rooted vines, the better solute uptakes and more formation of carbohydrates lead to improve fruit size. The results are also in accordance with Khandaker et al (2011). The highest fruit weight (68.98g) was in 1/4 girdled grafted vines, which was statistically at par with *in situ* + full girdling, *in situ* + 1/2 girdling, grafted + full girdling), grafted + 1/2 girdling), grafted without girdling, and own rooted + 1/4 girdling. However, the lowest fruit weight (61.52g) was observed in ungirdled own rooted vines. The significant increase in fruit weight in girdled vines is attributed to the more assimilates and more availability of carbohydrates to the fruits as a result of which the fruits gained more fruit weight. Kabeel et al (2018) also observed that girdling treatment significantly enhanced the fruit weight in comparison to control.The highest (16.03%) TSS was recorded in 1/4 girdled grafted vines which was found to be statistically at par with (15.30%) 1/2 girdled grafted vines (Table 3). The results of the present study are in accordance with the findings of Hockema and Echeverria (2000). This may be due to the increased photosynthetic rate provided by higher leaf fruit ratio and girdling (Lata et al 2010). The highest titratable acidity (1.55%) was recorded in ungirdled *in situ* vines and the lowest (1.23%) was recorded in 1/4 girdled own rooted vines. The improvement in fruit quality in terms of high TSS and low acidity in the present study could be attributed to accumulation of more carbohydrates above the girdled ring and reduction in inter-fruit competition for water, minerals and other assimilates. The results are in accordance with the findings of Eliwa (2003) and Lata et al (2010). The highest (76.92 mg/100g fruit) ascorbic acid was in 1/4 girdled in fruits from ungirdled own rooted vines which was found to be statistically similar with treatments of fully girdled *in situ* , ungirdled *in situ* , ungirdled grafted vine and fully girdled own

Table 3. Effect of girdling on the chemical characteristics of kiwifruit raised through different propagation methods

Treatment	TSS (%)	Titratable acidity (%)	Ascorbic acid (mg/100g fruit)	Sugars (%)			Sugar acid ratio
				Total sugars	Reducing sugars	Non-reducing sugars	
T_1	14.53	1.47	70.20	11.62	8.37	3.09	7.90
T_2	14.63	1.37	76.92	11.70	8.42	3.12	8.54
T_3	14.56	1.28	71.29	11.64	8.38	3.10	9.09
T_4	12.76	1.55	70.02	10.20	7.34	2.72	6.58
T_5	14.90	1.45	74.67	11.92	8.58	3.17	8.22
T_6	15.30	1.36	74.65	12.24	8.81	3.26	9.00
T_7	16.03	1.26	76.92	12.82	9.23	3.41	10.17
T_8	14.33	1.51	69.33	11.46	8.25	3.05	7.59
T_9	13.16	1.42	69.58	10.52	7.57	2.80	7.41
T_{10}	13.06	1.30	72.17	10.44	7.52	2.77	8.03
T_{11}	13.13	1.23	73.44	10.50	7.56	2.79	8.54
T_{12}	13.90	1.48	69.07	11.12	8.01	2.95	7.51
CD (p=0.05)	1.07	0.28	1.68	0.63	0.75	0.32	1.10

rooted . The positive relationship between girdled and vitamin C content due to less exposure of plant weight with more nutrients. Ascorbic acid is vulnerable to loss as it oxidizes early in the presence of light, heat, oxygen and nutrients. Koshita et al (2011) and Moqhaddam et al (2018) reported that girdling increases ascorbic acid content of fruits. The highest total sugars content (12.82%) and reducing sugars (9.23%)was obtained from 1/4 girdled grafted (T_7) vines and the lowest total sugars (10.20%) and reducing sugars (7.34%)were recorded in fruits obtained from ungirdled *in situ* vines. The increase in sugars contents of fruits in the girdled vines may be due to the increased photosynthetic rate provided by higher leaf fruit ratio and girdling. The results of this study coincide with Chanana and Gill's (2006) findings in peach and Roussos and Tassis (2011) findings in Mandarin. The effect of the 'Patharnakh' pear to girdling under sub-limb girdling was studied by Singh et al (2014).

The highest non-reducing sugars content (3.41%) was in 1/4 girdled grafted vines and the lowest (2.72%) were recorded in fruits from ungirdled *in situ*. The present results are in agreement with Koshita et al (2011) and Rather et al (2011) in litchi and Ahmad et al (2005) in grape. This might be due to the fact that girdling blocked the translocation of sucrose from the leaves to roots through phloem bundles. The temporarily blockage might have resulted in decreased in starch content of the roots and accumulation of sucrose in the leaves which helped to increase sucrose levels in fruits (Ghadage et al 2019).The sugar acid ratio was significantly influenced by different levels of girdling in kiwifruit vines raised through different propagation methods (Table 3). The highest sugar acid ratio (10.17) was reported in 1/4 girdled grafted vines and the lowest sugar acid ratio (6.58) were recorded with ungirdled *in situ* vines. The improvement in sugar acid ratio may be due to the higher accumulation of carbohydrates achieved by higher number of leaves per fruit and girdling of the plants. The findings of present investigation are in accordance with Yesiloglu et al (2000) who reported that girdling application provided earliness by increasing the total soluble solids/ acidity ratio. Ahmad et al (2005) observed that girdling proved most effective in increasing TSS/acid ratio and reducing sugars was also significantly improved.

Leaf macronutrients (N, P, K): The highest leaf nitrogen content (2.45%) in ungirdled own rooted vines. and, the lowest (2.24%) was in 1/4 girdled *in situ* vines (Table 4). The lowest potassium content (2.13%) was with fully girdled grafted vines. Yilmaz et al (2018) found that girdling reduced Photosystem II and leaf chlorophyll concentration. However, they observed a decrease in nitrogen level in the girdled trees.

Table 4. Effect of girdling on the leaf macro nutrients of kiwifruit raised through different propagation methods

Treatment	Leaf macronutrients status (%)		
	Nitrogen	Phosphorus	Potassium
T_1	2.37	0.26	2.23
T_2	2.36	0.24	2.26
T_3	2.24	0.17	2.25
T_4	2.35	0.21	2.17
T_5	2.43	0.22	2.13
T_6	2.41	0.27	2.36
T_7	2.29	0.25	2.43
T_8	2.26	0.29	2.18
T_9	2.30	0.28	2.24
T_{10}	2.42	0.25	2.34
T_{11}	2.34	0.23	2.35
T_{12}	2.45	0.19	2.44
CD (p=0.05)	0.02	0.02	0.04

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Received 12 December, 2021; Accepted 02 April, 2022

Indian Journal of Ecology (2022) 49(2): 502-507
DOI: https://doi.org/10.55362/IJE/2022/3552

Manuscript Number: 3552
NAAS Rating: 5.79

Response of Shoot Pruning on Growth, Flowering and Fruiting Characteristics of Guava under Sub-Himalayan Terai Region of West Bengal

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***Abstract*:** Guava is one of the important fruit crops grown worldwide. Shoot pruning improves the emergence of new flush and its role on flowering and fruiting characteristics was evaluated on this experiment. The effect on shoot pruning height and removal of top leaf bud by pinching was assessed on growth, flowering and fruiting characteristics of guava cv. L-49. The experiment was conducted at Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal.There were two factors heading back and pinching. Heading back at the level of 90, 120 and 150cm was done in January and pinching of one leaf pair was performed during the last week of June, 2018.The heading back at the level of 120 cm and no pinching were most effective for number of flowering bud (179.33), number of flowers (139.83), number of fruit set (95.33), total number of fruits (64.66), ascorbic acid (190.35 mg/100g), titratable acidity (0.28%) and heading back at the level of 120 cm and one pinching were effective in increasing number of primary shoots (39.50), flowering percentage (80.18%), fruit weight (172.00g).

Keywords: Heading back, Leaf pair pinching, Phenology, Canopy

Guava (*Psidium guajava* L.) is native to tropical America, extending from Mexico to Peru. The area under guava in India is about 262,000 hectares producing 3,648 million tonnes with a productivity of 13.9 MT/ha (Anonymous 2017).In North Indian conditions, two distinct flowering occurs in a year, first in April-May for rainy season crop and the second in August-September for winter season crop (Mitra et al 2008).Pruning is one of horticultural practices followed in the temperate and subtropical fruit crops to bring a balance between vegetative and reproductive growth of the plant. Untrained and unpruned guava trees become huge and unmanageable after a few years of growth. The bearing area is reduced and the interior of plants become entirely without fruits. Proper canopy management is therefore essential to avoid competition for light under high density planting and to achieve higher productivity. Pruning found to have pronounced effect on improving vigor of old orchards and increasing performance of fruit yield and quality (Bhagawati et al 2015). Pruning of guava is one of the most important practices that influence the vigour, productivity and quality of the fruits. Pruning at an early stage is done to develop a strong framework and capable for bearing a heavy crop load. The main advantages of pruning on bearing trees include the formation of new shoots, avoid overcrowding of branches, removal of criss-cross branches, diseased branches as well as water sprouts and root suckers. Guava bears on current season's growth and flowers appear in the axils of the new leaves, thus, it responds well to pruning. Pruning can be used as the better means to enhance the fruiting potential of guava and increasing the production. The pruning of apical shoots improved the growth and yield of guava fruit trees (Ali et al 2014).The different intensities of pruning improved vegetative growth and crop yield in grapes and other crops (Porika et al 2015, Malviya and Sharma 2016). The old and senile orcharding becomes economically non-viable and non-remunerative which leads to decline both in quality and quantity of fruits. For overcoming the problem of unproductive and uneconomic orchards existing in abundance, large scale uprooting and replacement with new plantations. Therefore, the present study was undertaken to record the performance of guava at differential pruning height and the effect of pinching on growth, flowering and fruiting characteristics of guava.

MATERIAL AND METHODS

The present experiment was carried out at Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India during 2018-19. Guava cv. L-49 was planted at distance of 4m X 4m and selected for evaluating the effect of height of heading back and pinching of shoots using two factor randomized block design with two factors such as heading back and pinching with eight treatment combinations and three replications. Heading back at 90, 120 and 150 cm was performed during January 2018 and pinching of one leaf pair was performed during the last week of June, 2018. The parameters were subjected to two factor Randomized block design (RBD) and analyzed statistically as per method by Gomez and Gomez (1984) using Proc Glm of Statistical Analysis System (SAS) Software (Version 9.3). The details of treatment combinations are

T_1= H_0P_0 (no heading back and no pinching),

T_2= $H_0 P_1$ (no heading back and one pinching in last June),

T_3= $H_1 P_0$ (90 cm heading back and no pinching),

T_4= $H_1 P_1$ (90 cm heading back and one pinching in last June),

T_5= $H_2 P_0$ (120cm heading back and no pinching),

T_6= H_2 P_1 (120cm heading back and one pinching in last June),

T_7= $H_3 P_0$(150cm heading back and no pinching),

T_8= $H_3 P_1$(150cm heading back and one pinching in last June) were followed during the experimentation.

The recommended dose of fertilizer (N: P:K) was applied at the ratio of 260:320:260 g/plant. Different growth parameters like days taken to emergence of vegetative buds, total number of primary shoots, length of the primary shoot (cm), fresh weight and dry weight of primary shoot (g), and carbohydrate content were recorded.

Tree volume (m^3): The tree volume (m^3) was calculated by following the formula given by Roose et al(1986) as V=4/6 $\pi r^2 h$, Where, h=height of tree (m) and E-W= East-West; N-S= North-South.

$$r = \frac{\text{Sum of East-West and North-South directions}}{4}$$

Flowering characteristics: The flowering characteristics were observed on the basis of all the plants of specific replication such as days taken to emergence of first flower bud after pruning, number of flowering buds,

Flowering percentage: It was calculated by following formula-

$$\text{Flowering percentage (\%)} = \frac{\text{Number of flowers}}{\text{Number of flower buds}} \times 100$$

Fruiting characteristics: Number of fruit set, total number of fruits, fruit weight (g), fruit diameter (cm), fruit set percentage (%). The fruit set percentage was recorded and mean values presented as per cent fruit set. Fruit set percentage was calculated by following formula-

$$\text{Fruit set (\%)} = \frac{\text{Total number of fruits}}{\text{Total number of flowers}} \times 100$$

Fruit quality parameters like total soluble solids (TSS), total sugar (%), reducing sugar (%), ascorbic acid (mg/100g) and titratable acidity (%) was determined under each treatment.

RESULTS AND DISCUSSION

Growth parameters: Effect of heading back and pinching: Emergence of vegetative buds: The heading back showed variation among the different heights; whereas, pinching levels has more statistical variation (Table 1). The maximum delay (45.00 days) on vegetative buds' emergence was in H_2 P_1(120cm heading back and one pinching in last June) and the lowest time required was in (33.66 days) in H_0 P_0 (No heading back and no pinching) and (35.83 days) in H_0 P_1(No heading back and one pinching in last June). As no heading back was performed in H_0 P_0 and H_0 P_1 the bud emergence time was comparatively lower than other treatment details. Suleman et al (2006) reported that among the three pruning levels in guava cv. Lucknow-49, 60 cm pruning intensity resulted in minimum days for sprouting of new shoots.

Number of primary shoots showed significant variation among the individual main factors and treatment combinations. The number of primary shoots was maximum (39.50) with T_6(H_2 P_1), which was statistically at par with H_3 P_0

Table 1. Effect of heading back and pinching on growth parameters

Treatments/ Combination		Days taken to emergence of vegetative buds	Number of primary shoots	Number of primary shoots/ m^3	Length of the primary shoot (cm)		
					3MAP	6MAP	9MAP
T_1	H_0P_0	33.66^{e}	13.33^{f}	0.25^{d}	7.06^{c}	20.23^{bc}	29.04^{b}
T_2	H_0P_1	35.83^{de}	16.83^{e}	0.28^{d}	5.86^{c}	13.79^{b}	19.79^{b}
T_3	H_1P_0	40.00^{bc}	17.83^{e}	0.40^{cd}	10.78^{ab}	34.49^{a}	55.76^{a}
T_4	H_1P_1	40.83^{bc}	23.33^{d}	0.53^{bcd}	8.13^{bc}	39.86^{a}	63.56^{a}
T_5	H_2P_0	42.16^{abc}	27.33^{c}	0.62^{bcd}	6.56^{c}	29.85^{ab}	50.95^{a}
T_6	H_2P_1	45.00^{a}	39.50^{a}	0.73^{bc}	$7.20b^{c}$	31.31^{ab}	54.02^{a}
T_7	H_3P_0	42.83^{ab}	36.66^{ab}	1.17^{a}	$7.58b^{c}$	37.61^{a}	63.96^{a}
T_8	H_3P_1	38.50^{cd}	35.83^{b}	0.90^{ab}	11.75^{a}	34.95^{a}	56.00^{a}

**Means with the same letter are not significantly different

(36.66).whereas, it was minimum (13.33) with H_0P_0 (control). Similar trends were also recorded for number of primary shoots per unit of tree volume. The number of primary shoots/ m^3 was in lowest (0.25) with T_1 (H_0P_0) which was statistically at par (0.28) with T_2 (H_0 P_1). The maximum (1.17) number of primary shoots/ m^3 was in severe heading back T_7(H_3 P_0) was statistically at par with T_8(H_3 P_1).The result indicates heading back (severe pruning) and pinching had strong effects on bud emergence and number of primary shoot development compared to no heading back and no pinching. Increase in number of sprouts per shoot by heading back may be due to overcome of apical dominance and supply of more food materials as also suggested by Lakhpathi et al (2013). The early emergence of vegetative bud sprout, numbers of shoots and shoot length of guava trees were observed by other workers (Jadhav et al 2002, Salah 2005).

The heading back at different heights has significant effects, whereas, pinching has no effect on length of emerged pruning shoot at different month after pruning. However, the treatment combinations show significant variation for this parameter. The length of primary shoot was higher in different stages in H_3 P_0,H_3 P_1 and H_1 P_1 treatment combinations. The highest newly emerged shoot length per tree canopy volume was recorded with severe heading back (H_3 P_0).No pruning with or without pinching gave poor performance on extension of new primary shoots. The increase in shoot length may be attributed to the reserve food material in the main scaffolds or branches due to which new growth was put forth just after the heading back as suggested by Mohammed et al (2006).

The tree volume significantly varied for height of pruning on other hand pinching has no effect. Tree volume was in highest (58.18 m^3) with T_2(H_0 P_1) and lowest tree volume at T_7 (severe pruning). It is observed that severe pruning with or without leaf pinching has negative impact on tree volume. Thakre et al (2016) found minimum annual increase in tree volume with one leaf pair pruning of fruited shoots. Hiremath et al (2017) observed that minimum plant height, plant spread and stem girth were noted in pruned plants. Pinching numbers and interaction of heading back levels and pinching numbers were found in altering trees volume of guava. Similar results were observed by Kumar and Rattanpal

Table 2. Effect of heading back and pinching on length of primary shoot, tree volume and, fresh and dry weight of new shoots

Treatments/ Combination		Length of the primary shoot		Tree volume (m^3)	Fresh weight (g)	Dry weight (g)
		12 MAP	12 MAP/m^3			
T_1	H_0P_0	43.06^d	0.85^{cd}	53.47^{ab}	9.08^c	4.66^{bc}
T_2	H_0P_1	34.75^d	0.60^d	58.18^a	9.83^{bc}	4.91^{abc}
T_3	H_1P_0	96.40^{bc}	1.92^{bc}	45.69^{ab}	11.83^{abc}	5.33^{abc}
T_4	H_1P_1	113.93^a	2.71^{ab}	44.63^{ab}	16.50^a	6.66^{ab}
T_5	H_2P_0	90.67^c	2.03^{bc}	45.49^{ab}	10.16^{bc}	4.33^c
T_6	H_2P_1	102.15^{abc}	1.88^{bcd}	55.24^{ab}	14.00^{bc}	6.33^{abc}
T_7	H_3P_0	108.97^{ab}	3.37^a	36.62^b	13.83^{ab}	6.91^a
T_8	H_3P_1	90.31^c	2.26^{ab}	39.78^{ab}	11.17^{bc}	5.58^{abc}

**Means with the same letter are not significantly different

Table 3. Effect of heading back and pinching on flowering characters

Treatments/ Combination		Days taken to emergence of first flower bud after pruning	Number of flowering buds	Number of flowering bud/ m^3	Number of flowers	Number of flowers/ m^3	Flowering percentage
T_1	H_0P_0	89.33^d	148.00^b	2.90^b	113.83^{ab}	2.21^{ab}	76.86^a (61.32)
T_2	H_0P_1	84.83^e	144.50^b	2.50^b	115.33^{ab}	1.99^b	79.83^a (63.41)
T_3	H_1P_0	95.00^c	164.50^{ab}	3.64^{ab}	132.67^{ab}	2.90^{ab}	80.17^a (63.71)
T_4	H_1P_1	97.00^b	158.00^{ab}	3.57^{ab}	124.17^{ab}	2.77^{ab}	77.91^a (62.08)
T_5	H_2P_0	98.50^b	179.33^a	4.04^{ab}	139.83^a	3.15^{ab}	77.90^a (62.01)
T_6	H_2P_1	99.83^a	155.17^{ab}	2.86^b	125.00^{ab}	2.45^{ab}	80.18^a (63.74)
T_7	H_3P_0	98.50^{ab}	145.83^b	4.60^a	107.67^{ab}	3.40^a	73.86^a (59.26)
T_8	H_3P_1	94.66^c	140.50^b	3.56^{ab}	102.50^b	2.60^{ab}	72.96^a (58.69)

**Means with the same letter are not significantly different, values in a parenthesis are arc sine value

(2010) where they found maximum tree volume in control trees and was minimum under pruning treatment by removal of half vegetative growth in guava. Singh et al (2012) showed that pruning decreased the tree canopy volume in guava. Fresh and dry weight of newly emerged primary shoots were comparatively more than the non-pruned guava plants significant variation among the fresh weight (16.50 g) and dry weight (6.91 g) was inH_1 $P_1$and H_3 P_0treatment combinations, respectively.

Flowering characteristics: The highest duration was in H_2P_1(99.83 days) followed by H_3P_0. The lowest days taken to emergence of flower bud was inH_0P_1, followed by H_0P_0. The flower bud emergence was delayed in heavy pruning, but the number of flower buds produced was comparatively higher in pruning treatment compared to unpruned plants. The maximum number of flowering buds (179.33) was in T_5, followed by H_1P_0,H_1P_1 and H_2P_1. The number of flower bud per unit volume was higher in T_7(H_3 P_0), and maximum number of flowers was in H_2P_0(139.83). However, the minimum number of flowers was in H_3P_1. All the treatment combinations showed significant variation on number of flowers/m^3. Data pertaining to the number of flowers/ m^3 was lowest (1.99) with H_0 P_1 (control). The highest number of flowers / m^3 (3.40) was in H_3 P_0. Pilania et al (2010) noticed that 25% pruning of previous season growth in guava produced maximum number of flowers/ shoot and maximum fruit diameter under 75% pruning of previous season growth followed by 50% pruning and minimum in control. The pinching has no significant effect over flowering. Heading back and pinching operation combination has non-significant for flowering percentages. However, the maximum flowering percentage (80.18%) was in H_2 P_1, followed by H_1 P_0. The interaction between heading back and numbers of pinching was found non-significant. The increase in flowering intensity with pinching as compared to the un-pinched trees indicates that pinching resulted in production of new growing points on the pinched trees reported by Saini et al(2016).Highest number of flower buds per shoot was in light pruning of guava (Bhagawati et al 2015) and maximum flowering intensity was in 60 cm pruning (Mohammed et al2006), whereas, number of flowers per shoot on severely pruned trees of guava was more than mild pruned trees (Jadhav et al 2002).

Fruiting characteristics: Heading back and pinching individually has no significant variation on number of fruit set and fruit set per unit tree volume initially. However, maximum initial fruit set was in H_2 P_0treatment combination. Maximum number of fruit set per unit tree volume was in severe pruning (H_3P_0), all the other heading back treatment combinations

Table 4. Effect of heading back and pinching on fruiting characters

Treatments/Combination	Fruit set	Fruit set/ m^3	Fruit set percentage	Number of fruits	Number of fruits/ m^3
T_1 H_0P_0	69.83^{ab}	1.37^{b}	61.55^{b} (51.69)	39.00^{b}	0.74^{b}
T_2 H_0P_1	81.17^{ab}	1.40^{b}	70.16^{b} (56.97)	38.50^{b}	0.65^{b}
T_3 H_1P_0	83.17^{ab}	1.80^{ab}	61.69^{b} (51.79)	41.66^{b}	0.87^{b}
T_4 H_1P_1	83.37^{ab}	1.84^{ab}	66.46^{ab} (54.63)	48.16^{ab}	1.07^{ab}
T_5 H_2P_0	95.33^{a}	2.15^{ab}	68.19^{ab} (55.68)	64.66^{a}	1.46^{a}
T_6 H_2P_1	84.00^{ab}	1.52^{ab}	66.95^{ab} (54.92)	48.33^{ab}	0.87^{b}
T_7 H_3P_0	74.17^{ab}	2.34^{a}	68.90^{ab} (56.12)	48.66^{ab}	1.47^{a}
T_8 H_3P_1	66.17^{b}	1.68^{ab}	64.41^{ab} (53.40)	41.66^{b}	1.05^{ab}

**Means with the same letter are not significantly different, values in a parenthesis are arc sine value

Table 5. Effect of heading back and pinching on fruit weight and diameter and quality parameters

Treatments/ Combination	Fruit weight (g)	Fruit diameter (cm)	TSS (^{0}B)	Reducing sugar (%)	Total sugar (%)	Ascorbic acid (mg/100g)	Acidity (%)
T_1 H_0P_0	168.67^{ab}	5.78^{c}	8.56^{b}	2.43^{bc}	6.67^{e}	149.26^{f}	0.18^{de}
T_2 H_0P_1	127.92^{c}	5.74^{c}	8.36^{b}	2.57^{ab}	6.59^{e}	151.19^{f}	0.16^{e}
T_3 H_1P_0	137.67^{abc}	6.48^{ab}	9.83^{a}	2.15^{c}	8.13^{b}	176.00^{c}	0.22^{bc}
T_4 H_1P_1	129.93^{bc}	5.79^{c}	9.76^{a}	2.83^{a}	8.30^{a}	181.19^{b}	0.19^{d}
T_5 H_2P_0	122.42^{c}	4.87^{d}	9.60^{a}	2.56^{ab}	7.50^{c}	190.35^{a}	0.28^{a}
T_6 H_2P_1	172.00^{a}	5.86^{bc}	9.16^{ab}	2.25^{c}	7.14^{d}	170.94^{d}	0.22^{b}
T_7 H_3P_0	133.50^{abc}	6.65^{a}	8.90^{ab}	2.79^{a}	7.09^{d}	166.41^{e}	0.27^{a}
T_8 H_3P_1	108.17^{c}	6.53^{a}	9.06^{ab}	2.35^{bc}	7.10^{d}	165.32^{e}	0.20^{cd}

**Means with the same letter are not significantly different

Fig. 1. Comparision of unpruned shoot and one leaf pair pinching of guava shoot

was statistically at par with T_7 (H_3P_0). The highest number of initial fruit set per unit area of tree volume observed on pruning treatments may be associated with development of a greater number of laterals, restoration of food reserve of plants is also suggested by Pratibha and Lal (2012).The heading back and pinching treatment individually has no effect on initial fruit set percentage of guava cv. L-49. The higher fruit set percentage was in T_2 (H_0P_1) compared to other treatment, indicating pinching has effect on fruit set percentage. The lowest initial fruit set percentage was in no heading back and no pinching treatment. Low initial fruit set percentage of T_1 (H_0P_0) may be due to a smaller number of developments of primary shoots, pruning and pinching compared to unpruned trees facilitate more production of new growing points as suggested by Brar et al (2007). However, contradictory report was also found by Dubey et al (2001) to found maximum fruit set in control over the pruned plants. Pruning of 25 percent of the shoot length of guava in mid-April was found to be the best treatment among for plant growth parameters, whereas, pruning of 50 percent of the shoot length in mid-May was best for obtaining maximum fruit yield in guava cv. L-49 for winter crop (Lian et al 2019).

The pinching has individually no effect on number of fruits per tree and number of fruits produced per unit area of tree. However, heading back or pruning has significant impact on production of number of fruits. Highest number of fruits was in T_5 (H_2P_0) that was statistically at par with T_7 (H_3P_0), T_6 (H_2P_1) and T_4 (H_1P_1). The beneficial effect of pruning and pinching in terms of production of new shoot may be related with the higher number of fruits compared to non-pruned plants. Individually pinching and heading back has no role on fruit weight. However, maximum fruit weight may be due to more canopy volume of T_1 (H_0P_0). Higher fruit weight in H_2P_1, may be is due to the in-vigour outing tree health due to the pruning. However,T_1 (H_0P_0) recorded higher fruit weight may be due to more canopy volume of T_1 plants following no pruning operation resulting in a smaller number of fruits having more weight. The pinching has no role on fruit diameter. Maximum fruit diameter was in T_7(H_3P_0) followed by T_8 (H_3P_1) and T_3(H_1P_0). The effect of differential pruning height and pinching had non-significant influence on TSS. Interaction effects of treatment combination were varying significantly. The maximum TSS (9.83 ºB) was in T_3 followed by T_4 and T_5. However, minimum (8.36ºB) was in T_2 followed by T_1.

Total sugar showed significant variation among the different treatment combinations. The highest total sugar percentage (8.30%) was in T_4, followed by T_3. The lowest total sugar percentage (6.59%) was in T_2 which was followed by T_1. The higher reducing sugar (2.83%) was in T_4 which was on par with T_7. However, lowest (2.15%) was in T_3. The maximum ascorbic acid (190.35 mg/100 g) was in T_5 followed by T_4. However, minimum (149.26 mg/100 g) was in T_1 followed by T_2. Acidity of fruit differed significantly among the differential pruning and pinching treatment. The higher percent of acidity (0.28%) was in T_5 which was on par with T_7. However, the lowest percent of acidity (0.16%) was in T_2 (control) which was on par with T_1 (control). More canopy volume of T_1plants following no pruning operation resulting in a smaller number of fruits, there was chances of development of less acidity compared to pruned plants.

CONCLUSIONS

The heading back at the level of 120 cm and no pinching were most effective in flowering and fruiting characteristics over unpruned trees. Hence, it is concluded that to standardize the heading back and pinching of guava cv. L-49 is a commercial cultivar of guava in West Bengal, India for getting higher fruit yield as well as superior quality of fruits.

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Received 12 October, 2021; Accepted 02 April, 2022

Indian Journal of Ecology (2022) 49(2): 508-514
DOI: https://doi.org/10.55362/IJE/2022/3553

Manuscript Number: 3553
NAAS Rating: 5.79

Diversity and Ecological Status of Major Lac Host Species in the Village Commons of the Periphery of Kuldiha Wildlife Sanctuary of Odisha

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***Abstract*:** An ecological study was carried out in village commons of fringe forests (i.e. 05 Km) in the tropical deciduous forests of the periphery of Kuldiha Wildlife Sanctuary of Odisha during 2018-19. This paper has endeavoured to assess the diversity and distribution pattern of trees vis-à-vis major lac host species in the outer peripheral region of Kuldiha Wildlife Sanctuary in the Garadihi Gram Panchayat of Nilgiri Block, Balasore, Odisha. An attempt was made to present floral diversity in the study site and estimated diversity index using Simpson's Diversity Index were determined to draw a comparative inference. Stratified random samplings were laid in the field. A total of 44 tree species consisting of 31 genera and 17 families were recorded. Fabaceae was the most dominant family with 13 species. *Butea monosperma,* a major lac host species, recorded the highest tree density (120.00 individual's ha^{-1}) and the lowest tree density (10 individual's ha^{-1}) was observed for *Neolamarckia cadamba* and *Ficus religiosa*. *Shorea robusta* had the highest basal area ha^{-1} of 164.56. The Importance Value Index (IVI) of trees was the highest for *Shorea robusta* (20.74) followed by *Schleichera oleosa* which was also a major lac host species (16.15) and *Holarrhena antidysenterica* (15.07) while the lowest was for *Neolamarckia cadamba* (1.82). Species evenness for trees was (0.951). Abundance/ Frequency ratio (A/F) for trees of 44 species exhibited mostly random distribution patterns for 26 species, 13 species contagiously and 5 species were regularly distributed.

Keywords: Village commons, Lac hosts, Floral diversity, Diversity index, Distribution pattern, Conservation

Tropical forests are well known for the most species-diverse terrestrial ecosystems in the earth, which provides a wide range of goods and services to the forest dwellers (Gosain et al 2015). The biodiversity of these forests provide a variety of resources which help to sustain the livelihood of local communities. Forests are declining rapidly due over-exploitation resulting in one of the most significant environmental and economic obstacles all over the world (Walther et al 2002, Htun et al 2011). Shrinkage of forest areas in the study sites led to the ecological problem such as soil erosion, extinction of many ethnobotanical important species of plants and animals (Bora and Kumar 2003). Inventory of plant species providing information on diversity will play an important tool for strengthening ability of *in-situ* and *ex-situ* conservation of biodiversity as well as the socio-economic setup of local communities that occurred from depletion of forests (Baraloto et al 2013, Malik et al 2014, Malik and Bhatt 2016) . The know-how composition and diversity of tree species is vital to understand the structure of a forest community for formulation and implementation of conservation strategy of the forest ecosystem. A significant portion of diversity of the study site has already been lost due to the versatile issues like illicit felling, habitat loss, forest fire, timber and fuel wood collection, livestock grazing pressures etc.

Odisha is traditionally an agrarian state and well-known for its rich and abundant biodiversity in India and in Southeast Asia. It is endowed with vast natural resources, diversified agro-edaphic conditions, rich flora and fauna, wide range of cropping patterns, various socio-cultural groups and people with multiple economic strata. The wide ranges of topographic, edaphic and climatic conditions have led to consociation of a variety of vegetation on different landscapes of village commons in this hill range. Among species of much ecological and economic importance to the forest fringes in the surroundings of Kuldiha Wildlife Sanctuary are Kusum (*Schleichera oleosa*), Palash (*Butea monosperma*) and Ber (*Ziziphus mauritiana*). Kusum (*Schleichera oleosa*) is the best lac host species for production of Kusumi lac strain. Palash (*Butea monosperma*) plant is very suitable for production of Rangeeni lac strain within a period of 5-6 years of regeneration. Ber (*Ziziphus mauritiana*) is also suitable for Kusumi and Rangeeni strains of lac within a period of 4-5 years of regeneration. Therefore, lac cultivation is expected to result in disturbances in forest community which in turn may lead to change in population structure of these species. Lac host species which not only provides livelihood to millions of lac growers but also helps in conserving vast stretches of village commons need priorities for conservation and protection and also required to be monitored. The information on distribution of plant communities are useful to understand the population dynamics of each species and how these major lac host species are distributed in relation to the other species in the same community are also studied.

Therefore, a necessity prevails to identify the vegetation composition and floristic status of upper storey and assess their diversity. A comprehensive phytosociological analysis of the forest ecosystem was done by incorporating parameters like relative density, abundance, relative frequency, relative basal area and Important Value Index, which will be applicable to plan for proper management intervention to enhance the sustainability development of forest biodiversity supporting livelihood through lac based activities in the study area.

MATERIAL AND METHODS

Study site: The present study was carried out in the Nilgiri block of Balasore district, Odisha, India by establishing ten numbers of randomly selected sites of Village Commons in Garadihi Gram Panchayat. All the sites are located on the undulating plain of Kuldiha foothill, blessed with rich floral and faunal diversity. It is located adjacent to Kuldiha Wildlife Sanctuary. Kuldiha Wildlife Sanctuary, a part of mega-habitat bounded by the tri-junction of Balasore, Mayurbhanj and Keonjhar districts, is covered with densely forested hill range spreading over 272.75 km^2. It is located in the South-western part of Balasore District under Nilgiri Civil Sub-Division in the State of Odisha and is declared as 'Kuldiha Wildlife Sanctuary' and lies between 21^0 20' to 21^0 30' North latitude & 86^0 26' to 86^0 45' East longitude. The area has a subtropical climate with three distinct seasons i.e. summer, monsoon and winter. The Sanctuary area is 272.75 sq km which includes Kuldiha, Devgiri and Tenda Reserve Forests and other Protected Forests. The periphery of the sanctuary is 150.5 kms. Kuldiha represents features of all the four Biotic Provinces such as Eastern Plateau, Chhotanagpur, Lower Gangetic Plain and Coastline. The mean annual rainfall is about 1630 mm. and enjoys a tropical climate. Because of its proximity to Bay of Bengal, climatically this tract is comparatively humid-hot. The mean maximum temperature is 38°C during April-May and minimum 8°C during November-January. The maximum temperature at times falls beyond 42°C. Forest type is mostly tropical deciduous forest type. Lac cultivation is also a subsidiary source of income of forest fringes. The lac host trees, namely Kusum (*Schleichera oleosa),* Palas (*Butea monosperma)* and Ber (*Ziziphus mauritiana*) are commercially exploited for lac cultivation which are known as common or major host plants or excellent host plants. Soil types vary from sandy to heavy red sandy loam found in the area.

Methodology: The primary data were collected from five major lac growing villages namely Tiakata, Garadihi, Chaindar, Balichua and Chekamara of Garadihi Gram Panchayat to survey all the possible habitats during 2018-19 from fringe forests (i.e. within 05 Km) around Kuldiha reserve forest of Balasore, Odisha. The study involves intensive field visits at regular intervals and careful investigations of the floral resources. The plants were collected, properly identified and when it was confusing to identify species in the field, the species were documented and herbarium specimens were prepared. The herbarium specimens were sent to College of Forestry, Odisha University of Agriculture and Technology (OUAT), Bhubaneswar, Odisha for proper identification. Standard field and herbarium methods given by Jain and Rao (1977), Bridson and Forman (1998) were followed for collection and preservation of plant samples. Herbarium specimens were prepared and the nomenclatures of the plant species were designated based on the regional floras like Flora of Presidency of Madras by Gamble and Fischer (1915-1935) and Flora of Odisha by Saxena and Brahmam (1994-1996). Each plant species recorded in the different quadrants in village commons were classified by family and genera.

Vegetation assessment: Phytosociological characteristics of tree species were studied by randomly laying out 10 quadrats of 10 x 10 m^2 sizes for trees (≥10 cm dbh) covering the entire study area. In the 100 m^2 quadrats the number of individuals of each tree species was counted and circumference at breast height (CBH at 1.37 m) from the ground was measured by using a girth tape. Buttressed trees were measured above the buttress. All the tree species in the quadrats were counted to estimate the diversity, frequency, density, abundance and Importance Value Index (IVI) of the woody vegetation. The size and the number of quadrats for study were determined following the principles of Kershaw (1973) and Mishra (1968). Floristic composition, density, diversity, dominance, distribution and tree population structure were studied according to Curtis and McIntosh (1950) and Mishra (1968). The importance value index (IVI) was calculated as reported by Curtis & McIntosh (1950), Mishra (1968) and Curtis (1953). It is used to identify the influence of each species in the community structure.

Abundance frequency ratio (A/F): Abundance to frequency ratio (A/F) has been computed following Whitford

(1949): WI = abundance/frequency (A/F Ratio) to assess the spatial distribution pattern of species and depending upon the ratios, distribution may be regular, random or contagious. A value of <0.025 would denote a regular distribution, values between 0.025-0.05 a random distribution and a value >0.05 would signify a contagious distribution. The data obtained were also used to enumerate community indices such as Shannon-Wiener's diversity index (Shannon and Wiener 1963) of species diversity of upper storey vegetation) and Pielou's evenness index (1966).

Shannon-wiener index (H): The diversity of the species was computed using the Shannon-Wiener index (H) as :

$H = \sum^{s}$pi ln pi i=1

Where s = Total number of species; pi = proportion of individuals in each species or abundance of the i-th species; and Ln is the natural logarithms to the base e.

All the collected data are put in the excel spreadsheet and according to the family of tree species the Simpson's formula has been worked out. Tree species whose numbers are more than 1, were assumed for calculating the Simpson diversity index as reported by Simpson (1949). Tree species whose numbers found were 1 or less was considered to have no diversity (Anandan et al 2014).

Simpson's species diversity index: Simpson's Diversity Index is a measure of diversity which takes into account the number of species present, as well as the relative abundance of each species. The formula for calculating D is presented as:

$$D = 1 - \left(\frac{\Sigma n\,(n-1)}{N\,(N-1)} \right)$$

Where n= the total number of individuals of each species, N=the total number of individuals of all species.

Pielou's index: Evenness Index was calculated using Pielou's index (D= -Σ pi2 / ln S), where S = species richness of the community, pi = proportion of individuals or abundance of the i^{th} species and ln is the natural logarithms to the base (Magurran 1988).

Association index: The inter-specific association was determined by association index which helps in assessing the main associates of an important species in the forest (Sukla et al 2015).

$$\textit{Association Index of a Species (A)} = \frac{\textit{Total no. of quadrats in which a species occurs along with another species (B) in the stand}}{\textit{Total no. of quadrats in which a species occurs in that stand}} \times 100$$

RESULTS AND DISCUSSION

Floristic composition: The present study on the phytosociological analysis of trees recorded the presence of a total of 44 number of tree species under 31 genera belonging to 17 families (Table 1). The number of species per genus was higher than 1.4 and the number of species per family was about 2.6. Majority of families are represented by one or two species only. The foremost dominant family was Fabaceae which contained 13 species followed by Moraceae, Myrtacea. The total tree density across the study sites was 1750 individuals ha^{-1} and total basal area/ha of 1322.5. The tree density varied from 10 to 120 individuals ha^{-1} and the basal area ranged from 3.22 to 164.56 m^2 ha^{-1} (Table 1). *Butea monosperma* exhibited the highest density (120 plants/ha) followed by *Hollarhena antidyesenterica* and the lowest density was found at *Neolamarckia cadamba* (10 plants/ha) (Table 1). *Shorea robusta* occupied the highest basal area of 164.56 m^2 ha^{-1}, followed by *Holarrhena antidysenterica* and *Schleichera oleosa*. The lowest basal area was in *Melia azedarach* (3.22 m^2 ha^{-1}). The Importance Value Index (IVI) of tree species varied from 1.82 to 20.74 . This indicated that in the study area *Shorea robusta* and *Schleichera oleosa* were the most dominant species whereas *Neolamarckia cadamba* and *Melia azedarach* were least dominant species. The most dominant trees in descending order of IVI were *Shorea robusta* (20.74), *Schleichera oleosa, Madhuca indica* and *Butea monosperma.* The least dominant species in ascending order of IVI were *Neolamarckia cadamba* (1.82) and *Melia azedarach* (2.25), *Albizia lebbeck* (3.31), . Most of the recorded species revealed random distribution (26 species). Insignificant number of species indicated clumped /contagious (13 species) and regular distribution (5 species). The association index of species for lac host species such as *Schleichera oleosa*, *Butea monosperma* and *Ziziphus mauritiana* varied widely and the most important associates were *S. robusta*, *B. lanzana*, *S. cerasoides* and *S. cumin* in the study sites.

Species diversity: The Shannon-wiener's diversity index, Simpson's dominance and Species evenness was 3.599, 0.973 and 0.951 respectively. All the indices were calculated only for tree species. The flora of the study sites of village commons was characterized by a variety of plant species. The tree species richness of 44 species represents a moderate level of diversity of plants (Table 1). The results of the present work are in accordance with that of different ecosystems under tropical climates. A total of 65 species of 36 families was recorded by Pradhan and Rahaman (2015) from three tropical dry deciduous forests of Birbhum District, West Bengal. Vinayaka and Krishnamurthy (2016) reported a total of 231 plant species of 96 are trees, 53 herbs, 51 shrubs and 31 are climbers in Hulikal state forest, Karnataka. In Malappuram sacred grove of Kollengode, Tamilnadu, Sukumaran et al (2018) recorded 36 trees, 18 shrubs, 26

Table 1. Phytosociological attributes of trees in the village commons of Garadihi G.P

Scientific name	Local name	Family	Density ha^{-1}	Basal area ha^{-1} (m^2/ha)	Association index of lac host species			A/F	IVI
					Kusum	Palas	Barakoli		
Acacia auriculiformis	Acacia	Fabaceae	100	64.45	0.17	0.25	0.50	1.00	11.45
Acacia leucophloea	Dhalaguhira	Fabaceae	20	37.10	0.33	0.05	1.00	0.05	5.67
Acacia nilotica	Babul	Fabaceae	50	24.66	0.33	0.13	1.00	0.13	6.45
Adina cordifolia	Kurum	Rubiaceae	30	11.78	0.50	0.08	1.50	0.03	5.19
Aegle marmelos	Bela	Rutaceae	20	13.05	0.33	0.05	1.00	0.05	3.85
Albizia lebbeck	Sirisha	Fabaceae	20	5.89	0.33	0.05	1.00	0.05	3.31
Albizia procera	Dhalasiris	Fabaceae	30	19.41	0.50	0.08	1.50	0.03	5.77
Alstonia scholaris	Chhatiyana	Apocynaceae	20	15.38	0.33	0.05	1.00	0.05	4.03
Anogeissus acuminata	Phasi	Combretaceae	40	20.95	0.67	0.10	2.00	0.03	7.32
Neolamarckia cadamba	Kadambo	Rubiaceae	10	5.09	0.17	0.03	0.50	0.10	1.82
Azadirachta indica	Nimba	Meliaceae	30	19.89	0.50	0.08	1.50	0.03	5.80
Bombax ceiba	Simili	Bombacaceae	40	36.08	0.67	0.10	2.00	0.03	8.46
Borassus flabellifer	Tala	Arecaceae	20	16.81	0.33	0.05	1.00	0.05	4.14
Buchanania lanzan	Char	Anacardiaceae	50	11.32	0.50	0.13	1.50	0.06	6.30
Butea monosperma	Palaso	Fabaceae	120	55.86	0.67	0.30	2.00	0.08	14.53
Cassia fistula	Sunari	Fabaceae	30	4.54	0.50	0.08	1.50	0.03	4.64
Cassia siamea	Sana chakunda	Fabaceae	50	35.37	0.67	0.13	2.00	0.03	8.98
Dalbergia lanceolaria	Sajanapati	Fabaceae	20	6.16	0.33	0.05	1.00	0.05	3.33
Dalbergia latifolia	Kala Sishu	Fabaceae	20	16.81	0.33	0.05	1.00	0.05	4.14
Dalbergia sissoo	Sishu	Fabaceae	30	9.91	0.33	0.08	1.00	0.08	4.19
Diospyros malabarica	Kala Kendu/Maakada kendu	Ebenaceae	30	44.34	0.50	0.08	1.50	0.03	7.65
Diospyros melanoxylon	Kendu	Ebenaceae	40	34.65	0.67	0.10	2.00	0.03	8.35
Eucalyptus tereticornis	Eucalyptus	Myrtaceae	80	70.18	0.17	0.20	0.50	0.80	10.74
Feronia elephantum	Kaitha	Rutaceae	40	27.89	0.50	0.10	1.50	0.04	6.98
Ficus benghalensis	Bara	Moraceae	20	34.45	0.33	0.05	1.00	0.05	5.47
Ficus cuspidifera	Dimiri	Moraceae	30	17.21	0.50	0.08	1.50	0.03	5.60
Ficus hispida	Baidimiri	Moraceae	30	11.22	0.50	0.08	1.50	0.03	5.15
Ficus racemosa	Dimiri / Lowa	Moraceae	20	6.70	0.33	0.05	1.00	0.05	3.37
Ficus religiosa	Aswastha	Moraceae	10	28.72	0.17	0.03	0.50	0.10	3.61
Holarrhena antidysenterica	Kulchi/Kurei	Apocynaceae	110	93.31	0.33	0.28	1.00	0.28	15.07
Madhuca indica	Mahula	Sapotaceae	40	33.86	0.50	0.10	1.50	0.04	7.43
Melia azedarach	Bilatinimba	Meliaceae	20	3.22	0.17	0.05	0.50	0.20	2.25
Phoenix sylvestris	Khajuri	Arecaceae	30	29.00	0.33	0.08	1.00	0.08	5.63
Protium serratum	Rimuli	Burseraceae	20	10.18	0.33	0.05	1.00	0.05	3.64
Pterocarpus marsupium	Bijasal/ Piasal	Fabaceae	40	10.20	0.67	0.10	2.00	0.03	6.51
Schleichera oleosa	Kusum	Sapindaceae	90	77.26	1.00	0.23	3.00	0.03	16.16
Semecarpus anacardium	Bhalia	Anacardiaceae	30	10.73	0.50	0.08	1.50	0.03	5.11
Shorea robusta	Sal	Dipterocarpaceae	100	164.56	0.50	0.25	1.50	0.11	20.74
Syzygium cerasoides	Poijamu/ Kaduaiamu	Myrataccae	60	36.97	0.50	0.15	1.50	0.07	8.81
Syzygium cumini	Jamu	Myrataccae	40	45.59	0.50	0.10	1.50	0.04	8.32
Tamarindus indica	Tentuli	Fabaceae	30	36.86	0.50	0.08	1.50	0.03	7.09
Terminalia tomentosa	Asana	Combretaceae	40	39.78	0.50	0.10	1.50	0.04	7.88
Ziziphus mauritiana	Barakoli	Rhamnaceae	20	14.40	0.33	0.05	1.00	0.05	3.96
Ziziphus xylopyrus	Gonti/Khataber	Rhamnaceae	30	10.73	0.50	0.08	1.50	0.03	5.11
Total			1750	1322.5					300

A/F= Abundance to Frequency Ratio; IVI- Importance Value Index herbs and 22 climbers. Composition of the forest and hence its type depend on aggregation of various species. Various factors, like seed dispersal, microclimate and other biotic factors promote the distribution of the species in an ecosystem. Tree species richness of study site was lower as compared to species recorded in Similipal biosphere reserve (Reddy et al 2007) which may be attributed to anthropogenic pressure and/ or low rainfall. The Fabaceae were exhibited to be the most dominant for their ability to produce numerous seeds, quick germination and symbiotic characters which might have promoted species of the plant family to easily establish within habitat types. However, the studies were similar with the works of Deka et al (2012), Pausas and Austin (2001) reported on species richness in relation to environment i.e. suitable habitat and an environmental condition promotes pollination, dispersal of seeds and ensuring establishment of species. Some families have characterised due to the presence of the least dominant species as being associated with unsuitable climatic conditions, diseases and trampling by herbivores which resulted in poor growth and establishment. Egbe et al (2012) reported similar activities affecting growth and distribution of species.

Plant diversity of an area is measured by density, abundance and distribution of individual species. The stand density of 1750 stems/ ha in the study site is comparable with the stem density in other tropical forests of different ecosystems e.g., 516.23 stems ha^{-1} for Nayagarh Forest Division, Odisha (Sahoo and Panda 2015, Sahoo et al 2017), 352 stems ha^{-1} in Northern Eastern Ghats (Panda et al 2013), 443 stems ha^{-1} in Malyagiri hills of Odisha (Sahu et al 2012), 298 stems ha^{-1} at Mudumalai Forest Reserve, India and 689 stems ha^{-1} at Sinharaja, Sri Lanka (Condit 2000). Mishra et al (2008) reported a tree density 650 - 970 individuals/ ha in Simlipal Biosphere Reserve which was lesser than the stem density recorded in this study. Importance value index of different plants in the present study area is compared with report of various other workers. In Similipal Biosphere Reserve, Mishra et al (2012) found that *Shorea robusta* was the most dominant species having IVI of 77.67 followed by *Terminalia alata* (16.13) and *Anogeissus latifolia* (13.43). *Wendlandia sp.* was the rarest species of the reserve forest with an IVI of 0.25. Most of the species in the present investigation showed less IVI values and occupied low ecological status of the ecosystem suggesting positive interactions among the tree species (Mishra et al 2012). Higher IVI values of plants depend on their good regeneration ability, more adaptability to specific site and environmental conditions. In the present investigation *Shorea robusta, Schleichera oleosa* and *Butea monosperma* showed wide association and good regenerating ability in the different sites of village commons. Moreover, adequate knowledge on IVI would play an important role for deciding the conservation practices of specific host plant populations of lac insects that are facing the vulnerability of extirpation by forest dependants in and the surroundings of this village commons. Tree species like *Schleichera oleosa, Butea monosperma. Ziziphus mauritiana, Shorea robusta, Buchanania lanzan, Madhuca indica, Dalbergia sissoo, Dalbergia latifolia, Pterocarpus marsupium* have local economic importance. Similarly, plant species like *Acacia nilotica, Azadirachta indica, Aegle marmelos, Alstonia scholaris* etc. have been used by the tribal population since time immemorial for medicinal purposes. Similar uses of studied species have been reported by various researchers (Mehra et al 2014, Bajpai et al 2016, Rout et al 2018). These plant species need to be conserved on priority basis against the factors like illicit harvesting, grazing by domestic animals and many other anthropogenic activities (WP, 2008-2017). Most of the upper storey vegetation showed a generally random type of distribution in the present study (Table 1). The abundance frequency ratio (A/F) for trees and shrubs indicates that forest seedlings grow close to the mother plant in the natural vegetation. Similar observations were also recorded by earlier researchers (Al-Amin et al 2004. Giliba et al 2011, Sobuj and Rahman 2011, Deka et al 2012) .

Adaptation of the species influences the species diversity which increases with the stability of the community. Shannon-Weiner (H′) index varied from 0.0295 to 0.184 with a total diversity value 3.599 of the trees. The findings were comparable with the report of earlier researchers (Sundarapandian and Swamy 2000, Kumar et al 2010, Panda et al 2013) in tropical forests of Indian sub-continent which falls within the range of 0.67 to 4.86. These findings suggest that the village commons represent a species diverse system. Maximum species diversity of 0.184 was in *Butea monosperma* while the minimum of 0.0511 was in many species of the study area indicating that over storey vegetation of the site had higher diversity. The dominance (Simpson's index) in the present study was 0.0273 have been compared with the reports in other forests (Lalfakawma et al 2009, Sahu et al 2012). This indicates that influence of anthropogenic and ecological factors brings about declining vegetation of the ecosystem.

CONCLUSION

Tropical forest in the periphery of Kuldiha Wildlife Sanctuary of Balasore district acts as one of the richest reservoirs of floral genetic diversity harbouring a number of indigenous forest plants, medicinal herbs, underutilized fruits and wild tubers. The study area reveals 44 species mostly showing random distribution. Out of the documented tree species, 3 species viz *Schleichera oleosa*, *Butea monosperma* and *Ziziphus mauritiana* were used as lac hosts of which *B. monosperama* was recorded with the highest stem density/ha and *S. oleosa* showed the maximum IVI. *S. robusta*, *B. lanzan*, *S. cerasoides* and *S. cumin* were found to be the most associated species of the of major lac host trees in the study site. Adequate conservation and management practices of these plant species not only maintain the forest biodiversity but also meet the basic needs of tribal population living in the peripheral areas of the village commons. The documentation of the tree diversity in the present study provides a base line input in understanding the threats of tropical forests, a suitable long term management intervention and conserving the phytodiversity of the forest ecosystem that would ensure sustained supply of goods and services for communities in the study area.

ACKNOWLEDGEMENT

The authors are thankful to the Divisional Forest Officer (DFO), Balasore Wildlife Division and their staff for providing opportunity and constant support during the study period to carry out the research work.

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Received 11 December, 2021; Accepted 22 February, 2022

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Indian Journal of Ecology (2022) 49(2): 515-520
DOI: https://doi.org/10.55362/IJE/2022/3554

Manuscript Number: 3554
NAAS Rating: 5.79

Genomic Characterization of *Episyrphus balteatus* (Diptera: Syrphidae) from Outer and Lower Himalayas, India

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***Abstract*:** The present study deals with genomic characterization of a hover fly *Episyrphus balteatus* using Randomly Amplified Polymorphic DNA. RAPD-PCR analysis was carried out to compare genomic DNA of six geographically distinct populations of *E. balteatus* from Outer and Lower Himalayas using decamer oligonucleotide primers. The RAPD-PCR method detected a number of discrete DNA bands with different intensities. Ten random primers produced 39 bands in the studied populations out of which 25 bands were polymorphic. These polymorphic bands were used to differentiate the six populations of *E. balteatus*. PIC (Polymorphism Information Content) and RP (Resolving Power) values was 0.3312 and 6.06 respectively. Genetic similarity between studied populations ranged from 0.564 to 0.872. Among the studied population the lowest genetic distance (0.128) was observed between population P1 and P3 whereas highest (0.436) was observed between P5 and P6. These changes in DNA showed the geographical accumulation of variations with the course of time that leads to differential adaptability towards the environmental pressures. Dendrogram was prepared using UPGMA. Cluster analysis reveals various evolutionary adaptations of *E. balteatus* populations. P1 and P3 are classified as most related populations whereas P6 is relatively distant from the other five populations.

Keywords: PCR, RAPD, Genomic, Polymorphic, *Episyrphus*

Episyrphus balteatus, commonly known as marmalade fly is cosmopolitan and distributed throughout the world. Predatory dipterans of syrphidae family are considered to be the most important group of aphidophagus insects which acts as predators of aphid population. Larvae of syrphids rank as the major natural enemies for suppressing the aphid populations and thus act as bio-control agents(Nelson et al 2012). Although the genetic makeup of a particular population of a species remains same but the genetic response to the environmental stress or changes become altogether different if the populations inhabit different geographical regions or different climatic conditions. This can change the structure of DNA over a period of time and is sufficient to categorize different populations of a particular species. Identification of geographically distinct populations of *Episyrphus* may play an important role in pest management programmes.A variety of DNA based methods each with its own advantage and disadvantages have been developed over a period of time to identify cryptic species, subspecies or geographically distinct populations. Random amplified polymorphic DNA (PCR) has been widely used in dipteran families Culicidae, Muscidae, Callipharidae, Sarcophagidae as a potential tool to differentiate sibling and cryptic species, in strain identification and in genetic mapping(Skoda et al 2002, Malviya et al 2012). The randomly amplified markers appeared on different loci, gives a pattern which are unique to a single population and can differentiate the populations of different geographical regions. The degree of relatedness of these patterns shows the genetic differences among populations and it also indicates the extent of variation that may leads to formation of a new species from a population.In the study reported here we selected six populations of *E. balteatus* from different climatic regions of Middle or Lower Himalayas, Outer Himalayas and Shivalik ranges for RAPD-PCR analysis to study DNA polymorphism using ten RAPD oligonucleotide markers.

MATERIAL AND METHODS

Live specimens of six populations of *E. balteatus* belonging to family Syrphidae were collected from six different regions of outer and Lower Himalayas. These populations were named as P1 to P6 for six different regions with their altitudes as mean sea level (Table 1). Immediately after collection they were preserved in three different ethanol concentrations 70, 90 and 100% until DNA was extracted. Collections of *E. balteatus* were made in March-April, 2017 with average day temperature 30°C and 67% relative humidity. Leg muscles of adult flies were used for DNA extraction. DNA was isolated using following method of Skevington and Yeates (2000).

Isolation of genomic DNA: Genomic DNA was standardized based on earlier procedures in terms of quantity, RNA contamination and DNA shearing. Tissue was mixed with 2% CTAB lysis buffer and incubated for 30 minutes at 65°C. After 5 minutes 300 µl of chloroform: isoamyl alcohol (24:1) was added and mixture was centrifuged at 10000 rpm for 3 minutes. The supernatant was removed and chloroform isoamyl alcohol step was repeated again. Further aqueous phase was collected into new tubes and 300 µl of chilled isopropanol was added. The tubes were kept for precipitation at -20°C for one hour and spun at 8000 rpm for 10 minutes. The supernatant was discarded and the DNA was washed with 200 µl of cold 70% ethanol. The DNA pellet thus formed was dried at 60°C for 30 seconds and was suspended in TE buffer (100 µl, pH 8.0 with RNAase 10 µg/ml)

DNA amplification and RAPD-PCR condition: PCR amplifications were done according to the protocol described by Williams et al (1990) with some modifications. Standardization of different components for PCR reaction was done by using the varying concentrations of template DNA, RAPD-PCR primers and Taq polymerase enzyme in 25 µl of reaction mixture (Table 2). Optimum concentrations of various components as worked out from standardization for a 25 µl reaction volume (Table 3) were consistently used in all the subsequent PCR-amplifications.

Three different DNA concentrations (10, 15, and 20 ng/µl) were tested and 10ng/µl was optimum for best amplifications of RAPD fragments. Polymerase chain reaction was carried out in Veriti 9-well thermocycler machine using the following cycling conditions: initial denaturation at 92°C for 5 minutes followed by 40 amplification cycles (30 seconds denaturation at 92°C, one minute annealing at 35°C and extension at 72°C for two minutes) and final extension at 72°C for seven minutes. The 10 primers, EB1- EB10 on *E. balteatus* samples to ascertain those suited for our level of analysis were tested (Table 4). Out of these, five generated

Table 3. Optimum concentrations of various components of PCR reaction mixture

Components	Volume in µl
Sterile water (mili-Q)	14.25
Taq polymerase (3U μl^{-1})	0.25
dNTP mix (2mM each)	2.0
DNA (10-20 ng μl^{-1})	1.0µl (10ng μl^{-1} final concentration)
RAPD primer	2.0
$MgCl_2$ (2.5mM)	3.0
Reaction buffer (10X)	2.5
Total	25

Table 4. Primers used for RAPD analysis of six populations of *E. balteatus*

Primer	Sequence
EB1	TGATCCCTGG
EB2	AGGGCGTAAG
EB3	CAGCCCAGAG
EB4	GTCCCGACGA
EB5	GGTGACGCAG
EB6	TGGGGGACTC
EB7	GTAGACCCGT
EB8	TGCGTGCTTG
EB 9	CTCTGGAGAC
EB10	TCTCCGCTTG

Table 1. Places of collection and their altitudinal range with in outer and lower Himalayas

S. No.	Location	Altitudinal range	Latitude (N)	Longitude (E)
P1	Doda (Bhaderwah)	1613 MSL	32° 58' 48.00"	75° 43' 12.00"
P2	Kathua (Nagri)	336-525 MSL	32° 22' 9.88"	75° 31' 31.40"
P3	Udhampur (Mianbagh)	756 MSL	32° 55' 27.52"	75° 08' 8.63"
P4	Poonch (Mandi)	981 MSL	33° 46' 12.00"	74° 05' 60.00"
P5	Jammu (Sehora)	327 MSL	32° 44' 8.48"	74° 52' 8.80"
P6	Rajouri (Shadra)	915 MSL	33° 14' 60.00"	74° 14' 60.00"

Table 2. Components of standardization PCR reaction mixture

Components	Variable PCR conditions
Template DNA (Episyrphus balteatus)	0.5-2µl (10-20ng/µl) DNA extract from single population was used in each PCR reaction mixture for determining the amount of template DNA for optimum amplification.
Primers	2.0- 5.0µl of RAPD primer (10nm solution) per reaction was studied for determining appropriate amount of primers in reaction mixture.
Taq polymerase enzyme	1-5 units of enzyme per reaction were used foe amplification of clear, distinctive bands of genomic DNA.

weak bands and five gave good result. The PCR products were separated on 1.5% agarose gels containing TE buffer and visualized using ethidium bromide. 100 base pair DNA size marker was used.

Analysis of PCR- RAPD results: Amplification products of each population were scored for the presence or absence of all bands identified. Ambiguous bands that could not be easily distinguished were not scored. The sizes of the RAPD bands were estimated by comparing with a 100 base pair ladder and recorded in a binary matrix that represent the presence (1) or absence (0) of a particular band. The binary matrix was used to estimate Jaccard's coefficient genetic similarity matrix and distance matrix within and in between different individuals (Jaccard 1908). A dendrogram was constructed based on the data of similarity matrix by using online (MAFFT version 7). Unweighted pair group method analysis (UPGMA). Polymorphism Information Content (PIC) was also calculated (Anderson et al 1993).

RESULTS AND DISCUSSION

During present investigation six geographically isolated populations of *Episyrphus balteatus* were studied for DNA polymorphism due to the effect of differential environmental pressure. The change in DNA sequences with the change in outer physical environment within a population can be easily detected through the use of RAPD-PCR technique. A number of discrete DNA bands with different intensities were shown by different primers tested. RAPD patterns were visualized and scored from gel photographs. Different primers used showed different species specific DNA bands and the level of amplification of some bands was not uniform. Out of 39 bands of genomic DNA formed by using ten decamer oligonucleotide primers, 25 bands were polymorphic in nature. These polymorphic bands were used to differentiate the six populations of *E. balteatus*. Maximum numbers of polymorphic bands were separated by primers EB2, EB3 and EB4 (Fig. 1b, c, d) and minimum number of polymorphic bands by primers EB5, EB7 and EB8 (Fig. 1e, g, h). EB1 and EB7 primer was successfully tested to define *E. balteatus* populations (Fig. 1a, g) where it separated three species specific bands (~1350, 1100, 500bp). EB2, EB3, EB4 (Fig. 1b,c, d) confirmed the possibility of an easy discrimination as it defined verydifferent RAPD profiles for the different populations of *E. Balteatus*. EB6, EB9, EB10 defined 2, 1, 1 species specific bands respectively (Fig. 1f, i, j).

The maximum polymorphic bands belonged to EB2 (4 bands), EB3 (4 bands) and EB4 (4 bands) with 100 percent DNA polymorphism and the minimum polymorphic bands belonged to EB7 primer (1 band) with 25 percent polymorphism. EB1 (3 bands), EB5 (1 band), EB6 (3 bands), EB8 (1 band), EB9 (2 bands) and EB10 (2 bands) showed 50, 33.33, 60, 33.33, 66.66 and 66.66 percent respectively. Primers EB1 and EB7 can be used to define the populations of *E. balteatus* for these primers produce some species specific DNA bands whereas primers EB2, EB3 and EB4 can be efficiently used to differentiate genetically different populations of *E. balteatus*. RAPD primers (monomorphic

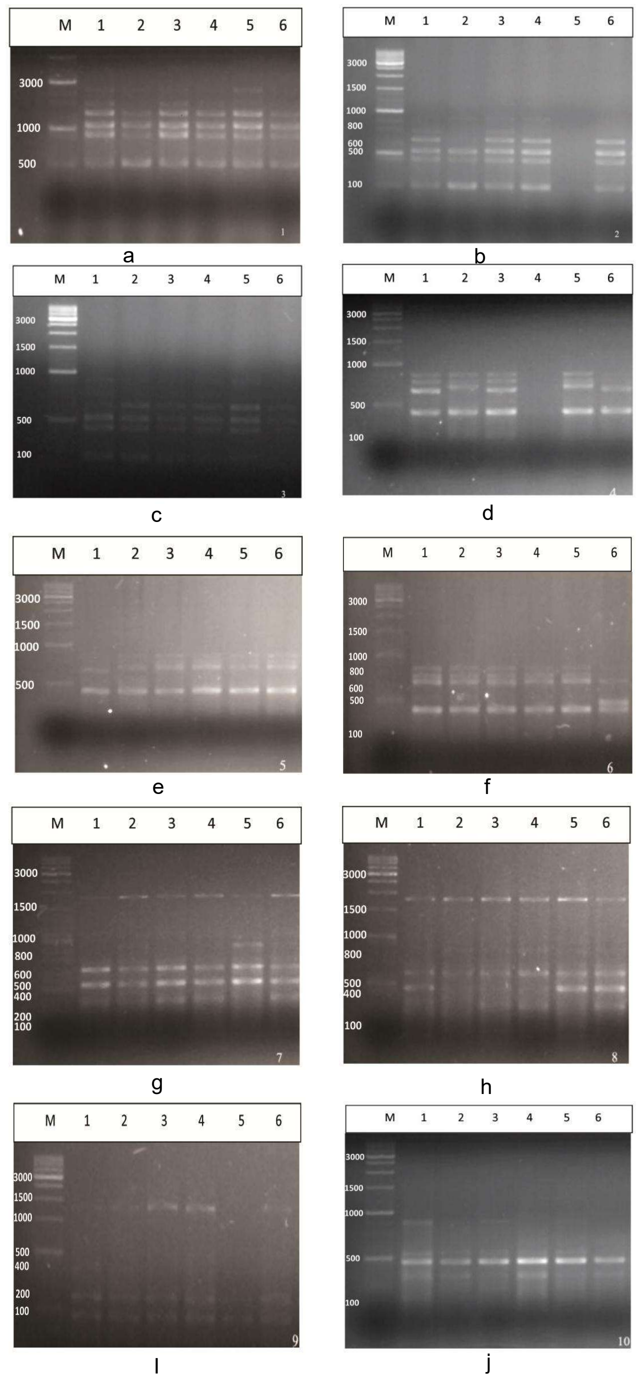

Fig. 1. RAPD-PCR banding pattern showing monomorphic as well as polymorphic markers in six geographically distinct populations of *E. balteatus*

and polymorphic) used to amplify the DNA from the individuals of the *E. balteatus* are mentioned here (Table 5 and 6 respectively). Fourteen monomorphic DNA bands (markers) were identified and these markers hold no practical value but are species specific in nature. Twenty five polymorphic markers identified hold enormous importance in molecular differentiation amongst the studied population. Different members in the six selected populations behaved differently with respect to the amplification of polymorphic markers. Use of these 10 decamer random primers identified genetic similarity index ranged from 0.564 between P5 (Jammu) and P6 (Rajouri) flies to 0.872 between (P1) Bhaderwah and (P3) Udhampur flies. High genetic similarity value is the indicator of genetic closeness of subpopulations. The present data indicates that P1 and P3 populations are most genetically related populations with lowest genetic distance of 0.128. The populations of Jammu (P5) and Rajouri (P6) region exhibited the highest genetic distance of 0.436.

PIC values, a reflection of allele diversity and frequency among the subpopulations ranged from 0.104 (EB5) to 0.547 (EB10). Presently used primers showed resolving power ranges from 3.66 (EB10) to 8.66 (EB1) (Table 7). The frequency of different allele for a specific primer among

Table 5. Different RAPD-PCR marker bands (monomorphic) observed in six populations of *E. balteatus*

RAPD Primer	Marker band (bp)
EB1	1300, 1000, 500
EB5	650, 400
EB6	700, 400
EB7	1850, 650, 500
EB8	1800, 600
EB9	100
EB10	450

Table 6. Different RAPD-PCR polymorphic marker bands amongst the populations of *E. balteatus*

RAPD-Primer	Marker band (bp)	*Episyrphus balteatus* population individuals					
		P1	P2	P3	P4	P5	P6
EB1	2500	1	0	0	0	1	0
	1500	1	0	1	0	0	0
	900	1	0	1	1	1	0
EB2	700	1	0	1	1	0	1
	550	1	1	1	1	0	1
	400	1	1	1	1	0	1
	100	1	1	1	1	0	1
EB3	650	0	1	1	1	1	1
	550	1	1	1	1	1	0
	425	1	1	1	1	1	0
	100	1	1	1	1	1	0
EB4	850	1	1	1	0	1	0
	750	1	1	1	0	1	0
	650	1	1	1	0	1	1
	400	1	1	1	0	1	1
EB5	850	0	1	1	1	1	1
EB6	800	1	1	1	1	1	0
	750	1	1	1	1	1	0
	500	0	0	0	0	0	1
EB7	900	0	0	0	0	1	0
EB8	450	1	0	0	0	1	1
EB9	1350	0	0	1	1	0	1
	200	1	1	1	1	0	1
EB10	900	1	0	1	0	0	0
	550	1	1	1	0	0	0

different populations of a single species suggests the amount of polymorphism shown by thepopulation. We can also relate these frequencies with the heterozygosity of respective populations. The frequency of different alleles can be used to calculate polymorphism information content (PIC) which is the information regarding the presence of polymorphic markers.

Statistical analysis of the data for genetic relatedness: All the monomorphic as well as polymorphic RAPD-PCR amplified bands were used to analyze genetic similarity between studied populations by using NTSYSpc version 2.2 software. The bands obtained were scored as '1' for presence and '0' for absence. The genetic similarity matrix was calculated using SimQual (Table 8). Among the studied population, the similarity of DNA bands ranged from 0.5641026 to 0.8717949. The lowest genetic distance of 0.128 was observed between populations collected from P1 (Bhaderwah) and P3 (Udhampur) regions. The populations of P5 (Jammu) and P6 (Rajouri) regions exhibited the highest genetic distance of 0.436.

UPGMA cluster analysis method was used to generate the dendrogram (Fig. 2). Both monomorphic and polymorphic DNA bands were taken into consideration for cluster analysis. On the basis of cluster analysis six populations based upon the genetic similarity data were classified into two main clusters A and B at the coefficient of GS 0.65. Group A consists of populations viz P1 (Bhaderwah), P2 (Kathua), P3 (Udhampur), P4 (Poonch) and P5 (Jammu). Group B consists of only one population P6

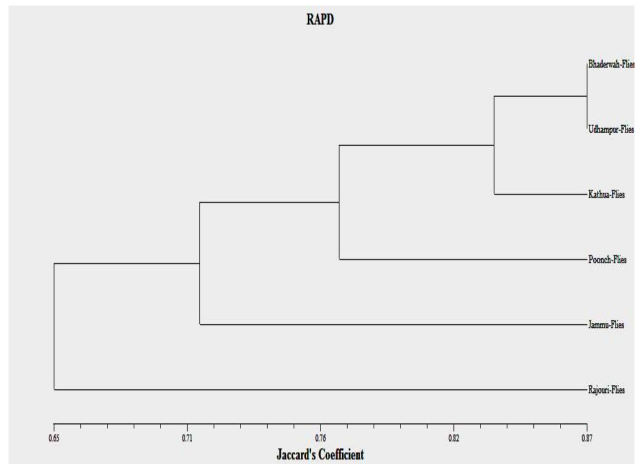

Fig. 2. Dendrogram showing genetic relatedness amongst six geographically distinct populations of *E. Balteatus*

Table 7. RAPD primers with the number of amplified bands, PIC (Polymorphism information content) and RP (Resolving power)

Primer	Nucleotide sequence (5'to 3')	PIC	RP	No of RAPD bands per primer	No of species specific RAPD fragments	Polymorphic bands (%)
EB1	TGATCCCTGG	0.39	8.664	6	3	3(50)
EB2	AGGGCGTAAG	0.37	6.33	4	0	4(100)
EB3	CAGCCCAGAG	0.307	6.664	4	0	4(100)
EB4	GTCCCGACGA	0.432	5.996	4	0	4(100)
EB5	GGTGACGCAG	0.104	5.666	3	2	1(33.33)
EB6	TGGGGGACTC	0.317	7.664	5	2	3(60)
EB7	GTAGACCCGT	0.243	6.332	4	3	1(25)
EB8	TGCGTGCTTG	0.25	5	3	2	1(33.33)
EB9	CTCTGGAGAC	0.352	4.666	3	1	2(66.66)
EB10	TCTCCGCTTG	0.547	3.666	3	1	2(66.66)
Total				39		25 (64.10)

Table 8. Genetic similarity matrix of six populations of *E. balteatus* derived from RAPD markers

	Bhaderwah	Kathua	Udhampur	Poonch	Jammu	Rajouri
Bhaderwah	1					
Kathua	0.7948718	1				
Udhampur	0.8717949	0.8717949	1			
Poonch	0.6923077	0.7948718	0.8205128	1		
Jammu	0.7179487	0.7692308	0.6923077	0.6666667	1	
Rajouri	0.5897436	0.6923077	0.6666667	0.7435897	0.5641026	1

(Rajouri). P1 (Bhaderwah) and P3 (Udhampur) populations were classified as the most related populations with a similarity percentage of 87% whereas lowest percentage of similarity occurred between P5 (Jammu) and P6 (Rajouri) populations with a coefficient value of 65%. Cluster analysis reveals various evolutionary adaptations of *E. balteatus* populations. P1 (Bhaderwah) and P3 (Udhampur) are classified as most related populations whereas P6 (Rajouri) population is relatively distant from the other five populations. Calado et al(2006) detected PCR-RAPD and PCR-RFLP polymorphisms in *Anopheles cruzii* (Diptera). They used seven primers for the comparisons within and among the populations of *Anopheles cruzii* during PCR-RAPD experiments. They calculated genetic distance among populations of *A.cruzii* varied from 0.0214 to 0.0673 suggesting that the individuals used in the analysis belong to a single species. Posso et al(2003) analyzed three populations of *Anopheles nuneztovari* (diptera) from Columbia to study genetic variation. They found a significant genetic distance (0.1131) between these populations. Variations among individuals were also significant (0.8869) by evaluation of these two parameters they concluded that three populations of *A. nuneztovari* are co-specific. Kaura et al (2009) characterized two populations of *Culex quiquefasciatus* using RAPD-PCR technique. Tyagi et al (2015) used RAPD DNA markers to differentiate the five sibling species of *Anopheles culicifacies*. Thetotal of 34 DNA bands was generated and these all are polymorphic in nature which can be used to differentiate between sibling species. The molecular weights of these bands were in the range of 2800 to 375 bp. They calculated average genetic distance between the species to be 0.58 ranging from 0.15 to 1.12. Silvester et al (2016) observed high intraspecific genetic diversity in populations of *Vibrio parahaemolyticus* along the southwest coast of India using RAPD-PCR. Tyagi et al (2012) studied genetic divergence in *Glycine max* genotypes from different environments.

CONCLUSIONS

The present research findings showed variations in DNA among six sub-populations of *E. balteatus* through the formation of 25 RAPD bands. The mean polymorphism percentage obtained was 64.10. The PIC value (allelic or intraspecific genetic diversity) ranged from 0.104 to 0.547. The genetic similarity of DNA bands ranged from 0.564 to 0.872. The lowest genetic distance of 0.128 was observed in case of P1 and P3 populations, indicating the most genetically related populations whereas the populations of P5 and P6 exhibited highest genetic distance of 0.436 indicating least relatedness. Present findings could be useful in population genetic studies as well as course of evolution among dipteran syrphid flies as less molecular data is available.

Received 27 November, 2021; Accepted 21 February, 2022

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Indian Journal of Ecology (2022) 49(2): 521-526
DOI: https://doi.org/10.55362/IJE/2022/3555

Manuscript Number: 3555
NAAS Rating: 5.79

In-silico Determination of Insecticidal Potential in Lepidopteron Specific Crystal Toxins with Midgut Alkaline Phosphatase Using Molecular Docking

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***Abstract*:** Alkaline phosphatase (ALP) enzyme plays an important role in binding of lepidopteran specific insecticidal crystal toxins Cry1Ac and Cry1Ab on GPI-anchored membrane receptor. In most of the cases crystal toxin interaction with ALP or Aminopeptidase N (APN) mediated by the terminal N-acetyl galactosamine (GalNAc) moiety. Among toxins Cry1Ac (PDB Id-4ARY) and Cry1Ab (PDB Id - n642) expresses less binding affinity about (-5.79 and -5.62) to GalNAc in ALP or APN region, respectively. The diptera specific crystal toxins Cry4Ba structure resembles to the lepidopteran specific toxins as it mimics like Cry1Aa for binding to ALP receptor by showing least binding affinity about (-6.99). Cry4Ba may be repurposed along with the novel *Bt* crystal toxins for lepidopteron insects as toxicity over Cry1Ac or Cry1Ab which will effective to bind with ALP or APN for toxin receptor interaction and help to minimize the rate of resistance. The Cry4Ba pyramided in combination with other Cry genes in different crops like cotton and maize would be an efficient strategy to increase crop protection by delaying the lepidopteran insect resistance.

Keywords: Lepidoptera, Alkaline phosphatase, Receptor crystal toxin, Resistance

Bacillus thuringiensis (*Bt*) a gram positive bacterium member of the *Bacillaceae* family was firstly identified and isolated in Japan by Ishiwata in 1902 who considered this microbe responsible for *Bombyx mori* infection in silkworm, followed by the study of Berliner on moth *Ephestia kuehniella* larvae evaluated as cry δ-endotoxins capable of killing insects produced by *Bt* (Melo et al 2016, Zhang et al 2017). There are several strains of *Bacillus thuringiensis (Bt)* which known as biological control agent to produce crystalline proteins by sporulation during their stationary phase of growth, which are demonstrated as lethal to lepidopeterous, coleopeterous and dipterous insects due to their specificity and toxicity toward certain insect orders (Jisha et al 2013, Lucena et al 2014). Cry toxins can cause death by two mechanism by inactive protoxin complex of (Cry alone or Cry and Cyt toxins together) with high molecular mass, which is cleaved upon ingestion into the active component proteins known as inactive protoxin crystals which were solubilized by the high alkaline environment in the digestive tract in the insect midgut with their ability to induce both pore formation (sequential binding model) and ion channel activation (signalling pathway model) lead to insect death (Bravo et al 2007, Zhang et al 2017). The another mechanism of crystal toxin like Adenylyl cyclase belongs to signalling pathway in which cadherin receptors used to report toxicity in insects by stimulation of protein kinase A by involving “G protein” activation via upregulation of cAMP levels leads to cytological changes such as cell swelling and lysis in insects (Zhang et al 2006, Bravo et al 2007, Fernandez-Chapa et al 2019). For different crystal toxins there were major receptors such as Alkaline phosphatase (ALP), Midgut membrane bound cadherin-like protein, Aminopeptidase N (APN) as binding sites in different lepidopteran insects (Du et al 1994, Zhao et al 2017, Wang et al 2019). After binding of crystal structures on such membrane receptors, oligomer formation and pre-pore complex takes place which is more flexible than its monomeric form and will be stabilized by the alkaline pH in the midgut of lepidopteran and dipteran larva (Rausell et al 2004, Parker and Feil 2005). Alteration or mutation in any one of the mechanisms such as solubilisation of crystal toxin in protoxin to active form, binding of crystal toxins to ALP, APN or Cadherin (CAD) receptors, pre-pore oligomeric structure leads to intoxication and development of resistance (Herrero et al 2001, Bravo et al 2007). To reverse the intoxication mechanism and resistance potential in insects, second generation transgenic cotton Cry2Ab alone or in combination with Cry1Ac has been developed (Tabashnik et al 2002). *B.*

thuringiensis endotoxins that are currently utilized in commercial transgenic insect resistant crops also pyramiding of multiple *B. thuringiensis* genes that encode different insecticidal proteins with several modes of action has greatly increased to control of major pest species. These toxin oligomers binds with high affinity to APN and ALP which are GPI anchored receptor located in specific membrane micro domain called lipid-rafts, leading to the membrane insertion by forming ion leakage pores that causes osmotic lysis which results in extensive damage to the midgut epithelial cells and eventual larval death (Ning et al 2010, Sengupta et al 2013, Song et al 2015, Tay et al 2015, Wei et al 2019). The first generation of transgenic *Bt* cotton, Cry1Ac shown to be highly effective on susceptible strain of pink bollworm (PBW) (Ojha et al 2014). Reduced Cry1Ac binding activity of ALP receptor on PBW midgut membrane seen to be resistant to ligand Cry1Ac (Ojha et al 2014). The development of insect resistance known as complex phenomenon involving several mechanisms which operates simultaneously within lepidopteron insect strain (Welling et al 1976, Jurat-Fuentes et al 2011).

The crystal toxin receptors characterized as a glycosylated protein implying that carbohydrate residue GalNAc in active catalytic site of ALP which plays an important role in toxin receptor interaction and subsequent cry toxin specificity (Boonserm et al 2005, Bravo et al 2007, Sengupta et al 2013). Multiple structure alignment of Cry4Ba belongs to Lepidoptera and Diptera selective classes structurally similar to Cry1Aa and Cry2Aa than the Coleoptera specific Cry3Aa (Boonserm et al 2005). Cry4Ba which was isolated from *Bacillus thuringiensis* subspecies *israelensis* have toxic action against the larvae of *Aedes* and *Anopheles* mosquitoes. The *Aedes aegypti* mosquito belongs to diptera order have membrane bound ALP functions as a Cry4Ba receptor, responsible for mediating Cry4Ba toxicity while GPI-APN isoforms showed a dramatic increase of resistance in *A. aegypti* mosquito larvae (Dechklar et al 2011, Saengwiman et al 2011). So, the main objective of our study is to investigate the insect resistance molecular mechanism of midgut enzyme ALP and its interactions with various insecticidal crystal toxins via *In-silico* Molecular Docking analysis. It is a computational method of studying binding interactions in terms of binding energies is immensely used in the process of drug discovery which shows position, orientation and conformation of ligand in the active site of protein. This study is performed to analyse the most suitable crystal toxins such as Cry1Ac, Cry2Ab and Cry4Ba which shows binding affinity towards GalNAc present in ALP binding pocket in a lepidopteran larval midgut and mediate the toxin-receptor interaction.

MATERIAL AND METHODS

To perform molecular docking studies computer generated representation of the ligand GalNAc retrieved from PubChem were used to study their binding affinity with different lepidopteran specific *Bt* Crystal toxins (Cry1Ac, Cry1Ab and Cry4Ba). The main objective of molecular docking study is to finding out conformation with their least binding energies.

Protein Structure: The lepidopteran specific biological macromolecular protein structures Cry1Ac (PDB Id- 4ARX), Cry1Ac (PDB Id-4ARY), Cry1Ac (PDB Id-4W8J), Cry4Ba (PDB Id-1w99) were retrieved from RCSB databank which contains experimentally-determined structures of proteins. Ligplots were obtained from PDBSum-Generate database which utilizes 4 characters, to get the ligands with their ligplots. Crystal toxins were taken for study having resolution above 2.0 Å.

Homology modelling: Since Cry2Ab structure was not available in RCSB-PDB; FASTA sequence was retrieved from UniProtKB (P21254) (CR2AB_BACTK) and it has been utilised for homology modelling. Further due to unavailability of ligands in its homologous 3D model, Cry1Ab similar to Cry1Ac was considered for molecular docking analysis (Lee et al 1995, Karim et al 2000, Iva´n Arenas et al 2009). Homology modelling of insecticidal and pesticidal crystal protein Cry1Ab for *Bacillus thuringenesis* sub species *kurstaki* (Lepidopteran specific) (UniprotKB-POA370) (CR1AB_BACTK) was envisaged. Then we got the Swiss model of Cry1Ab (PDB Id: n642) (sequence identity-88.1 %) for further molecular docking procedures (Fig. 1). The ligplots were used for studying interacting sites of the protein of interest and ALP present in the midgut of PBW with accordance to GalNAc (ligand) receptor for sugar binding moiety of crystal toxins in the active site of the enzyme.

Molecular docking: The AutoDock 4 suite (*ver.* 1.5 6rC2) was used to perform the docking of GalNAc into the carbohydrate binding site of various crystal toxins like Cry1Ac, Cry2Ab and Cry4Ba. The results were further analysed by a statistical scoring function which converts interacting energies into numerical values called docking score (Moon et al 2018). Auto Dock 4 consists of two main programs: Auto Dock which perform docking of the ligand to a set of grids that will describes rigid target protein and Auto Grid. Graphical user interface of Auto Dock, Auto Dock Tools (ADT) built on Python Molecular Viewer was used for docking studies. Proteins and ligand were cleaned in Discovery Studio 3.1 Visualizer and Marwin view. Hydrogen atoms were added to the modelled structure and converted into PDBQT format by AutoDock. A 3D grid box of size (60 x 60 x 62) was defined, with a grid space that covered the above-mentioned residue. The standard docking protocol was performed using Lamarckian genetic algorithm by keeping receptor as rigid and ligand as flexible.

RESULTS AND DISCUSSION

Structural and functional analyses of midgut ALP and APN have major role which binds to Cry1Ac and Cry2Ab receptor with high affinity in susceptible insects of *Plutella xylostella*, *Pectinophora Gossypiella*, *Helicoverpa Armigera* and *Helicoverpa Zea* in monomeric form and then bound to cadherin in midgut converts it into oligomeric form. *In-silico* molecular docking analysis of various lepidopteron specific crystal toxins with target receptor ALP in which GalNAc existing on the active site shows various interacting sites with their docking score (Fig. 2, Fig. 3). In case of Cry2Ab and Cry1Ac resistant insects toxin binding activities were altered by their binding receptors (Tabashnik et al 2002, Iva´n Arenas et al 2009, Caccia et al 2012, Malthankar and Gujar 2014, Chen et al 2015, Wei et al 2019, Xiao and Wu 2019). *In vitro* interaction studies of GalNAc states that it is binding determinant in the oligomeric structure of Cry1Ac affiliated to APN (Aminopeptidase N) which induced a conformational change in the toxin and enhanced its insertion into lipid membranes (Pardo et al 2006). Mutation in ABCC genes or

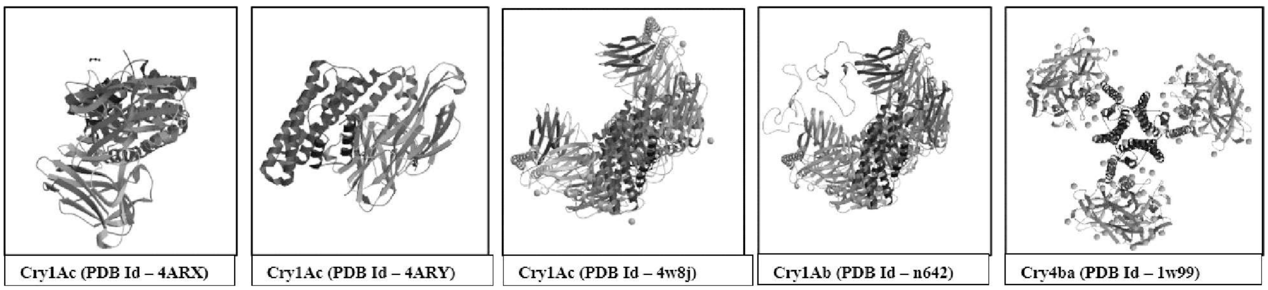


Fig. 1. PDB structure of different lepidopteran specific crystal toxins

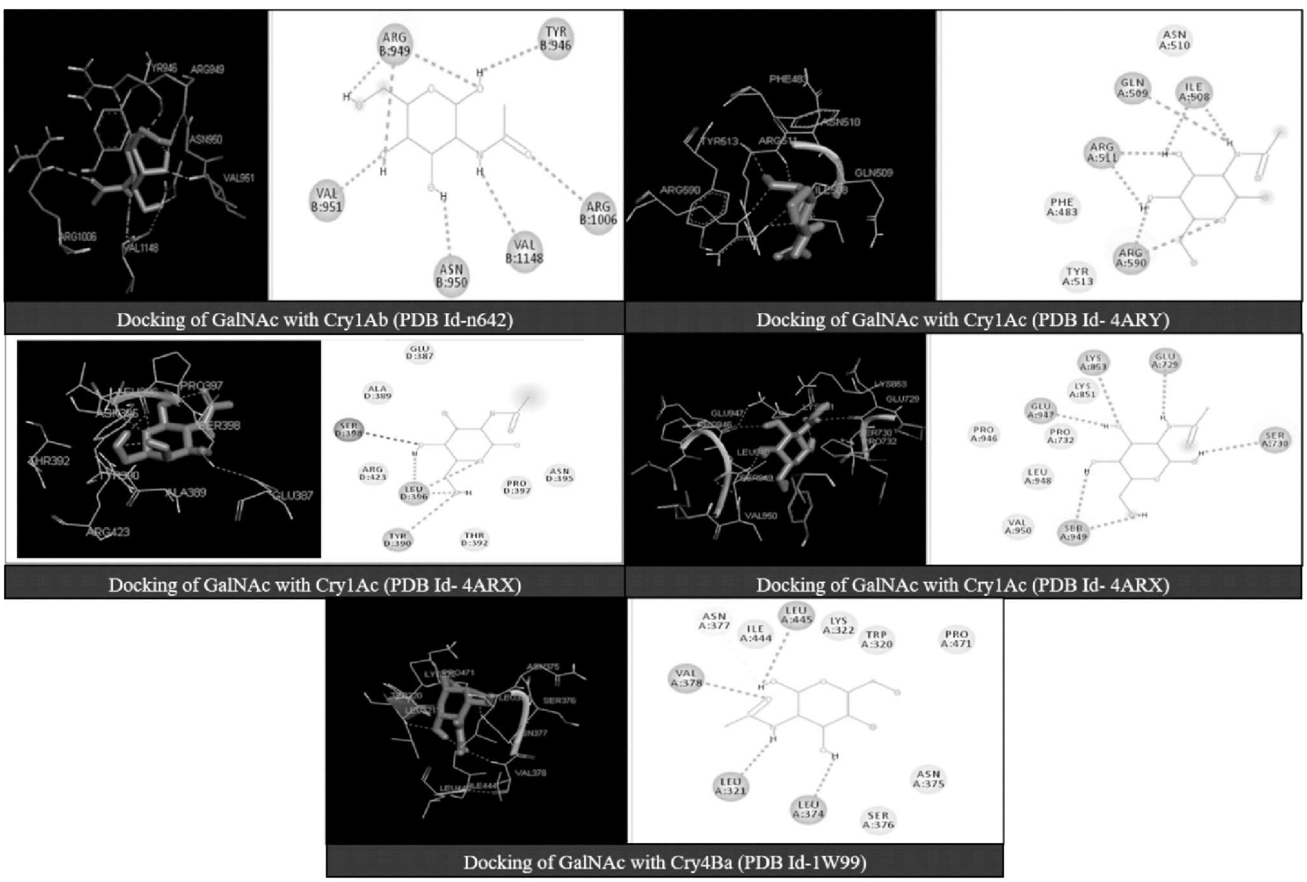
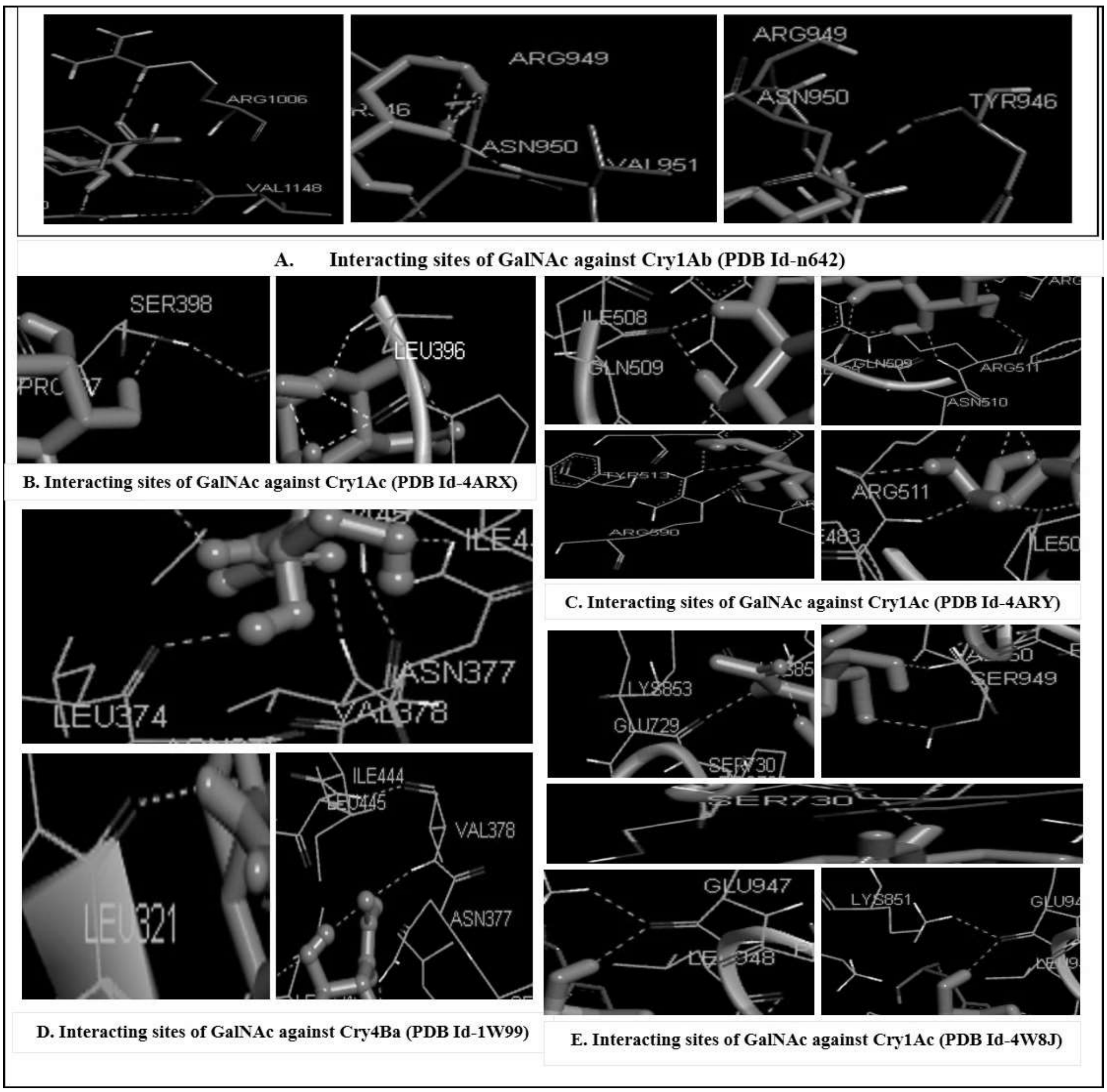


Fig. 2. 3D and 2D images of molecular docking of GalNAc with various crystal toxins

alteration in MAPK signalling pathway also resists the crystal toxin binding to midgut ALP leads for resistance for Cry1Ac toxin in Diamond back Moth (Guo et al 2015).

In-silico data analysis, diptera specific crystal toxin Cry4Ba holds a good docking score with GalNAc in ALP as it shows structural similarity with lepidopteran specific crystal toxins, than performed assay with crystal toxin Cry1Ac and Cry1Ab (Boonserm et al 2005). Cry4Ba holds a lowest docking score (-6.99) which states that it possesses higher affinity towards ALP GalNAc receptor which shows 5 interacting sites i.e. LEU A 374, VAL A 378, LEU A 445, LEU A 321, ASN A 377. While Cry1Ac (4ARY) and Cry1Ab (n642) also shows good toxin receptor interaction. Cry1Ac (PDB Id-4ARY) and Cry1Ab (PDB Id - n642) shows lowest binding docking score -5.79 and -5.62 towards GalNAc receptor respectively so both can show a good toxin receptor interaction with ALP in the midgut of lepidopteran insects. In response to all crystal toxins, Cry1Ab shows maximum 6 interactive sites i.e. ARG B 1006, VAL B 1148, ASN B 950, VAL B 951, TRYP B 946 and ARG B 949 with different amino acids (Table 1). None of the similar interaction was found in crystal toxins when compared to their ligplots so it may be concluded that, toxin receptor interaction not occurred on ligplot interacting sites but occurred via distinct amino acids. The interpretation drawn from the *In-silico* data analyses, that GalNAc moiety on the receptor ALP is recognised by the domain III of crystal toxins at its monomeric form. Then the oligomer formation of crystal toxins takes place when it gets interacted to other midgut receptors like CAD (Cadherins) and facilitates the oligomer formation and pore formation will



A. Interacting sites of GalNAc against Cry1Ab (PDB Id-n642)

B. Interacting sites of GalNAc against Cry1Ac (PDB Id-4ARX)

C. Interacting sites of GalNAc against Cry1Ac (PDB Id-4ARY)

D. Interacting sites of GalNAc against Cry4Ba (PDB Id-1W99)

E. Interacting sites of GalNAc against Cry1Ac (PDB Id-4W8J)

Fig. 3. Interacting sites of ligand GalNAc with various crystal toxins

Table 1. Docking score of crystal toxins for ALP receptor expressing GalNAc in their active site

Crystal toxins	N – Acetylgalactosamine (GalNAc)	
	Docking score	Interacting sites
Cry1Ac (PDB Id-4ARX)	-4.36	LEU A 396, TYR A 390, SER D 398
Cry1Ac (PDB Id-4ARY)	-5.79	ILE A 508, ARG A 511, ARG A 590, GLN A 509
Cry1Ac (PDB Id-4W8J)	-5.65	LYS A 851, GLU A 947, GLU A 729, SER A 730, SER A 949
Cry1Ab (PDB Id-n642)	-5.62	ARG B 1006, VAL B 1148, ASN B 950, VAL B 951, TRYP B 946, ARG B 949
Cry4Ba (PDB Id-1w99)	-6.99	LEU A 374, VAL A 378, LEU A 445, LEU A 321, ASN A 377

lead to larval death. But with a continuous exposure to crystal toxins, lepidopteran insects get resistant to them by altering mutations in their receptor binding site in the midgut ultimately leads to low cross affinity for binding of ALP, APN or cadherin receptors due to absence of midgut site for toxin receptor interaction which will reduce oligomer formation and insertion.

Insects exhibit low genetic diversity having uniform populations with rear mutations due to which alteration in receptor genes mediates resistance to diverse control strategies. Introducing novel *Bt* crystal toxins is a need for increasing susceptibility of insects towards toxins killing mechanisms as lepidopteran insects are now becoming resistant to previous *Bt* crystal toxins (Ahmed et al 2015, Xiao and Wu 2019). Cry toxin mutants are innovative and efficient tools that can be applied to transformed plants for insect control (Lucena et al 2014). CRISPR /Cas9-mediated knockout and host mediated RNAi has a potential avenue for increasing crop resistance by inhibiting egg production of target pests (Xiao and Wu 2019). Fusion of two insecticidal crystal proteins or fusion of crystal proteins with vegetative insecticidal protein like Vip3Aa with Cry1Ac which will improve the insecticidal activity against various midgut receptors targets (Ahmed et al 2015, Javaid et al 2018). Genetically modified Crystal toxins Cry1AbMod and Cry1AcMod were also effective against a laboratory-selected strain of pink bollworm resistant to Cry2Ab as well as to Cry1Ab and Cry1Ac (Tabashnik et al 2013). According to *In-silico* findings, Cry4Ba may be repurposed for lepidopteran insect toxicity over Cry1Ac or Cry2Ab, along with the novel *Bt* crystal toxins is a need for increasing susceptibility of insects towards toxins killing mechanisms as lepidopteran insects are now becoming resistant to previous *Bt* crystal toxins. It will be effective in binding of toxin receptor interaction and help to minimize the rate of resistance.

CONCLUSION

In-silico molecular docking analysis of various lepidopteran specific crystal toxins with GalNAc in their active site of midgut receptor ALP addresses its important role in toxin receptor interaction. Dipteran specific crystal toxin Cry4Ba having similarity with lepidoptera specific crystal toxins holds a good docking score of -6.99 with GalNAc ligand. As Lepidoptera already acquires resistance to various known crystal toxins like Cry1Ac and Cry2Ab via altering their receptors so pyramiding of transgenic crops with Cry4Ba might prolong resistivity. This study states that, along with Cry1Ac and Cry1Ab, Cry4Ba may be repurposed for lepidopteran which will facilitate for more toxin receptor interaction between crystal toxins and midgut receptors like ALP or APN on binding determinant GalNAc. It will lower the resistivity of lepidopteran insects to crystal toxins which will lead to larval death Replace with The resistivity of lepidopteran larvae towards thr cry toxinn will be lower leading to the larval mortality.

ACKNOWLEDGEMENT

This work was supported by grants from the 'Department of science and technology Project (DST), sponsored by Science and engineering research board (SERB), India under EMR scheme.

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Received 20 December, 2021; Accepted 02 April, 2022

Indian Journal of Ecology (2022) 49(2): 527-533
DOI: https://doi.org/10.55362/IJE/2022/3556

Manuscript Number: 3556
NAAS Rating: 5.79

Status of *Bemisia tabaci* (Gennadius) in Context of its Biology and Ecology in Cotton Agroecosystem

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Abstract: Cotton is an important cash crop and extensively cultivated in different parts of the world. Many factors are responsible for its low productivity and production but the magnitude of insect pests that damage cotton crop from sowing to maturity, is most important. Introduction of Bt cotton lead to drastic reduction in bollworms incidence but sucking insect pests such as whitefly, mealybug, jassid and thrips aphids has increased. Among these, whitefly, *Bemisia tabaci* is most serious pest of cotton. At present, it is globally distributed and known to infest several plant species. It causes damage to cotton crop by direct feeding and contamination of lint by honey dew and sooty mould. It transmits a deadly cotton leaf curl virus. *B. tabaci* has strong relationship with abiotic factors like temperature, humidity and precipitation. Temperature has positive correlation and relative humidity has negative correlation with whitefly. A combination of temperature and relative humidity is highly important for its multiplication in cotton. For a multi-voltine and multi-crop pest like *B. tabaci* estimating rates of mortality in the field is extremely complex and difficult. So, life table studies are important to predict pest outbreaks and to develop pest management strategies.

Keywords: *B. tabaci*, Cotton, Biology, Ecology, Life tables

Cotton is a premier cash crop of India cultivated on an area of 11.3 million hectare, with an annual production of 37.0 million bales and average lint yield of 541 kg per hectare during 2017-18 (Anonymous, 2019). Among the various factors responsible for low production and productivity of cotton, the magnitude of insect pests that damage cotton crop from sowing to maturity is most important. Cotton is a sensitive/complex crop, on which pest attacks periodically and harboured 1,326 species of insects from sowing to maturity in different cotton growing areas of the world (Hargreaves 1948) and 162 species have been reported on the crop in India (Sundramurthy and Chitra 1992). Insect pest complex of cotton crop is broadly divided into four categories namely sucking insect pests, foliage feeders, bollworms and lint stainers. Among these, nine are considered as key pests in different zones resulting in 50-60 per cent loss in seed cotton yield (Dhawan 2004). Due to various reasons, the incidence of insect pests has increased tremendously resulting into failure of cotton crop in the past in Punjab, Haryana, Rajasthan, Andhra Pradesh and Gujarat states of India (Dhawan 2000). With the introduction of Bt cotton in 2002 in India and particularly in Northern states in 2005, lead to drastic reduction in bollworms incidence but sucking insect pests such as whitefly, mealybug, jassid and thrips aphids has increased.

Among the sucking insect pests, whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) has assumed the status of a serious pest of cotton in the recent past and during *kharif* 2015, it appeared in epidemic form in Punjab and Haryana. It is a polyphagous pest and feeds on about 600 plant species including many ornamental and greenhouse crops (Li et al 2011). Improved transportation technology and increased frequency of international transport of plant material has contributed to the extension of the geographical range of the *B. tabaci* complex. At present, it is globally distributed and occurs on all continents except Antarctica. It was first recorded on tobacco in Greece in 1889 and on cotton at Pusa, Bihar (India) during 1905 (Misra and Lambda 1929) and assumed the status of a serious pest on cotton in undivided Punjab in the 1930s. Subsequently, outbreaks of this pest were noticed in different cotton growing states in India, Andhra Pradesh (1984-87), Tamil Nadu, Maharashtra and Karnataka (1985-87), Gujarat (1986-87) and Punjab (1996). Up to 1995, it was a minor pest in Punjab, but became a major pest 1996 onwards (Dhawan et al 2007). It became a major pest on cotton in India after 1984 (Patil et al 1990). The use of synthetic pyrethroid on non-Bt cotton to control bollworms in early 1980s favoured whitefly multiplication (Dhawan et al 2007). Over the years, whitefly has created a niche in agroecosystem and has almost become a pest of regular occurrence in all the cotton growing areas of North-West India. Losses from the species complex in worldwide agricultural systems have been extensive and its emergence as a major threat in agricultural production systems has been characterized by outbreaks in many parts of the world (Gerling and Henneberry 2001).

Whitefly can cause damage to the cotton crop directly by the sucking the sap from the leaves of cotton plants resulting in leaf yellowing, leaf wilting, leaf drop and overall decline in seed cotton yield and indirectly by the excretion of honeydew by nymphs and adults on which sooty mold (black fungus) grows. The presence of sooty mold on leaves interferes with photosynthesis and affects the overall health and growth of the plant as well as lint quality. The third type of damage is caused by transmitting cotton leaf curl virus and the infected plants exhibit leaf curling, crumpling, vein thickening, cupping and plant stunting causing a loss of 10.5-92.2 per cent seed cotton yield in Punjab (Singh et al 1994). Sukhija et al (1986) reported 8-31 per cent loss in seed cotton yield due to the attack of whitefly, whereas Natarajan et al (1986) estimated losses to the tune of 15-20 per cent in South India. About 30-80 per cent loss in cotton was reported in Pakistan by Hameed *et al* (1994). Bedford and Mackham (1993) reported monetary losses of $ 500 m in cotton and vegetables. It also acts as a sole vector of more than 100 plant viruses, which cause diseases to many commercial crops in different parts of the world (Jones 2003). For the management of whitefly, insecticides are mainly used by the farmers. The repeated use and excessive doses had resulted in toxicity to natural enemies, insect resistance especially organophosphates, cyclodienes, synthetic pyrethroids and even for neconicotinoids (imidacloprid, thiamethoxam and acetamprid) and insect growth regulators like pyriproxyfen (Cahill et al 1995 and Byrne *et al* 2003). Although, most control efforts are insecticide based, but the most successful management is facilitated by an understanding of the biology and ecology of the species and melding of chemical, biological, cultural and other control tactics. In this paper, biology and ecology of *B. tabaci* have been reviewed for its proper management on cotton.

Life stages of *Bemisia tabaci:* Whitefly is generally a misnomer as it is not a true fly. In fact, it is closely related to scale insects, mealybugs and aphids in the order Hemiptera. Both adult and nymphal stages produce extracuticular wax that soils their body. The wax is nothing but the tightly curled threads of about 1 mm in diameter. Females normally possess two pairs of wax plates while males are provided with four pairs of wax plates. The hind and forelegs are generally instrumental in spreading the waxy material over the entire body except the eyes.

Egg: Females firmly embed the eggs in leaf tissue with a vertical orientation (Buckner et al 2001). Eggs are laid either singly or in scattered groups usually in circular groups, on the underside of leaves, with the broad end touching the surface and the long axis perpendicular to the leaf. Eggs are whitish when first laid but gradually turn brown. A glue like substance is deposited at the base of the pedicel to cement the eggs in place. Eggs draw water through their pedicels from the leaf, thereby preventing the desiccation before hatching. Hatching occurs after 5-9 days at 30°C but, this depends on host species, temperature and humidity. On smooth leaf varieties of cotton, the adults usually deposit eggs in semicircle. The eggs could be spindle shaped (Rao and Reddy 1989) and sub elliptical (Hussain and Trehan 1933). Under field and insectary conditions on cotton, females have been reported to lay 28 to 43 eggs (Husain and Trehan 1933). Egg laying under controlled temperature laboratory conditions has been highly variable, ranging from 32 to 257 eggs per female over a temperature range of 25.5 to 32.6°C (Butler et al 1983, Horowitz 1983, Bethke et al 1991 and Powell and Bellows 1992).

Crawler: First instar nymphs generally called crawlers, are flat, oval, transparent, light green and scale-like. This first instar is the only stage of this insect which is mobile. It moves from the egg site to a suitable feeding location on the lower surface of the leaf where its legs are lost in the ensuing moult and the larva becomes sessile. During hot summer, the crawlers walk quickly in search of suitable sites for settling on the same leaf (Hussain and Trehan 1933). The crawler may walk for few hours to cover a distance of a few millimeters before settling down on the leaf. Soon after settling, crawler inserts its mouthparts into leaf tissues and the stylet follows an intracellular path until the phloem is penetrated and sap extraction begins.

Nymph: The crawlers turn into sedentary stage. Both the subsequent stages, viz. second and third instar nymphs are sedentary and creamy white to yellow in colour, pointed at the rear end and possess oval shape. After the completion of nymphal stage, these insects turn into pseudopupal stage (Reddy and Rao 1989).

Pupa: The last nymphal stage (fourth instar) is often referred to as pseudo-pupa or puparium and is about 0.7 mm long and lasts about 6 days. It is within the latter period of this stage that the metamorphosis to adult occurs. It possesses two red eye spots, oval in shape and devoid of long waxy spines. Like the second and the third instar nymphs, it is again immobile.

Adult: The adult of whitefly is white, about one mm long with a pale yellow body which remains covered with pairs of tent like white wings of uniform size. Males are slightly smaller than the females. The body and both pairs of wings are covered with a powdery, white to slightly yellowish, waxy secretion. Adult emergence usually takes place in the morning. Compound eyes of the adult are red. Adults start to copulate as early as 2-6 hours post-emergence and females become fertilized on day they emerge (Luan et al 2008). Maximum emergence takes place between 8.00 a.m. to 1.00

p.m. (Hussain and Trehan 1933). Adults often remain near the pupal case for 10 to 20 minutes following emergence to spread and dry their wings. Males and females are sexually immature at emergence (Li et al 1989). The period of egg laying may range from 1-22 days depending on temperature under field and insectary conditions and 2-5 days under laboratory conditions. Female usually lays about 100 pear shaped eggs on the lower surface (Reddy and Rao 1989). Sharaf and Batta (1985) reported the adult longevity between 7.6-11.7 days.

Biology of *B. tabaci:* It has been studied by several workers. Adults begin feeding immediately after emergence and mate within 1-2 days. At 24.5 to 28°C, the average pre-oviposition period is 1.6 days (Ohnesorge et al 1981). Gameel (1978) reported that eggs on cotton hatched in 20.5 and 5.2 days, respectively at 15 and 40°C. The egg hatching reduced to 62 per cent at 15°C and 59 per cent at 40°C, but it ranged from 92 to 98 per cent at 25 to 35°C. In the field, the first, second, third, and fourth nymphal instars period completed in 2-4, 4-8, 4-8, and 4-8 days, respectively. Adult males were shorter lived (13.0 days) than females (61.5 days) on cotton from September to December in Sudan. Being polyphagous, it remains active throughout the year on a variety of hosts. However, on cotton, it is active during May-October in North, Central and South Zone of India (Dhawan et al 2007). The detailed investigations on the biology of the whitefly were first made in undivided Punjab by Hussain and Trehan (1933), whereas in South India, the extensive study on biology was carried out in Andhra Pradesh during the mid-eighties at the time of its outbreak on cotton (Anonymous 1989). In North India, eggs hatch in 3-5 days during active cotton season (April-September) but hatching extends to 5-17 days in October-March at low temperature conditions. The nymphal stage is about 9-14 days during March-April and 17-73 days during October-March (Hussain and Trehan 1933). Duration of egg stage varied from 4.35-5.9 days during different seasons viz. pre-monsoon, monsoon and post-monsoon (Aneja 2000). However, the studies carried out in Punjab demonstrated the total nymphal period of 7-13 days during the active cotton season on different cotton varieties (Butter and Vir 1991). Pupal period is generally 2-8 days (Hussain and Trehan 1933). In another study, under Punjab conditions, Aneja (2000) reported that duration of first, second, third nymphal instars and pupal stage varied from 3.90 to 6.40, 4.85 to 6.80, 2.75 to 6.65 and 4.60 to 5.65 days, respectively.

The total life cycle takes about 14-27 days in April-September, 36 days in October-November and 92-107 days in November-February and 30 days in March. The total duration of life cycle at Pusa and New Delhi been recorded as 12-17 days in August-September (Misra and Lamba 1929). In another study, the life cycle took 13-16 days in April-October and 33-47 days in November-February at Delhi on different hosts (Mohanty and Basu 1987). Study carried out in Punjab reported the total life cycle of 26-44 days during active cotton season (Aneja 2000). There are about 10-12 generations of the pest in a year. The adult longevity is normally 2-5 days in summer and may go up to 24 days in November (Hussain and Trehan 1933). In South India, life cycle is the shortest (13 days) in September and the longest (20.5 days) in December (Rao and Reddy 1989). The complete development period from egg to adult stage takes 15-70 days depending upon the weather conditions. In south, the female laid 28-300 eggs depending on the host and temperature conditions. The average fecundity of female is 43 eggs. The total fecundity between 18.1-26.8 eggs was reported in another study by Aneja (2000). However, Butter and Vir (1991) observed an average fecundity between 12-43 eggs. The sex ratio (Male: female) is usually 1: 1. The proportion of male and female is generally high in March-August, while it is low during September-February (Pruthi and Samuel 1942). The sex ratio is dependent on temperature, being 1: 1.8 at 30^{0}C and changed to 1: 3.1 at 14^{0}C (Sharaf and Batta 1985). However, Broad and Puri (1993) did not record range in the sex ratio on various crops during different months and ruled out the effect of temperature on sex ratio.

The studies carried out on the biology of whitefly on resistant and susceptible cultivars in South India indicated no difference in incubation, nymphal and pupal periods and duration of life cycle. However, the average egg load on resistant varieties was 8.8-15.1 eggs per leaf against 41.5-53.9 eggs per leaf on susceptible cultivars. The average fecundity was 12.53 and 48.53 eggs per leaf on resistant and susceptible varieties, respectively. The survival of different stages, viz. nymph, pupa and adult was 75.1, 81.8 and 89.3 per cent on resistant varieties against 87.0, 90.5 and 95.8 per cent on susceptible varieties, respectively (Anonymous 1989). Egg density can be as high as 1,200 eggs per square inch. The egg, nymphal and total development period of *B. tabaci* varied from 6.02-7.48 days, 15.87-19.87 days and 19.00-23.30 days, respectively on different genotypes during June-July whereas the respective durations in August-September were 5.60-7.60, 16.00-18.23 and 17.77-21.67 days, respectively. The egg survival varied from 53.33-86.67 per cent during June-July. Nymphal survival ranged from 42.83 per cent on PA 183 genotype to 70.67 per cent on F 846 genotype (Jindal 2004). In a similar study Ashfaq et al (2010) observed that maximum population of the *B. tabaci* on transgenic genotypes VH-255 and I-2086 while, the lowest population was recorded on non-transgenic genotype CIM-496. Chandi and Kular (2014, 2015) reported that during post-monsoon season duration of egg, first, second and third nymphal instar and pupal stage varied from 4.87 to 5.90, 4.81 to 5.02, 4.50 to 4.92, 4.52 to 5.30 and 3.95 to 4.45 days, respectively on different cultivars, however during monsoon season respective durations varied from 4.20 to 5.30, 4.67 to 4.93, 3.73 to 4.30, 4.37 to 4.93, 3.60 to 4.32 and 4.82 to 5.35 days, respectively on different Bt and non-Bt cultivars.

Ecology of *B. tabaci:* It has strong relationship with abiotic factors like temperature, humidity and precipitation. Upper temperature thresholds for growth and development are probably greater than 35^{0}C (Butler et al 1983). But a definite combination of temperature (27^{0}C) and relative humidity (71%) is highly important for the multiplication of whitefly in cotton system (Singh and Butter 1985). Effect of temperature on life functions is well documented under laboratory conditions. Time to complete immature stage development varies with change in temperature and can also be affected by the host plant. Total development times of eggs and the four nymphal stages in the field may vary greatly (14 to 107 days). Egg development in the laboratory takes five days at 34.7°C and 23 days at 15.4°C (Butler *et al* 1983, Wagner 1995). Nymph development times in the laboratory varied from 10.7 days at 27.5°C to 36.3 days at 17.7°C (Enkegaard 1993 and Wagner 1995). Differences in development times of as much as 10 days have been observed on different hosts at similar temperatures (Coudriet et al 1985 and Tsai and Wang 1996).

The duration of the egg stage varied from 22.5 days at 16.7°C to five days at 32.5°C, whereas eggs failed to hatch at 36.0°C. The total development time from egg to adult varied from 65.1 days at 14.9°C to 16.6 days at 30.0°C. Development took longer, and there was evidence of aestivation at temperatures fluctuating between 27 and 43°C. Peak emergence of adults occurred between 6 and 9 a.m. The average number of eggs laid per female was 81 at 26.7°C and 72 at 32.2°C. Males lived an average of 7.6 and 11.7 days, and females lived an average of 8.0 and 10.4 days, at 26.7 and 32.2°C, respectively (Butler *et al* 1983). Verma et al (1990) observed that eggs did not develop properly below 10^{0}C and above 36^{0}C. Optimum development of eggs was found between 25 and 30^{0}C and the optimum rate of adult development between 20 and 30^{0}C. Bishnoi et al (1996) reported that optimum temperature of 25-30^{0}C and humidity range of 40-58 per cent for build-up of cotton whitefly. Adult males in the laboratory have been observed to live 8-10 days at 16-32 °C and females 10-35 days at 14-32^{0}C (Butler et al 1983 and Enkegaard 1993).

Temperature is the major contributing factor in determining the density of whitefly. Whitefly population density generally begins to increase, coinciding with the closing of the crop canopy of cotton and repeated irrigations. With the receding of monsoon season, the whitefly population tends to remain high on cotton and responsible for creating conditions like development of sooty mould, blackening and stickiness of seed cotton. Dhawan and Simwat (1999) recorded significant negative relationship of whitefly with minimum temperature and evening relative humidity. The correlation of whitefly with sunshine and rainfall, however, was inconsistent. A significant negative correlation was found between whitefly catch and maximum/minimum temperatures and a significant positive correlation with mean morning relative humidity. The studies carried out in Karnataka showed that all the weather parameters collectively influence the whitefly population (Naik and Lingappa 1992). Besides, the changes in quantity of food resources seemed to influence the population fluctuations in this pest species. In Central India, temperature 28-36^{0}C and 60-92 per cent relative humidity during the period of scanty rainfall between August to January favour the build-up of this pest (Jayaswal 1989). However, in North India (Punjab), the population build of the pest is negatively correlated with temperature and rainfall.

Ashfaq et al (2010) showed that temperature had a positive effect on the population of whitefly whereas relative humidity was negatively correlated with whitefly. Darwish et al (2000) determined that 25 and 30^{0}C were found to be the most favourable for the development of egg and nymphal stages. Threshold temperatures of 10.52, 4.59 and 7.06^{0}C were calculated for the development of egg, nymph and from egg to adult stages, respectively. Based on the thresholds, these stages needed about 81.5, 371.7 and 426.7 day-degrees, respectively to complete their development. Chandi (2014) reported that net reproductive rate, finite rate of increase and intrinsic rate of increase was more at 32^{o}C in combination with 65 per cent RH.

Life table studies: Multiple abiotic and biotic mortality factors act on insect populations. These forces may be naturally occurring, as in case of predators, parasitoids, pathogens, host-plant effects and weather or manmade such as cultural manipulations and the use of insecticides. Understanding of the timing, spatial distribution and magnitude of these mortality factors is central to the study of population dynamics. It is also central to predicting pest outbreaks and in developing better pest management systems that take advantage of, and build upon, existing mortality forces (Naranjo and Ellsworth 2005). The construction of life tables is a robust method for describing and quantifying mortality in a population (Deevey 1947). Analysis of life tables developed for many insects have provided knowledge about population dynamics and their regulation in many ecological systems. The construction of life tables is vital to the description and understanding of the mortality factors in a population. Such analyses are not only of considerable theoretical interest, but also provide a rational and predictive basis for pest control.

Many biotic and abiotic mortality factors impact the population dynamics of *B. tabaci* in agricultural ecosystems, yet we have a poor understanding of the rates of these mortality factors and how they may be involved in overall population regulations. For a multi-voltine and multi-crop pest like *B. tabaci,* estimating rates of mortality in the field is extremely complex and difficult. The effect of various conventional insecticides is generally well known; however, studying the effect of such factors as predation and parasitism is much more difficult. Life table studies categorize the sources of mortality and provide a means to quantify rates of death from various factors over the course of a generation (Naranjo and Ellsworth 1999).

Comparative study on the life table parameters of whitefly was carried out in growth chamber under 24±2^{0}C, 55±3% RH and 16:8 (L: D) photoperiod in Iran by Samih et al (2003). The results revealed that age specific mortality (qx) began at the 22nd day and reached the highest value at the 49th day. Life expectancy (ex) was 26.9 at the initiation of development which was reduced to zero at the 28th day. Life table studies of *B. tabaci* by Naranjo and Ellsworth (1999) revealed that predation and dislodgment were major sources of egg and nymphal mortality, and overall survival from egg to adult ranged from 0-18.2 per cent. The major sources of mortality were predation (17%) and missing (18%). A very small fraction of the eggs were inviable (0.5%) and nearly 65 per cent of the eggs hatched. In another study, Naranjo and Ellsworth (2005) observed that median rates of mortality were in ranked order: predation (0.532), dislodgment (0.453), unknown factors (0.369), egg inviability (0.109), and parasitism (0.100). When pooled over all factors, the highest median marginal rates observed were during the egg stage (0.531) and the 4th nymphal stadium (0.687) and rates during the first three nymphal stadia ranged from 0.167 to 0.226. Naranjo (2007) used a combination cohort-based life table studies to measure egg mortality and recruitment studies to measure egg to settled first instar mortality in the cotton fields of Phoenix and Arizona and noted that crawler survival was 89.2 per cent.

Age specific reproduction parameters of whitefly on cotton were studied by Samih and Izadi (2006) in Iran. At 24±2ºC, 55±3% RH and 16:8 h (L: D) photoperiod, gross fecundity rate and gross fertility rate was 66.38 and 45.57, respectively. Cohort-based, partial life tables were constructed by Karut and Naranjo (2009) to determine the mortality, parasitism, predation sources and rates of mortality factors affecting *B. tabaci* on cotton in the eastern Mediterranean region of Turkey over a two year period. Across 10 independent cohorts, the highest median rate of marginal mortality pooled over all stages was attributed to parasitism (0.69) followed by predation (0.67). The greatest amount of marginal immature mortality occurred during the fourth nymphal stadium (median=0.77) and mortality during this stage was also most predictive of variation in total mortality. Pooled over all developmental stages, the highest rates of irreplaceable mortality were associated with parasitism (median: 0.112), followed by predation (0.088), dislodgement (0.020) and unknown (0.017). Field estimates of mortality from life table studies in cotton indicate that both eggs and nymphs are subject to mortality from many factors, with total surviva1 of immatures averaging just over 6 per cent (Naranjo 2001).

Life table of *B. tabaci* under natural conditions were constructed at vegetative and flowering stage of Bt cotton by Chandi (2014). Rainfall and natural enemies were responsible for reduction in *B. tabaci* population under natural conditions. Egg inviability was also responsible for mortality in egg stage. The net reproductive rate, intrinsic rate of increase and finite rate of increase were higher at vegetative stage than at flowering stage but the mean length of generation was more at flowering stage than at vegetative stage.

CONCLUSION

B. tabaci is most serious pest of cotton and is known to infest more than 600 plant species globally. High reproductive rate and multiple host sequences provide optimal conditions for its development. Temperature has positive correlation and relative humidity has negative correlation with whitefly. However, multi-voltine and multi-crop pest like *B. tabaci*, estimating the rates of mortality in the field is extremely complex and difficult. Therefore, life table studies are important to predict whitefly outbreaks and by understanding biology and ecology, we can properly manage this pest in cotton.

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Received 21 November, 2021; Accepted 02 April, 2022

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Indian Journal of Ecology (2022) 49(2): 534-542
DOI: https://doi.org/10.55362/IJE/2022/3557

Manuscript Number: 3557
NAAS Rating: 5.79

Role of Melanin Production by *Helminthosporium* species on Pathogenicity in Graminaceous Hosts

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***Abstract*:** Fifty foliar blight diseased samples collected from wheat, barley and oat growing areas of north-western India revealed that *Bipolaris sorokiniana* was present in all the isolates collected from barley, wheat and *Phalaris minor,* while *Drechslera avenae* was associated with isolates from oats. All the test isolates were pathogenic on their susceptible check *viz.,* PL426 (barley), HD-2329 (wheat), OL-9 (oats) and *Phalaris minor.* Minimum incubation period (2 days), maximum no. of lesions per leaf (9.29), maximum size of lesions (9.30 mm^2) and highest terminal disease severity score (89) were recorded with isolate Bsb1 from barley, followed by Bsw32 from wheat. The highest melanin production was recorded in isolate Bsb1 (2.58 µg g^{-1}) followed by 2.52 µg g^{-1} and 2.49 µg g^{-1} in isolate Bsp43 and Bsw32, respectively. Comparison of melanin production and pathogenic behaviour of different isolates revealed that more aggressive isolates on their respective hosts also produced higher melanin as compared to other isolates and strong positive correlation (r=0.749) existed between the pathogenicity and melanin production in different isolates of *Helminthosporium*.

Keywords: *Helminthosporium, Bipolaris, Drechslera*, Pathogenicity, Melanin, Correlation, Temperature regimes

Cereals are an important component of diet of the most of human beings throughout the world. The cereals crops are infected by a number of pathogenic microbes i.e. fungi, bacteria, viruses and insect pests in world and India and among the different fungal pathogens, *Helminthosporium* spp. are of major threat leading to huge economic yield losses in different cereal crops (Jayasena et al 2000, Vaish et al 2011, Singh et al 2021). *Helminthosporium* species parasitize on graminaceous hosts including barley, corn, rice, oat, wheat, sorghum and several weed hosts thus causing various types of foliar blights or leaf spot diseases and the type of lesions produced on these hosts depends upon the species involved. Different strains of *Helminthosporium* species may vary in their pathogenic or physiological behaviour. In nature or in axenic culture, sectoring usually give rise to new forms. Graminicolous *Helminthosporium* were categorised into several generas including *Bipolaris, Curvularia, Drechslera* and *Exserohilum* (Manamgoda et al 2014). The fungus *Bipolaris sorokiniana* cause spot blotch or foliar blight and is one of the most important fungal diseases of barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*) (Arabi et al 2011). This pathogen is favoured by warm and humid climate and produces necrotic lesions on leaf, sheath and stem and reproduces asexually by producing thick walled conidia (Aggarwal 2009). Continuing rainfall for 5 to 6 days followed by daily mean temperatures of 20- 30 ºC favours rapid development of the disease epidemics on wheat and barley (Kumar et al 2002) resulting in yield loses of upto 6-7% and 10 % in wheat and barley, respectively due to poor grain filling (Rioux et al 2016). *Drechslera avenae* (*Helminthosporium avenae;* teleomorph *Pyrenophora avenae*) causes necrotic dark brown lesions at seedling stage in oats causing mortality of the plants. The symptoms on young leaves appear as reddish to dark black coloured longitudinal stripes causing foliar blight disease (Kaur et al 2021). Physiological specialization at species level in *Helminthosporium* was first described by Christensen (1926) reporting varied virulence in fungal isolates to various graminaceous hosts and moreover, the isolates from the same geographical region and morphological group had different degrees of virulence (Ghazvini and Tekauz 2007, Polini et al 2009).

All loculoascomycetes, some pyrenomycetes, discomycetes and many deuteromycetes produce melanin, a polymer of 1,8 dihydroxynaphthalene (DHN) which is important for the survival of the fungal pathogens of these groups (Cordero and Cassadevall 2017). It has been implicated as a pathogenicity factor in *Magnaporthe* and *Colletotrichum* spp (Wang et al 2018, 2020, Gupta et al 2021). Melanin helps in the persistence of conidia and hyphae, and in the formation of appressoria and perithecia in many phytopathogenic fungi (Henson et al 1999). It provides protection against oxygen free radicals, cell wall degrading enzymes produced by microbial antagonists (Butler et al 2001), UV radiation (Cordero and Cassadevall 2017) and thus enabling fungal pathogens of plants and animals to survive under adverse environmental conditions (Romero-Martinez et al 2000). Melanin synthesis in melanocytes was proved to be regulated by temperature (Kim et al 2003). However, information about its association with pathogenicity among different *Helminthosporium* spp. under Indian conditions is meagre, hence, the present study was undertaken to assess the association of melanin with the aggressiveness of *Helminthosporium* isolates infecting different graminaceous hosts from different north western regions of India and the effect of different temperature regimes on its production.

MATERIAL AND METHODS

Fungal isolates, culture conditions, maintenance of pure culture and pathogenicity of isolates: Surveys of different barley, wheat and oats growing areas of Punjab and adjoining states were conducted during the year 2016-17. Fifty leaf samples showing typical symptoms of foliar blight/ spot blotch were collected from different infected hosts and locations (Table 1). The pathogen was isolated from single lesion from the infected leaf tissue following standard procedure and incubated at 25±2°C (Kolte and Vishunavat 2005). The purified monoconidial cultures were maintained on potato dextrose agar (PDA) slants at 4°C. The isolates were tested for their pathogenicity on susceptible variety of the respective hosts *viz.,* PL 426 (barley), HD 2329 (wheat), OL -9 (oats) and *Phalaris minor* (weed host) under pot-house maintained at temperature and relative humidity of 26±2°C and 80-95%, respectively. Plants were grown in 10 inches diameter pots filled with sand, FYM and field soil (1:1:2) using recommended package of practices (Anonymous 2019).

Preparation and spraying of inoculum: Mass inoculum of all the isolates were prepared separately in 100ml Erlenmeyer flasks on sorghum seed medium. The imbibed sorghum grains @ 20g $flask^{-1}$ were autoclaved at 20psi for 20 minutes and were inoculated with 2-3 discs (10mm diameter) of 7 days old colony of each isolate separately under aseptic conditions. The flasks were incubated at 25±2°C for 15 days. The flasks were shaken daily to promote sporulation and prevent mycelium clumps and the grains were completely covered with fungal growth after 10-12 days. Inoculum was prepared in sterilized water by taking approx. 20 infected sorghum seeds and shaking those well to detach the spores from grains in water. 1-2 drops of Tween-80 were also added in spore suspension. The suspension thus obtained was sieved through the sterilized muslin cloth to remove the grains and mycelium. The spore concentration was adjusted to 5×10^4 spores/ ml with the help of haemocytometer.

One-month old seedlings of each host cultivar at 3-4 leaf stage were spray inoculated with conidial suspension of each of their respective isolates in isolation @ 5×10^4 spores ml^{-1} using hand atomizer. The inoculated plants were then allowed to dry for 2-3 hrs and were incubated in polyhouse having humidifiers for 12 h, to provide enough saturated moisture to enhance infection and were later incubated for 10 days.

Symptom development: Initially water-soaked spots developed within 2-3days which later turned into yellow and necrotic area on the inoculated leaves. Observations were recorded on incubation period (days after inoculation), number of lesions $leafn^{-1}$ (10-15 days after inoculation on flag, first and second leaf), size of lesions (in mm^2, length x breadth of five biggest spots) for each isolate. The terminal disease severity was measured in double-digit figure using 0-9 scale (Saari and Presscott 1975).

Estimation of melanin content in *Helminthosporium* isolates: Melanin content was extracted and estimated in all the 50 isolates as per the method described by Gadd (1982).

Effect of different temperature regimes on melanin production by *Helminthosporium* isolates: Petri plates containing freshly prepared PDA medium were inoculated aseptically by placing 5 mm discs from 6 days old culture of each of the 50 isolates and then these plates were incubated at different temperature regimes viz; 15°C, 20°C, 25°C, 30°C and 35°C for the growth of the pathogen. The extraction and estimation of melanin in each isolate at different temperature regimes was undertaken according to the method as described above.

Statistical analysis: The data obtained from the pot house and laboratory experiments were analysed using completely randomized design (CRD) and dendrogram based on pathogenic variability among the different isolates was generated using the software PAST (version 2.6). Pearson's correlation coefficient was also calculated to analyse the correlation between aggressiveness and melanin production in different isolates.

RESULTS AND DISCUSSION

Pathogen associated with diseased samples: The isolated fungus and its species were identified based on the morphological characters as per the key of Manamgoda et al (2014). The test isolates were arbitrarily named as Bsb1 to Bsb29 (barley), Bsw30 to Bsw41 (wheat) Bsp42 to Bsp45 (*Phalaris minor*) and Da46 to Da50 (oats) (Table 1). Based on colony characteristics on PDA medium, the isolates were divided into three categories having black, greyish white and white coloured colonies (Table 2).

Pathogenic behavior of isolates: The isolates were pathogenic on their susceptible check i.e. PL426 (barley), HD

Table 1. Identification of pathogens associated with spot blotch/foliar blight disease on different hosts under north-western regions of India

Isolate No.	Host	Location	Pathogen involved
Bsb1	Barley	Ludhiana (Punjab) (30.9°N 75.85°E)	*Bipolaris sorokiniana*
Bsb2	Barley	Samrala (Punjab) (30.84°N 76.19°E)	*Bipolaris sorokiniana*
Bsb3	Barley	Abohar (Punjab) (30.1334°N 74.2001°E)	*Bipolaris sorokiniana*
Bsb4	Barley	Ganganagar (Rajasthan) (29.9094° N, 73.8800° E)	*Bipolaris sorokiniana*
Bsb5	Barley	Ganganagar (Rajasthan) (29.9094° N, 73.8800° E)	*Bipolaris sorokiniana*
Bsb6	Barley	Barnala (Punjab) (30.3819° N, 75.5468° E)	*Bipolaris sorokiniana*
Bsb7	Barley	Hisar (Haryana) (29.1492° N, 75.7217° E)	*Bipolaris sorokiniana*
Bsb8	Barley	Rohtak (Haryana) (28.8955° N, 76.6066° E)	*Bipolaris sorokiniana*
Bsb9	Barley	Jagraon (Punjab) (30.7923° N, 75.4670° E)	*Bipolaris sorokiniana*
Bsb10	Barley	Sangala, Sangrur (Punjab) (30.4646° N, 75.8875° E)	*Bipolaris sorokiniana*
Bsb11	Barley	Mastuana sahib (Punjab) (30.2662° N, 75.7752° E)	*Bipolaris sorokiniana*
Bsb12	Barley	Malerkotla (Punjab) (30.5246° N, 75.8783° E)	*Bipolaris sorokiniana*
Bsb13	Barley	Kheri, Sangrur (Punjab) (30.1905° N, 75.8811° E)	*Bipolaris sorokiniana*
Bsb14	Barley	Patiala (Punjab) (30.3398° N, 76.3869° E)	*Bipolaris sorokiniana*
Bsb15	Barley	Mansa (Punjab)(29.9995° N, 75.3937° E)	*Bipolaris sorokiniana*
Bsb16	Barley	Ahmadgarh (Punjab) (30.6796° N, 75.8243° E)	*Bipolaris sorokiniana*
Bsb17	Barley	Jalandhar (Punjab) (31.3260° N, 75.5762° E)	*Bipolaris sorokiniana*
Bsb18	Barley	Amritsar (Punjab) (31.6340° N, 74.8723° E)	*Bipolaris sorokiniana*
Bsb19	Barley	Sri Muktsar Sahib (Punjab) (30.4762° N, 74.5122° E)	*Bipolaris sorokiniana*
Bsb20	Barley	Fazilka (Punjab) (30.4036° N, 74.0280° E)	*Bipolaris sorokiniana*
Bsb21	Barley	Sidhpur (Himachal Pradesh) (32.1953° N, 76.3536° E)	*Bipolaris sorokiniana*
Bsb22	Barley	Malana (Himachal Pradesh) (32.0617° N, 77.2613° E)	*Bipolaris sorokiniana*
Bsb23	Barley	Bajaura (Himachal Pradesh) (31.8465° N, 77.1605° E)	*Bipolaris sorokiniana*
Bsb24	Barley	Bhuntar (Himachal Pradesh) (31.8862° N, 77.1455° E)	*Bipolaris sorokiniana*
Bsb25	Barley	Shamshi (Himachal Pradesh) (31.8933° N, 77.1384° E)	*Bipolaris sorokiniana*
Bsb26	Barley	Ner chowk (Himachal Pradesh) (31.6085° N, 76.9153° E)	*Bipolaris sorokiniana*
Bsb27	Barley	Berthin (Himachal Pradesh) (31.4188° N, 76.6427° E)	*Bipolaris sorokiniana*
Bsb28	Barley	Andreta (Himachal Pradesh) (32.0401° N, 76.5676° E)	*Bipolaris sorokiniana*
Bsb29	Barley	Palampur (Himachal Pradesh) (32.12°N 76.53°E)	*Bipolaris sorokiniana*
Bsw30	Wheat	Mansa (Punjab) (29.9995° N, 75.3937° E)	*Bipolaris sorokiniana*
Bsw31	Wheat	Kheri, Sangrur (Punjab) (30.1905° N, 75.8811° E)	*Bipolaris sorokiniana*
Bsw32	Wheat	Ludhiana (Punjab) (30.9010° N, 75.8573° E)	*Bipolaris sorokiniana*
Bsw33	Wheat	Jagraon (Punjab) (30.7923° N, 75.4670° E)	*Bipolaris sorokiniana*
Bsw34	Wheat	Jalandhar (Punjab) (31.3260° N, 75.5762° E)	*Bipolaris sorokiniana*
Bsw35	Wheat	Ganganagar (Rajasthan) (29.9094° N, 73.8800° E)	*Bipolaris sorokiniana*
Bsw36	Wheat	Ganganagar (Rajasthan) (29.9094° N, 73.8800° E)	*Bipolaris sorokiniana*
Bsw37	Wheat	Hisar (Haryana) (29.1492° N, 75.7217° E)	*Bipolaris sorokiniana*
Bsw38	Wheat	Rohtak (Haryana) (28.8955° N, 76.6066° E)	*Bipolaris sorokiniana*
Bsw39	Wheat	Jagraon (Punjab) (30.7923° N, 75.4670° E)	*Bipolaris sorokiniana*
Bsw40	Wheat	Malan (H.P.) (32.1134° N, 76.4202° E)	*Bipolaris sorokiniana*
Bsw41	Wheat	Bajaura (H.P.) (31.8465° N, 77.1605° E)	*Bipolaris sorokiniana*
Bsp42	*Phalaris minor*	Abohar (Punjab) (30.1469° N, 74.2008° E)	*Bipolaris sorokiniana*
Bsp43	*Phalaris minor*	Sri Muktsar sahib (Punjab) (30.4762° N, 74.5122° E)	*Bipolaris sorokiniana*
Bsp44	*Phalaris minor*	Hisar (Haryana) (29.1492° N, 75.7217° E)	*Bipolaris sorokiniana*
Bsp45	*Phalaris minor*	Hoshiarpur (Punjab) (31.5143° N, 75.9115° E)	*Bipolaris sorokiniana*
Da46	Oats	Sangrur (Punjab) (30.2458° N, 75.8421° E)	*Drechslera avenae*
Da47	Oats	Malerkotla (Punjab) (30.5246° N, 75.8783° E)	*Drechslera avenae*
Da48	Oats	Jalandhar (Punjab) (31.3260° N, 75.5762° E)	*Drechslera avenae*
Da49	Oats	Amritsar (Punjab) (31.6340° N, 74.8723° E)	*Drechslera avenae*
Da50	Oats	Fazilka (Punjab) (30.4036° N, 74.0280° E)	*Drechslera avenae*

2329 (wheat) OL- 9 (oats) and *Phalaris minor* (Table 3). The barley isolates, Bsb1, Bsb2, Bsb9, Bsb12, Bsb13, Bsb19 and Bsb26 were fast in developing the initial symptoms and the minimum incubation period was recorded in Bsb1 (2 days) and in rest of the isolates the disease development took 3-5 days. Similar trend was also observed with isolates from wheat, weed host and oats. Isolate Bsw32 was comparatively fast in developing foliar blight symptoms on the susceptible host (3 days) while rest of the isolates it ranged from 4-6 days. Similarly, in case of weed host and oats, isolate Bsp43 and Da46 were faster in developing the initial symptoms in weed host (3 days) and oats (4 days), respectively as compared to other isolates. In barley, maximum average number of lesions (9.20) was recorded in isolate Bsb1 followed by Bsb26 and isolate Bsb16 produced least number of lesions (3.80). The average number of lesions ranged from 4.60 to 8.70 in rest of the isolates.

In wheat, isolate Bsw32 recorded maximum mean number of lesions (8.20) followed by Bsw33. Among weed host and oats, the maximum number of lesions were recorded with isolate Bsp43 (6.70) and Da46 (6.40). The development of necrotic area also varied significantly in different isolates. The maximum size of necrotic area in barley (9.30 mm^2) was in isolate Bsb1 followed by 9.20mm^2 in isolate Bsb26 and was minimum (2.8mm^2) in isolate Bsb22. Lesion size varied from 3.00 to 8.85mm^2 in rest of the isolates. Among wheat isolates, lesion size was maximum in Bsw32 (7.80mm^2) followed by 7.00mm^2 in isolate Bsw39 and was least in Bsw41 (2.6mm^2). In weed host and oats, the maximum size of lesions was recorded in isolates Bsp43 (7.60mm^2) and Da46 (6.60 mm^2), respectively. In comparison of all the *Helminthosporium* isolates, isolate Bsb1 from barley was the fastest in developing the initial symptoms with maximum number and size of the necrotic area and was highly aggressive on its susceptible check with maximum disease severity score of 89 as compared to all other isolates. Among barley and wheat isolates, the highest terminal disease severity (TDS) of 89 and 78 was in isolate Bsb1 and Bsw32, respectively, while isolates Bsp43 and Da46 from weed host and oats were more aggressive on their susceptible checks with maximum TDS of 68. All the isolates were differentiated by comparing all the different parameters using software PAST (version 3.26) and a dendrogram was generated (Fig. 1). All the isolates converged into two groups i.e. 1 and 2 (Table 4). Group 1 consisted of single isolate Bsb1 and group 2 was further divided into subgroups i.e. 2a and 2b. Group 2a further converged into 2a (i) with ten isolates, while 22 isolates comprised grouped 2A were clustered in group 2b (i), while 2b (ii) consist of 13 isolates. Based on their pathogenic behaviour, it was observed that isolate Bsb1 was distinctly variable in pathogenic behaviour as compared to all other isolates.

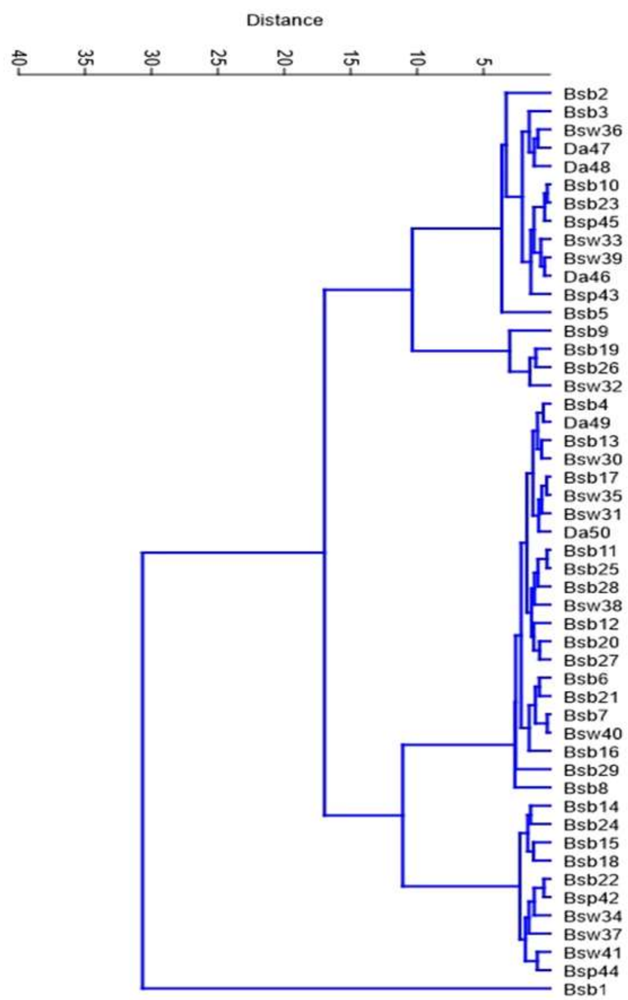

Fig. 1. Dendrogram generated based on the pathological variation among different isolates

Table 2. Grouping of isolates according to colony colour

Group	Colony colour	Isolates	Total no of isolates
1	Black	Bsb1, Bsb9, Bsb19, Bsb21, Bsb23, Bsb26, Bsw32, Bsw36, Bsw39, Bsp43, Da46, Da47, Da48	13
2	Greyish white	Bsb2, Bsb3, Bsb4, Bsb5, Bsb6, Bsb7, Bsb8, Bsb10, Bsb11, Bsb12, Bsb13, Bsb14, Bsb15, Bsb16, Bsb17, Bsb20, Bsb22, Bsb24, Bsb25, Bsb27, Bsb28, Bsb29, Bsw30, Bsw31, Bsw33, Bsw34, Bsw35, Bsw37, Bsw41, Bsp44, Bsp45, Da49, Da450	33
3	White	Bsb18, Bsw38, Bsw40, Bsp42	4

Table 3. Pathogenic behaviour of different *Helminthosporium* isolates as depicted by incubation period, no. of lesions/leaf, size of lesions and terminal disease severity

Sr. No.	Isolate	Incubation period (days)	No. of lesions per leaf	Size of lesions (mm^2)	Terminal disease severity
1	Bsb1	2	9.20	9.30	89
2	Bsb2	3	8.66	8.50	68
3	Bsb3	4	7.33	5.00	67
4	Bsb4	5	5.00	4.10	56
5	Bsb5	4	6.00	3.20	67
6	Bsb6	4	4.80	3.60	57
7	Bsb7	4	5.00	3.10	56
8	Bsb8	4	6.80	4.00	58
9	Bsb9	3	6.50	7.30	76
10	Bsb10	4	6.66	7.20	67
11	Bsb11	4	5.60	5.10	56
12	Bsb12	4	5.70	6.10	57
13	Bsb13	5	4.40	5.20	56
14	Bsb14	4	5.40	5.00	46
15	Bsb15	4	5.20	4.00	47
16	Bsb16	4	3.80	3.70	56
17	Bsb17	5	5.00	4.20	57
18	Bsb18	4	4.60	3.60	46
19	Bsb19	3	8.70	8.85	77
20	Bsb20	4	5.60	5.10	57
21	Bsb21	4	5.33	3.00	57
22	Bsb22	5	4.80	2.80	46
23	Bsb23	4	6.60	7.00	67
24	Bsb24	4	5.75	4.00	45
25	Bsb25	4	5.40	5.20	56
26	Bsb26	3	8.75	9.20	78
27	Bsb27	4	6.33	4.80	57
28	Bsb28	4	5.20	6.00	56
29	Bsb29	5	5.33	6.20	58
30	Bsw30	5	4.25	4.60	56
31	Bsw31	5	4.80	4.70	57
32	Bsw32	3	8.20	7.80	78
33	Bsw33	4	7.00	6.50	68
34	Bsw34	6	4.80	3.60	46
35	Bsw35	5	5.25	4.20	57
36	Bsw36	4	6.25	5.10	67
37	Bsw37	6	5.50	3.80	45
38	Bsw38	5	5.80	5.20	56
39	Bsw39	4	6.40	7.00	68
40	Bsw40	4	5.20	3.10	56
41	Bsw41	5	3.33	2.60	45
42	Bsp42	5	5.00	3.20	46
43	Bsp43	3	6.70	7.60	68
44	Bsp44	5	4.20	3.00	45
45	Bsp45	4	6.60	7.50	67
46	Da46	4	6.40	6.60	68
47	Da47	4	6.33	6.00	67
48	Da48	4	5.20	5.40	67
49	Da49	5	5.00	4.60	56
50	Da50	5	5.50	5.00	57
	CD (p=0.05)	-	0.10	0.14	-

Melanin content in different *Helminthosporium* isolates: The highest melanin production was in isolate Bsb1 (2.58 µg g^{-1}) followed by Bsp43 and Bsw32 (Table 5). The lowest melanin production was recorded in the isolates Bsb18, Bsw38, Bsw40, Bsp42, respectively. Pearson's correlation coefficient (r) between melanin production and TDS among different isolates was 0.749, thus showing a strong correlation between the two variables (Fig. 2).

Effect of different temperature regimes on melanin production: In some isolates maximum melanin production was recorded at 25°C while in others at 30°C implying that overall maximum production of melanin was recorded in temperature range of 25-30°C with mean melanin production of 1.50µg g^{-1} among all the test isolates (Table 5). The growth of the isolates was scarce at minimum temperature of 15°C i.e. from zero to very less (0.05 µg g^{-1} in Bsb1), while was slightly high at temperature of 20°C with mean melanin production of 0.0046 and 0.69 µg g^{-1} at 15° and 20°C, respectively. Melanin production showed declining trend at higher temperature of 35°C and average melanin production among different isolates was recorded to be 0.64µg g^{-1}. A large amount of pathogenic diversity existed among *Helminthosporium* and variation in aggressiveness was observed among the isolates from different geographical regions. In the present study, all the test isolates were pathogenic on their susceptible check PL 426 (barley), HD 2329 (wheat) OL- 9 (oats) and *Phalaris minor* to varying degree of virulence. Based on the cluster analysis, all these isolates converged into two groups i.e. 1 and 2. The first group consist of only single isolate Bsb1 while group 2 was further divided into two subgroups i.e. 2a and 2b. Isolate Bsb1 was distinctly variable in its pathogenic behaviour with maximum number and size of the necrotic area developed and was highly virulent on its susceptible check with maximum disease severity score of 89. The results obtained in the present study corroborated with Ghazvini and Tekauz (2007) who evaluated virulence diversity of 127 *B. sorokiniana* isolates on 12 barley genotypes and identified eight virulent groups. The lesion number/leaf was significantly different depending on the isolate, irrespective of the plant part and infection by *B. sorokiniana* was highly variable, and very sensitive to environmental conditions. Similarly, Polini et al (2009) also observed that 35 *B. sorokiniana* isolates in Brazil and other countries showed different degree of virulence despite being from the same geographical region and morphological group. The169 virulent isolates of *B. sorokiniana* isolated from different wheat growing areas of Bangladesh by Sultana et al (2018) reported a clear evidence of positive relationship among the components. Further, hierarchical cluster analysis revealed that all the isolates converged into five groups and variation in aggressiveness was observed among the isolates from different wheat growing areas.

Melanins alone cannot be responsible for causing disease in the host but rather it is implicated to provide protection against oxygen free radicals, cell wall degrading enzymes produced by microbial antagonists, UV radiation and thus enabling fungal spores to survive under adverse environmental conditions. In the present study, the estimation of melanin content was recorded in the test isolates at standard temperature of 25 °C and also at different temperature regimes of 15° C to 35°C. The maximum melanin production was in the isolated Bsb1 (2.58 µg/g) followed by Bsp43 and Bsw32 at 25°C. Melanin production in some of the isolates was recorded maximum at 25°C while in others at 30°C and thereafter it decreased. Temperature

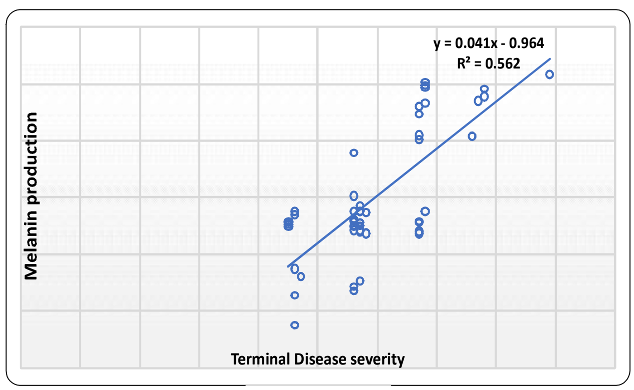

Fig. 2. Correlation between melanin production and virulence in different *Helminthosporium* isolates

Table 4. Grouping of the isolates based on their pathogenic behaviour

Group	Sub-group	Isolate (s)	Total number of isolate(s)
1	-	Bsb1	1
2	2a (i)	Bsb14, Bsb15, Bsb18, Bsb22, Bsb24, Bsw34, Bsw37, Bsw41, Bsp42, Bsp44	32
	2a (ii)	Bsb4, Bsb6, Bsb7, Bsb8, Bsb11, Bsb12, Bsb13, Bsb16, Bsb17, Bsb20, Bsb21, Bsb25, Bsb27, Bsb28, Bsb29, Bsw30, Bsw31, Bsw35, Bsw38, Bsw40, Da49, Da50.	
	2b (i)	Bsb9, Bsb19, Bsb26, Bsw32	17
	2b (ii)	Bsb2, Bsb3, Bsb5, Bsb10, Bsb23, Bsw33, Bsw36, Bsw39, Bsp43, Bsp45, Da46, Da47, Da48.	

Table 5. Melanin production by different *Helminthosporium* isolates

Sr. No.	Isolate	Melanin (μg g^{-1}) production at different temperature regimes.				
		15°C	20°C	25°C	30°C	35°C
1	Bsb1	0.05	1.67	2.58	2.77	1.74
2	Bsb2	0.00	0.70	1.38	1.17	0.69
3	Bsb3	0.00	0.58	1.30	1.20	0.79
4	Bsb4	0.01	1.15	1.90	2.01	1.12
5	Bsb5	0.00	0.41	1.19	1.24	0.52
6	Bsb6	0.00	0.47	1.26	1.31	0.53
7	Bsb7	0.00	0.66	1.32	1.26	0.48
8	Bsb8	0.00	0.63	1.37	1.35	0.70
9	Bsb9	0.03	1.11	2.04	1.39	0.92
10	Bsb10	0.00	0.58	1.29	1.35	0.61
11	Bsb11	0.00	0.52	1.22	1.16	0.64
12	Bsb12	0.00	0.69	1.21	1.28	0.54
13	Bsb13	0.00	0.58	1.38	1.43	0.42
14	Bsb14	0.00	0.19	0.88	0.79	0.19
15	Bsb15	0.00	0.17	0.81	0.95	0.21
16	Bsb16	0.00	0.54	1.26	1.24	0.62
17	Bsb17	0.00	0.47	1.38	1.27	0.64
18	Bsb18	0.00	0.04	0.39	0.53	0.02
19	Bsb19	0.01	0.79	2.35	2.51	1.15
20	Bsb20	0.00	0.19	0.77	0.76	0.21
21	Bsb21	0.00	0.88	1.43	1.48	0.65
22	Bsb22	0.00	0.70	1.35	1.30	0.53
23	Bsb23	0.00	1.20	2.01	2.09	0.74
24	Bsb24	0.00	0.06	1.27	1.00	0.08
25	Bsb25	0.00	0.09	1.31	1.12	0.09
26	Bsb26	0.04	1.18	2.46	2.54	0.62
27	Bsb27	0.00	0.88	1.38	1.43	0.73
28	Bsb28	0.00	0.63	1.25	1.26	0.48
29	Bsb29	0.00	0.68	1.19	1.35	0.41
30	Bsw30	0.00	0.53	1.30	1.22	0.58
31	Bsw31	0.00	0.76	1.26	1.34	0.52
32	Bsw32	0.02	1.24	2.49	2.52	0.98
33	Bsw33	0.01	1.22	2.33	2.22	1.09
34	Bsw34	0.00	0.54	1.38	1.45	0.60
35	Bsw35	0.00	0.88	1.22	1.37	0.71
36	Bsw36	0.00	1.40	2.05	2.22	1.07
37	Bsw37	0.00	0.56	1.25	1.27	0.43
38	Bsw38	0.00	0.05	0.69	0.65	0.02
39	Bsw39	0.00	1.21	2.39	2.41	1.10
40	Bsw40	0.00	0.02	0.73	0.78	0.05
41	Bsw41	0.00	0.58	1.29	1.34	0.62
42	Bsp42	0.00	0.05	0.65	0.58	0.22
43	Bsp43	0.01	1.26	2.52	2.46	1.16
44	Bsp44	0.00	0.60	1.30	1.30	0.45
45	Bsp45	0.00	0.58	1.21	1.30	0.40
46	Da46	0.03	1.19	2.47	2.40	1.08
47	Da47	0.00	1.09	2.30	2.36	0.98
48	Da48	0.02	1.04	2.24	2.45	1.87
49	Da49	0.00	0.73	1.52	1.46	0.62
50	Da50	0.00	0.34	1.29	1.35	0.24
	Mean	0.0046	0.69	1.50	1.50	0.64
	CD (p=0.05)	0.0038	0.01	0.02	0.02	0.02

regulation of melanin synthesis in the present studies is in accordance with the results of Kim et al (2003). Similarly, Suwannarach et al (2019) also reported that melanin pigment production by an endophytic fungus, *Spissiomyces endophytica* SDBR-CMU319 was maximum at 25°C in glucose yeast extract peptone medium at an initial pH value of 6.0 over three weeks of cultivation. Further, it was observed that the isolates which were more aggressive on their respective hosts (Bsb1, Bsb9, Bsb26, Bsw32, Bsp43 and Da46) were also reported to be higher melanin producers as compared to other isolates. Hence, melanin production in the fungus was positively corelated (r= 0.749) with the pathogenicity of the fungal isolates. Black coloured isolates recorded more melanin content as compared to mixed and white isolates. The association of melanin content with pathogenicity and virulence in *Bipolaris oryzae* was also reported by Singh et al (2016). Melanization of *B. sorokiniana* mycelia was an important factor for conidia production was also proved by Bashyal et al (2010) who revealed that conidiogenesis in black, white and mixed subpopulation of *B. sorokiniana* was positively correlated with melanin content/g of mycelium. Similarly, positive significant correlation between sporulation and melanin content in *B. sorokiniana* infecting wheat has also been proved by Aggarwal et al (2011).

CONCLUSION

All the test isolates were pathogenic on their susceptible check. The isolate Bsb1 from barley recorded the highest melanin content and was also most aggressive on its susceptible check followed by Bsw32 from wheat. Comparing the melanin production and pathogenic behaviour of different isolates revealed that the isolates which were more aggressive on their respective hosts also produced higher melanin as compared to other isolates and this study proved that a strong positive correlation existed between the pathogenicity and melanin production in different isolates of *Helminthosporium*.

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Received 12 October, 2021; Accepted 22 February, 2022

Indian Journal of Ecology (2022) 49(2): 543-548
DOI: https://doi.org/10.55362/IJE/2022/3558

Manuscript Number: 3558
NAAS Rating: 5.79

Role of Weather Parameters on Development of Early Blight of Tomato Caused by *Alternaria solani*

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Abstract: The field experiment as conducted to study on the influence of weather parameters on the intensity and development of early blight of tomato during *Rabi*, 2018-19 and 2019-20 at Agriculture Research Station, Gunjevu, Holenarasipur taluk, Hassan district. The epidemiological studies clearly revealed that per cent disease index (PDI) progressing at a linear rate as the growth of the plant advances and weather parameters like minimum temperature, evening relative humidity, morning relative humidity rainfall, number of rainy days found significant and in negative correlation with disease development. The multiple linear regression analysis clearly revealed that coefficient of multiple determinants (R^2) was 0.94 indicating that these weather factors responsible up to an extent of 94.00 per cent for early blight disease development. The regression equation also reveals that increase in 1 per cent of morning relative humidity the PDI increased by 0.446%. While, when there was increase in 1° C of minimum temperature the per cent disease severity decreased by 12.606 per cent.

Keywords: Early blight, *Alternaria solani*, Weather parameters, Correlation, Regression analysis, Epidemiology

Tomato (*Solanum lycopersicum* L.) is the most widely accepted vegetable crop after potato belongs to nightshade family (Solanaceae) and is native to the Andean region of South America and presently cultivating in around 140 countries. India ranks second, next to China both in area and production of tomato crop where tomato occupies in an area of 0.81 million hectares with yearly production of 20.51 million tonnes and productivity of 16.10 tonnes ha^{-1} (Anonymous 2018). In India, it is cultivated in a different agroclimatic zones ranging from temperate to arid. Among the different biotic and abiotic factors, diseases are considered as the main production constraints which are responsible for the reduction in yield. Early blight caused by *Alternaria solani* (Ellis and Martin) Jones and Grout is considered as important foliar disease and pathogen is a soil inhabiting air borne pathogen responsible for blight, collar rot and fruit rot of tomato. Meteorological parameters are the critical components of disease triangle. Early blight of tomato will occur frequently and severely in regions with heavy dew, high humidity, rainfall and relatively high temperatures. Chothani et al (2017) observed that increase in disease severity index (DSI) of early blight of tomato was comparatively higher in the maximum and minimum temperatures (35.2-38.3°C), Evening RH (30-58 %) and wind speed (1.2-2.2 km hr^{-1}) during 41th to 46th Standard meteorological week (SMW), which were most congenial for disease development. The abiotic factors like minimum temperature and evening relative humidity were negatively highly correlated, while maximum temperature had negative significant impact on *Alternaria* leaf blight of tomato. Wind speed showed positive and highly significant effects on development of early blight. Similarly, Pandey (2011) reported that *Rabi* sown tomato was susceptible to early blight .Meteorological parameters are the critical components of disease triangle. Early blight of tomato will occur frequently and in severely in regions with heavy dew, high humidity, rainfall and relatively high temperatures. Considering the importance of the early blight in tomato an attempt was made to know the influence of weather factors on disease development.

MATERIAL AND METHODS

The effect of weather factors like temperature (maximum and minimum), relative humidity (morning and evening in per cent), rainfall (mm) and a number of rainy days on the intensity and development of early blight of tomato was observed at Agricultural Research Station, Gunjevu, Hassan. The location comes under the Southern transition zone (Zone-7) of Karnataka state at 12.874°N latitude, 76.379° E longitude with an altitude of 874m above the mean sea level. The experiment was conducted during *Rabi*, 2018-19 and 2019-20. The susceptible cultivar, Alankar seedlings of 25 days old was transplanted in the main field with a spacing of 90cm x 45 cm in a plot size of 30m x 10 m. Twenty plants were selected randomly, labeled and the severity of blight was recorded using a 0-9 scale (Mayee and Datar, 1986). These values were converted to Per cent

Disease Index (PDI) using Wheeler's formula (1969).The observations were made on disease intensity and severity starting from the first day of its appearance and till the end of the crop. It was correlated with weather parameters by simple correlation and multiple regression analysis was also carried out.

RESULTS AND DISCUSSION

Disease development (PDI): The first appearance of the early blight was noticed on 21 days after transplanting in 2018-19 and 23 days after transplanting during 2019-20. The early blight disease during 2018-19 was initiated during 39th SMW, that is during September 3rd week (6.77 %) and the disease severity progressively increased throughout the cropping period (Table 1). The disease development was initially slow but it reached to the maximum of 57.77 per cent during the 5th SMW of 2019. The maximum temperature ranged from 27.29 to 30.80°C, minimum temperature ranged from 11.00 to 14.50 ° C with morning relative humidity between 78.34 to 98.00 per cent and evening relative humidity ranged from 60.21 to 79.25 per cent along with rainfall 56.40 mm to 88.10mm has favoured the development of the early blight during *Rabi*, 2018-19. Similarly during 2019-20 the early blight disease was initiated during 39th SMW (4.44 %) and the disease severity progressively increased throughout the cropping period and it has reached to maximum PDI of 62.22 per cent on 5th SMW of 2020 (Table 2). The maximum temperature ranged from 26.07 to 30.56°C, minimum temperature ranged from 11.10 to 15.25°C with morning relative humidity between 86.83 to 98.25 per cent and evening relative humidity ranged from 60.15 to 78.83 per cent along with rainfall 7.20 mm to 79.40 mm during disease initiation stage favoured the development of the early blight during *Rabi*, 2019-20.

Correlation and multiple linear regression analysis between early blight severities of tomato in relation to weather parameters: During 2018, among the different weather parameters maximum temperature showed non-significant relationship with PDI. Minimum temperature was significantly negatively correlated with PDI. Morning relative humidity and evening relative humidity were significantly negatively correlated with PDI. The rainfall and number of rainy days showed significantly negatively correlated with PDI (Table 3). However, as per the correlation analysis of PDI with inter dependent weather parameters such as minimum temperature with morning relative humidity, minimum temperature with rainfall and minimum temperature with number of rainy days have shown a significantly positive

Table 1. Effect of weather parameters on disease development of early blight of tomato during 2018-19

SMW	Max. T (°C)	Min. T (°C)	Morning RH (%)	Evening RH (%)	Rainfall (mm)	Rainy days	PDI
38	28.90	15.50	100.00	78.43	21.00	1.00	0.00
39	29.50	15.50	98.00	78.23	88.10	4.00	6.77
40	29.75	14.50	98.00	79.25	14.20	2.00	15.22
41	29.85	14.50	96.00	71.36	40.00	2.00	21.44
42	30.07	14.02	94.56	70.00	56.40	3.00	29.11
43	30.87	14.25	98.36	70.00	0.00	0.00	35.11
44	30.89	13.75	98.25	69.87	0.00	0.00	39.55
45	30.85	13.02	96.00	68.45	0.00	0.00	43.33
46	27.91	12.75	95.36	67.56	0.00	0.00	44.66
47	27.35	12.65	94.23	66.78	0.00	0.00	45.77
48	27.45	12.25	94.25	65.24	0.00	0.00	47.77
49	27.29	12.18	86.56	65.32	0.00	0.00	49.11
50	28.21	11.85	84.65	64.36	0.00	0.00	52.12
51	28.57	11.56	84.23	63.54	0.00	0.00	52.88
52	28.86	11.36	83.58	63.85	0.00	0.00	53.11
1	29.60	11.16	81.26	62.89	0.00	0.00	53.55
2	29.80	11.00	80.54	62.78	0.00	0.00	53.77
3	29.70	11.15	79.35	62.48	0.00	0.00	54.22
4	30.80	11.26	78.48	60.45	0.00	0.00	56.22
5	30.70	11.00	78.34	60.21	0.00	0.00	57.77

SMW- Standard Meteorological Week

correlation. Interaction effects of minimum temperature with morning relative humidity were significantly positive correlated with PDI of early blight. Similarly rainfall interaction effects with rainy days have shown significantly positive correlation with early blight severity. The data subjected to multiple linear regression analysis to find out the relative contribution of independent variables (weather factors) on dependent variable (PDI). The regression equation reveals that coefficient of multiple determinants (R^2) was 0.978 indicating that it was highly significant for the data and weather parameters influenced 97.80 per cent variation in the development of the disease (Table 4). The regression equation also reveals that increase in 1 per cent of morning relative humidity the PDI increased by 0.908. While, when there was increase in 1° C of minimum temperature and 1% of evening relative humidity the per cent disease severity decreased by 8.382 and 1.840 respectively.

During 2019, among the different weather parameters

Table 2. Effect of weather parameters on disease development of early blight of tomato during 2019-20

SMW	Max. T (°C)	Min. T (°C)	Morning RH (%)	Evening RH (%)	Rainfall (mm)	Rainy days	PDI
38	26.50	15.25	98.25	78.32	67.20	2.00	0.00
39	26.07	15.16	98.00	78.83	79.40	2.00	4.44
40	26.14	15.25	98.25	78.00	48.80	3.00	6.55
41	28.21	14.42	98.10	76.85	7.20	2.00	14.33
42	29.57	14.23	98.00	76.16	35.00	4.00	26.55
43	30.00	13.78	96.52	76.24	30.60	0.00	34.55
44	29.25	13.48	90.00	75.64	20.00	0.00	39.11
45	28.25	13.16	96.35	75.00	0.00	0.00	39.55
46	26.16	12.58	96.00	72.36	0.00	0.00	45.33
47	26.91	12.36	86.83	71.28	0.00	0.00	49.77
48	26.17	12.35	88.83	70.16	0.00	0.00	53.33
49	27.16	12.14	90.16	70.25	0.00	0.00	55.55
50	27.91	11.78	90.50	69.85	0.00	0.00	56.22
51	27.92	11.59	99.50	68.48	0.00	0.00	58.22
52	28.12	11.56	94.00	66.48	0.00	0.00	59.33
1	28.18	11.48	91.83	65.40	0.00	0.00	60.22
2	28.84	11.35	92.66	64.12	0.00	0.00	60.88
3	29.35	11.15	97.00	63.26	0.00	0.00	61.22
4	30.18	11.26	92.66	62.56	0.00	0.00	61.77
5	30.56	11.10	92.33	60.15	0.00	0.00	62.22

SMW- Standard Meteorological Week

Table 3. Correlation between per cent disease index of early blight of tomato in relation to weather parameters (2018-19)

Parameter	Y	X1	X2	X3	X4	X5	X6
Y PDI	1.00						
X1 Maximum temperature (°C)	-0.092	1.00					
X2 Minimum temperature (°C)	-0.954**	0.131	1.00				
X3 Morning RH (%)	-0.778**	-0.029	0.901**	1.00			
X4 Evening RH (%)	-0.964**	0.056	0.963**	0.849**	1.00		
X5 Rainfall (mm)	-0.718**	0.128	0.659**	0.426	0.625**	1.00	
X6 Rainy days	-0.768**	0.150	0.713**	0.469*	0.709**	0.966**	1.00

** - Significant at 1% probability
* - Significant at 5% probability
Where,
Y= PDI, X1 =Maximum temperature (°C), X2 = Minimum temperature (°C)
X3 = Morning Relative humidity (%), X4 = Evening Relative humidity (%)
X5= Rainfall (mm), X6= No. of Rainy days

except maximum temperature all other weather parameters *viz.,* minimum temperature , morning relative humidity, evening relative humidity , rainfall and rainy days were showed significant and negative correlation with PDI. It is precise to consider interaction effect of interdependent weather parameters for correlation of early blight disease severity rather than correlation of weather parameters with progress of disease during the season. The correlation analysis of PDI with inter dependent weather parameters such as maximum temperature with evening relative humidity, minimum temperature with morning and evening relative humidity, minimum temperature with rainfall and minimum temperature with number of rainy days have showed significantly positive correlation. Interaction effects of maximum temperature with evening relative humidity have significant and negative correlation. Whereas, minimum temperature with morning relative humidity, minimum temperature with evening relative humidity , minimum temperature with rainfall and minimum temperature with number of rainy days has significant and positive correlation with PDI of early blight. The multiple linear regression equation reveals that, coefficient of multiple determinants (R^2) was 0.98 indicating that these weather factors responsible up to an extent of 98.80 per cent for early blight disease development (Table 6). The regression equation also reveals that increase in 1°C of maximum temperature and 1 per cent of evening relative humidity the PDI increased by 1.187 and 1.425 respectively. While, when there was increase in 1°C of minimum temperature and 1per cent morning relative humidity the per cent disease severity decreased by 19.115 and 0.501 respectively.

The correlation analysis of pooled data of 2018-19 and 2019-20 revealed that, among the different weather parameters except maximum temperature (r = 0.089) all

Table 4. Multiple linear regression of per cent disease index of tomato early blight in relation to weather parameters (2018-19)

Parameter	X1 Maximum temperature (°C)	X2 Minimum temperature (°C)	X3 Morning relative humidity (%)	X4 Evening relative humidity (%)	X5 Rainfall (mm)	X6 No. of rainy days
β –value(RC)	0.669	-8.382	0.908	-1.840	-0.247	4.867
SE of β (r)	0.723	3.024	0.292	0.603	0.143	3.147
Intercept (α)			170.509			
R^2 value			0.978			

Multiple linear regression equation $Y = \alpha + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6$

$Y = 170.509 + 0.669\ X_1 - 8.382X_2^{*} + 0.900\ X_3^{**} - 1.840\ X_4^{**} - 0.247X_5 + 4.867X_6$

Table 5. Correlation between per cent disease index of early blight of tomato in relation to weather parameters (2019-20)

Parameter	Y	X1	X2	X3	X4	X5	X6
Y PDI	1.00						
X1 Maximum temperature (°C)	0.418	1.00					
X2 Minimum temperature (°C)	-0.982**	-0.406	1.00				
X3 Morning RH (%)	-0.571**	-0.029	0.507**	1.00			
X4 Evening RH (%)	-0.880**	-0.476*	0.937**	0.401	1.00		
X5 Rainfall (mm)	-0.872**	-0.326	0.851**	0.510*	0.705**	1.00	
X6 Rainy days	-0.788**	-0.197	0.773**	0.567**	0.617**	0.704**	1.00

Table 6. Multiple linear regression of per cent disease index of tomato early blight in relation to weather parameters (2019-20)

Parameter	X1 Maximum temperature (°C)	X2 Minimum temperature (°C)	X3 Morning relative humidity (%)	X4 Evening relative humidity (%)	X5 Rainfall (mm)	X6 No. of rainy days
β –value (RC)	1.181	-19.116	-0.504	1.424	0.009	0.828
SE of β (r)	0.529	2.541	0.216	0.441	0.059	1.001
Intercept (α)			199.191			
R^2 value			0.98			

Multiple linear regression equation $Y = \alpha + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6$

$Y = 199.191 + 1.181X_1^{*} - 19.116\ X_2^{**} - 0.504\ X_3^{**} + 1.424\ X_4^{**} - 0.009\ X_5 + 0.828\ X_6$

Table 7. Correlation between per cent disease index of early blight of tomato in relation to weather parameters (2018 and 2019)

Parameter	Y	X1	X2	X3	X4	X5	X6
Y PDI	1.00						
X1 Maximum temperature (°C)	0.089	1.00					
X2 Minimum temperature (°C)	-0.959	-0.072	1.00				
X3 Morning RH (%)	-0.567**	-0.136	0.689**	1.00			
X4 Evening RH (%)	-0.851**	-0.285	0.901**	0.683**	1.00		
X5 Rainfall (mm)	-0.765**	-0.057	0.727**	0.398**	0.628**	1.00	
X6 Rainy days	-0.771**	-0.007	0.730**	0.433*	0.623**	0.833**	1.00

Table 8. Multiple linear regression of per cent disease index of tomato early blight in relation to weather parameters (2018 and 2019)

Parameter	X1 Maximum temperature (°C)	X2 Minimum temperature (°C)	X3 Morning relative humidity (%)	X4 Evening relative humidity (%)	X5 Rainfall (mm)	X6 No. of rainy days
β –value (RC)	0.651	-12.606	0.446	0.173	0.028	-1.589
SE of β (r)	0.590	1.545	0.161	0.339	0.062	1.184
Intercept (α)	132.307					
R^2 value	0.94					

Multiple linear regression equation $Y = \alpha + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6$

$Y = 132.307 + 0.651\ X_1 - 12.606\ X_2^{**} + 0.446\ X_3^{**} + 0.173\ X_4 - 0.028\ X_5 - 1.589\ X_6$

other weather parameters *viz.,* minimum temperature (r = - 0.959), morning relative humidity (r = - 0.567), evening relative humidity (r = -0.851), rainfall (r = - 0.765) and rainy days with correlation co-efficient of -0.771 showed significant and negative correlation with PDI (Table 7). It is precise to consider interaction effect of interdependent weather parameters for correlation of early blight disease severity rather than correlation of weather parameters with progress of disease during the season. The correlation analysis of PDI with inter dependent weather parameters such as minimum temperature with morning and evening relative humidity, minimum temperature with rainfall and minimum temperature with number of rainy days has showed significant and positive correlation. Interaction effects of minimum temperature with morning relative humidity (0.689), minimum temperature with evening relative humidity (0.901), minimum temperature with rainfall (0.727) and minimum temperature with number of rainy days (0.730) has significant and positive correlation with PDI of early blight.

The multiple linear regression analysis of the pooled that clearly revealed that coefficient of multiple determinants (R^2) was 0.94 indicating that these weather factors responsible up to an extent of 94.00 per cent for early blight disease development (Table 8). The regression equation also reveals that increase in 1per cent of morning relative humidity the PDI increased by 0.446. While, when there was increase in 1°C of minimum temperature the per cent disease severity decreased by 12.606. Parmar et al (2020) reported that maximum temperature and minimum temperature was highly significant and negatively correlated with PDI with correlation coefficients of -0.913 and -0.875 respectively. Further, they also reported that value of coefficient of determination (R^2 = 0.933) indicating that weather factors were influenced up to an extent of 93.00% for early blight disease development.

CONCLUSION

The epidemiological studies represented that per cent disease index (PDI) progressed in linear rate as the growth of the plant advances and weather parameters like minimum temperature, evening relative humidity, morning relative humidity rainfall, number of rainy days found significant and in negative correlation independently with individual factors with disease development. But, in reality under field conditions weather factors influence one another and have interaction with each other have significant positive influence and the development of early blight disease in tomato and more precise to consider interaction effect.

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Received 22 November, 2021; Accepted 12 March, 2022

Indian Journal of Ecology (2022) 49(2): 549-552
DOI: https://doi.org/10.55362/IJE/2022/3559

Manuscript Number: 3559
NAAS Rating: 5.79

Scenario of Early Blight and Leaf Curl of Tomato in Gwalior Districts of Madhya Pradesh

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Abstract: *Alternaria solani* causes disease of foliage (early blight), basal stems of seedling (collar rot), stem of adjust plant (stem lesion) and fruit rot of tomato. Among them, early blight is the most destructive. Present investigations were undertaken to study the disease incidence of early blight in Gwalior districts, which ranged from 12.50 to 51.30%. Maximum disease incidence was recorded in Shyawari (51.30%), while minimum incidence was recorded in Duhiya (12.50%). The leaf curl disease of tomato ranged from 15.33 to 63.20% and maximum disease incidence of tomato leaf curl disease on tomato recorded in Ganpatpura (63.20%) while minimum disease incidence was recorded in Birampura (15.33%).

Keywords: Tomato, Early blight, Leaf curl, Survey, Disease incidence

Tomato [*Lycopersicon esculentum* Mill (2n=24)] is considered as “Poor man's orange” in India. It is the most important and useful member of the family Solanaceae and is grown in tropics as well as subtropics during *Rabi* and *Kharif* season. Tomato is an annual vegetable crop grown over the world is considered as protective food as because of its nutritional value and its wide production (Somappa et al 2013). India ranks second in area and production. In Madhya Pradesh area and production of tomato is 65.72 ha and 1937.37 tons, respectively with productivity 29.5 tons ha^{-1} (Anonymous 2014). There are several diseases known in tomato which caused by fungi, bacteria, viruses and nematodes. Early blight of tomato among all fungal diseases is one of the most important disease (Munde et al 2013). It is very destructive in temperate humid climates. Although the disease is called early blight, but can occur on the plant at all stage of development. Early blight can cause decrease in fruit quantity and quality (Kumar and Srivastava 2013). Epidemics can also occur in semiarid climates where frequent and prolonged nightly dews occur (Roten and Reichert 1964). Epidemic of early blight having coefficient of disease index (CODEX) 71.66% was noticed to cause a remarkable loss up to 78.5% in the yield of tomato (Datar and Mayee 1981). It is most prevalent and destructive throughout the tomato growing areas causing loss of millions of Dollar annually worldwide including India (Datar and Mayee 1982). In present study farmer's field surveyed for finding the status of early blight of tomato in Gwalior districts of Madhya Pradesh. Tomato is affected by several viral diseases. Tomato leaf curl virus disease is reported to be the most devastating (quantitative and qualitative) causing heavy yield losses. Often, the loss reaches to the extent of 100 per cent during summer throughout India (Mishra et al 2014). Tomato leaf curl disease (ToLCD) was first reported in northern India by Vasudeva and Sam Raj (1948) and subsequently from central India (Varma 1959) and southern India (Govindu 1964, Sastry and Singh 1973). Symptoms of ToLCD include leaf curling, vein clearing and stunting, which can often lead to sterility (Saikia and Muniyappa 1989). Symptoms of leaf curl virus causes, are interveinal yellowing, vein clearing, and crinkling and puckering of the leaves accompanied sometimes by rolling of the leaf margins especially older leaves become leathery and brittle. The disease also induces severe stunting, bushy growth, and partial or complete sterility depending on the stage of the plant at which infection has taken place. Diseased plants bear few or no fruit. The pathogen transmitted by whiteflies but not by sap inoculation (Vasudeva and Samraj 1948, Nariani and Vasudeva 1963, Verma et al 1975, Muniyappa et al 1991). *Tomato leaf curl virus* (ToLCV) is the name given to a group of whitefly transmitted geminivirus (family *Geminiviridae*, genus Begomovirus) which causes leaf curl disease of tomato in many regions of India. ToLCV isolates those from northern India have two components (DNA-A and DNA-B). The ToLCV isolates from southern India (Bangalore) have a DNA-A-like monopartite genome (Muniyappa, et al 2000). Characters of begomoviruses is having small circular single stranded DNA genome that replicates via double stranded replication intermediates by using rolling circle (RC) mechanism (Saunders et al 1991).

MATERIAL AND METHODS

Present investigations were undertaken to study *Alternaria solani* (Ellis and Martin) causing early blight of tomato (*Lycopersicon esculentum* Mill*).* A systematic survey was carried out for recording the incidence of early blight on tomato grown in farmer's field in villages of Gwalior districts at the time of different stage of development. Five fields in each of villages were surveyed. Using five plants from each field disease severity was assessed by using 0-5 scale based on the percentage of infected leaf area. Percent disease incidence was also estimated. Different locations were visited during *rabi* season 2020 for assessing the intensity of the disease. Some plants from each cultivars or crop were taken randomly every time from each locality. The disease samples collected during the survey and early blight severity in the field is assessed in terms of percentage defoliation and the average fraction of necrotic leaf area on the plant after that the samples were examined microscopically to conform the symptoms and prevalence of *Alternaria* sp. pathogenic on tomato. Disease scale to calculate the per cent disease incidence of Alternaria leaf blight of tomato is included in Table 1.

Per cent disease incidence (PDI) was worked out by using the formula given by Wheeler (1969).

$$\text{PDI}=\frac{\text{Sum of all individual disease ratings}}{\text{Total No. of plants observed x Maximum disease grade}}\times 100$$

RESULTS AND DISCUSSION

A roving survey was carried out during the *Rabi* 2020 for there per cent disease incidence in early blight of tomato and severity of tomato leaf curl disease (ToLCD) in different tomato growing areas of Gwalior districts. The symptoms of ToLCD observed during survey were yellowing, puckering, upward curling of leaves, reduces leaf size, internodal length stunting and bushy appearance due to reduced internodal length with partial to complete sterility, purple pigment on the curled leaf margin. The early infection in plants did not produce any fruits or bear few fruits/ small fruits. The initial symptoms of early blight are small, dark necrotic lesions that usually appear on the older leaves and spread upward as the plant become older. As lesion enlarge, they commonly have concentric rings with a target like appearance, and they are often surrounded by a yellowing zone. (Sherf and MacNab 1986). In each field the incidence of early blight was recorded. The data summarized in Table 2 reveals that the disease incidence of early blight in Gwalior districts ranges from 12.50 to 51.30%. The overall mean in early blight of tomato in Gwalior district is 32.54 per cent. In Gwalior district the maximum disease incidence was recorded in Shyawari (51.30 %) followed by Ganeshpura (46.5%), Gobai (43.5%), Siroli (41.50%), Ekehra (37.5%), Jigniya (36.5%), Chandhrapura (36.5%), Karguva (33.7%), Bijoli (31%), Badagaon (28%), Birampura (27.5%), Sonigav (24%), Ganpatpura (22.5%) and Khureri (15.7%), while minimum incidence was recorded in Duhiya (12.50%).

The incidence of tomato leaf curl disease on tomato in the surveyed areas ranged from 15.33 to 63.20 per cent. Among the surveyed villages, the maximum disease incidence of ToLCD on tomato recorded in Ganpatpura (63.2%) followed by Shyawari (57.3%), Badagaon (56.7%), Jigniya (51.3%), Gobai (45.2%), Ekehra (44.5%), Khureri (42.5%), Karguva (41.66%), Ganeshpura (37.6%), Duhiya (34.7%), Bijoli (22.6%), Sonigav (21.5%), Siroli (16.7%) and Chandhrapura (15.6%), while minimum disease incidence was recorded in Birampura (15.33%).

Our data indicates that the early blight and leaf curl disease of tomato varied with village to village. Pachori et al (2016) reported that in field surveyed in Gwalior, Bhind and Morena districts the maximum disease incidence was found in Ekeraha (34.2% PDI). In Bhind district the range of disease incidence was recorded 27.5 to 55 PDI with mean incidence of 38.2 per cent. The maximum disease incidence was found in Mehgaon (55% PDI), which was followed by Gingirkhi (47.42% PDI), Jamana (30.6% PDI), Gormi (30.5% PDI) and minimum disease incidence was found in Daboha (27.5% PDI). In Morena district, the percent disease incidence ranged from 37.40 to 61.27 with mean incidence of 47.43 per cent. The maximum disease incidence was found in Ambah (61.27% PDI), which was followed by Sirmorkapura (51.5% PDI), Dimni (45.5% PDI), Ranpur (41.5% PDI) and minimum disease incidence was found in Bharatpura (37.4% PDI). The survey also revealed that, the severity and incidence of early blight of tomato varied from location to location, obviously due to various factors like temperature, relative humidity, rainfall, sowing dates, diverse cultivars used and even it could also be attributed to existence of pathogenic variability. The higher

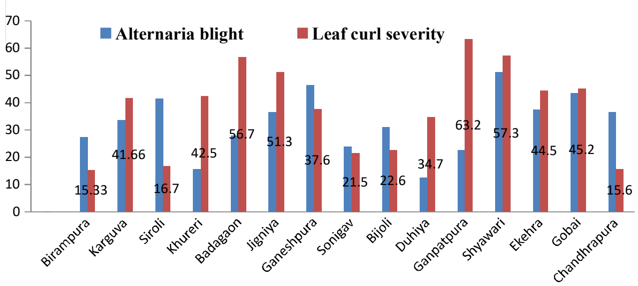
Table 1. Disease scale to calculate the percent disease incidence of Alternaria leaf blight of tomato (0-5 scale given by Datar and Mayee 1982)

Grade	Per cent leaf area infected
0	<1
1	1-5
2	6-20
3	21-40
4	41-75
5	>75

disease incidence may be due to vulnerability of the cultivars or favourable environmental conditions. That must have helped for buildup of inoculum and subsequently resulting in increased disease severity. Such higher incidence of early blight was also recorded by Datar and Mayee (1981). Present finding is in agreement with Munde et al (2013) who carried out a survey of early blight of tomato disease at Thane, Raigad, Ratnagiri and Sindhudurg districts and showed that *A. solani* was constantly associated with early blight infected plants of tomato at all the locations. Similarly, Ganie et al (2013) also reported that the disease was prevalent in all the potato growing areas of Kashmir valley surveyed during 2009 and 2010. Kamble et al (2009) also reported early blight incited by *Alternaria solani* was found to be major disease of tomato under agroclimatic conditions of Konkan region and revealed that, early blight disease intensity in Raigad district ranged between 20.78 to 42.3 per cent and 35.12 to 55.75 per cent in Thane district. Balai et al (2013) also assessed the disease intensity of Alternaria blight during rabi seasons

Table 2. Survey of early blight of tomato in Gwalior districts of Madhya Pradesh

District	Block	Village	Alternaria blight (PDI)	Leaf curl severity
Gwalior	Morar	Birampura	27.50	15.33
		Karguva	33.70	41.66
		Siroli	41.50	16.70
		Khureri	15.70	42.50
		Badagaon	28.00	56.70
		Jigniya	36.50	51.30
		Ganeshpura	46.50	37.60
		Sonigav	24.00	21.50
		Bijoli	31.00	22.60
		Duhiya	12.50	34.70
		Ganpatpura	22.50	63.20
		Shyawari	51.30	57.30
		Ekehra	37.50	44.50
		Gobai	43.50	45.20
		Chandhrapura	36.50	15.60
	Mean		32.54	37.75



2009-10 and 2010-11 in Azamgarh, Ballia, Bhadohi, Chandauli, Ghazipur, Jaunpur, Mau, Mirzapur, Sohanbhdra and Varanasi of Eastern Uttar Pradesh and five neighboring districts of Bihar, viz. Sivan, Buxar, Arah, Bhabhua and Aurangabad. And found disease intensity range in different areas from 16.93 to 38.59 per cent and 15.12 to 38.86 per cent. Similarly Atik (2007) and Randhawa (2004), also conducted survey in different areas and found that none of the surveyed tomato field was found to be free from early blight disease of tomato. Variations were found in disease incidence in all surveyed fields because of the variation in climatic condition of area and agronomic practices of a particular area. Tomato leaf curl disease is of major concern in the cultivation of the tomato crop. The disease is highly devasting in many states of the Indian subcontinent including Karnataka state. In Gwalior districts the ToLCD is found in every field surveyed. Survey was done to assess the incidence and severity of tomato leaf curl disease in certain major tomato growing districts of northern Karnataka. The results revealed that the per cent incidence and severity differed from location to location. However, the tomato leaf curl disease and the vector whitefly were percent in almost all the tomato fields surveyed. Tomato leaf curl disease is ranging from 5.0 to 86.6 per cent incidence and 2.0 to 45.2 per cent severity. Among the districts, Haveri district recorded the highest 86.6 per cent incidence of the disease followed by Yadgir district which recorded the disease incidence of 84.6 per cent and Bagalkot district recorded the least incidence of 39.1 per cent. The maximum disease severity of ToLCD on tomato was recorded in Yadgir (45.2%), followed by Haveri (44.1%) least severity of ToLCD was in Bagalkot district (15.6%). The reasons for the differences in the incidence and severity of disease in areas surveyed may be considered as due to the variation in the source of inoculum, vector population, climatic conditions and the area. The causes for high incidence of disease in Haveri and Dharwad districts are extensive cultivation of tomato crop and the prevalence of whitefly vector in these districts, whereas, high incidence in Yadgir and Kalburgi districts could be due to high vector population because of high temperature which favors whitefly multiplication. The another reason may be for high incidence of the disease in district is due to cultivation of mono-cropping over a larger area, introduction of *B. biotype*, *B tabaci* has also been considered to be one of the major factors for the disease to assume epidemic proportion. Similar observations were recorded by Saikia and Muniyappa (1989), Reddy et al (2011) and Ehsanullah (2014).

CONCLUSION

The tomato leaf curl and alternaria leaf blight diseases are important major constraint in the cultivation of tomato crop. Survey was done to assess the incidence and severity of both diseases, the percent disease incidence and severity may differ varied might be due to the variation in the source of inoculum, vector population, climatic conditions and the area. The probable cause of high incidence of disease in Ganpatpura, Shywari and Badagoan are the prevalence of whitefly vector in these villages and also high temperature which favours whitefly multiplication. Tomato early blight is also favoured by warm temperature and extended period of leaf wetness from dew, rainfall and crowed plantation as it is noted in Shyawari, Ganpatpura and Siroli villages. An understanding of the role of environmental conditions and its consequence an infection and survival of pathogen is needed to make tomato less vulnerable to early blight pathogen.

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Received 21 December, 2021; Accepted 21 March, 2022

Indian Journal of Ecology (2022) 49(2): 553-558
DOI: https://doi.org/10.55362/IJE/2022/3560

Manuscript Number: 3560
NAAS Rating: 5.79

Forest Fragmentation Analysis in Part of Kalsubai Harishchandragad Wildlife Sanctuary of Northern Western Ghats, Maharashtra

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Abstract: The Western Ghats is rich in a variety of flora, fauna and specifically about its endemism. The uncontrolled human interference in the area created the problems that leads to environmental degradation. In the Western Ghats, changing land-use patterns caused forest fragmentation, habitat loss, human-wildlife conflict, loss of movement corridor for the wildlife and it became a primary concern for sustainability of biodiversity. To understand the forest fragmentation in the study area, the research work attempts to developed forest fragmentation analysis for the year of 1991 to 2020 using the Landscape Fragmentation Tool (LFT). The result revealed that from 1991 to 2020, non-forest types like water bodies, agriculture land, barren land, scrubland and settlement has been increased by 3.71% (834 ha), 3.36% (755 ha), 2.22% (499 ha), 1.92% (433 ha), and 0.08% (18 ha) respectively. Fragmentation analysis reveals increasing edges by 3.14% (707 ha) and a decrease in the core forest by 6.12% (1376 ha). The result shows that forests are becoming more fragmented and isolated during a period of last three decades. This would help to understand and conserve the forest environments.

Keywords: Forest fragmentation, Landscape fragmentation Tool, Habitat loss, Western ghats

The forest fragmentation causes the loss of biodiversity, loss of animal habitat and aggravated problem of human-wildlife conflict (Badhe and Jaybhaye 2021). The movement of animals is inhibited or restricted when a forest becomes isolated. Several researchers examined landscape fragmentation using geospatial techniques (McGarigal et al 2002, Vogt et al, 2007, Jaybhaye et al 2016, Batar et al 2017). A forest fragmentation study was done and has been implemented in several nations including India, Malaysia, North Korea, the Democratic Republic of Congo, the United Kingdom and the USA (Kupfer 2006, Abdullah and Nakagoshi 2007, Reddy et al 2013, Shapiro et al 2016 and Aditya et al 2018). Some studies emphasize that forest fragmentation is creating problems for ecosystems by fragmenting the forested area and creating edges along the forest area that result in decreasing core forest area. The forest fragmentation problem has diverse dimensions and has been linked to habitat losses and additional environmental issues (Fischer and Lindenmayer 2007). In general, fragmentation is not only dealing with forest fragmentation but also understand the spatial relationship between areas and habitat. Forest fragmentation has two dimensions: forest degradation and forest changes in spatial arrangement (Long et al 2010). The most effective tool for forest cover monitoring by remote sensing data provides a cost-efficient explanation for regular observations to forest cover changes (Potapov et al 2013). In addition, geospatial data is the main current solution for understanding of forest cover and fragmentation (Achard and Hansen 2012, Metha and Singh 2021). Forest fragmentation analysis mapping by geospatial technology provide a clear picture of the deforestation (Stehman 2013).

Deforestation is associated with long term reduction of canopy cover in the area, particularly its transformation to other non-forested land use, significant loss of canopy without either a strong reduction in the forest area that has been effectively tracked on various dimensions for tropical forests using geospatial techniques (Asner et al 2006, DeFries et al 2007). The influence of human activities on forest fragmentation has been addressed in recent studies through several possible analyses (Numata et al 2011, Haddad et al 2015, Molinario et al 2015, Riitters et al 2016) using the available geospatial data on forest cover (Hansen et al 2013, Asner 2014, Rose et al 2015). Recent research has also shown that core forests are becoming more fragmented and isolated.

Study area: The study area of the research work is the part of Kalsubai Harishchandragad Wildlife Sanctuary located on the Sahyadri mountain ranges which is part of the Western Ghats of Maharashtra and is situated between Latitude 19°25'57" to 19°34'04" North and Longitude 73°37'51" to 73°46'25" East covering an area of 225 sq. km (15 km × 15 km dimension) (Fig. 1). The elevation of the area varies from 148 m to 1508 m above MSL while most of the area is situated near the crest line of Western Ghats. Geologically this area is part of the Deccan Trap. The Western Ghats is rich in a diversity of flora and fauna and is declared to be a biological hotspot as biodiversity is adversely impacted by human interference. The Kalsubai Harishchandragad Wildlife Sanctuary is replete with abundant kinds of flora and fauna. This region receives excessive rainfall of about 600 cm. The green landscape is stocked with beautiful vegetation and shrubs like Beheda, Avali, Gulchavi, Kharvel, Siras, Aashind, Parjambhual, Hirda, and Lokhandi under the bracket of trees. The different animals in the study area, like the leopard, jackal, hyena, barking deer, Palm civet, Indian giant squirrel, mongoose, jungle cat, and also many species of mammals and birds. The Pravara River originates on the eastern slope of Sahyadri in between Kulang and Ratangad forts and runs through the heart of the study area. Wilson Dam (Bhandardara Dam) was erected across the Pravara River in 1910.

MATERIAL AND METHODS

The landscape fragmentation tool was used to measure the extent of the fragmentation in part of the Kalsubai Harishchandragad Wildlife Sanctuary. For the research analysis, the geospatial technique is used to have visual output (MacLean and Congalton 2010). This tool was built by the Center for Land Use Education and Research (CLEAR) at the University of Connecticut (Parent et al 2007). The land use land cover (LULC) maps for the study area were generated from the data sources of Landsat satellite images for the years 1991 and 2020. The data set of Landsat 5 TM scenes from February 1991 and Landsat 8 OLI scenes from January 2020 were used to identify the land cover classes. These images were chosen for the study region based on Spatio-temporal concern of the area, images availability and the quality of the datasets. The research method is split into two parts: image classification and landscape fragmentation tool.

Image classification: For the years 1991 and 2020, the change in forest fragmentation and its relationship to human land use type were observed using satellite images of the study area with a spatial resolution of 30 m. During the cloud-free dry season, these satellite images were collected and the images have been corrected atmospherically, geometrically and topographically before the using to measure variations in fragmentation and forest cover. Based on a geospatial approach like satellite image classification using hybrid classification method and extensive fieldwork were conducted for rectification the LULC results (Rahman et al 2016). The classification of satellite image was accomplished as dense vegetation, open vegetation, agriculture, barren land, fallow land, shrubland, settlements, and water bodies.

Landscape fragmentation tool: The landscape fragmentation tool (LFT) was developed by the Center for Land Use Education and Research (CLEAR) at the University of Connecticut using a defined edge width of within 100 m. It categorises and quantifies four different classes of forest fragmentation: core forest, edge forest, patch forest and perforated forest. Furthermore, the core forest was split into small core forest' (<250 acres), medium core forest (250-500 acres) and large core forest' (>500 acres) (Fig. 2). According to peer opinion 100 m width was regarded as edge width for analysis. The landscape fragmentation tool was used to identify the forest fragmentation based on satellite images (Holdt et al 2004, Vogt et al 2007, Parent et al 2007, Hurd and Civco 2010). For the fragmentation analysis using

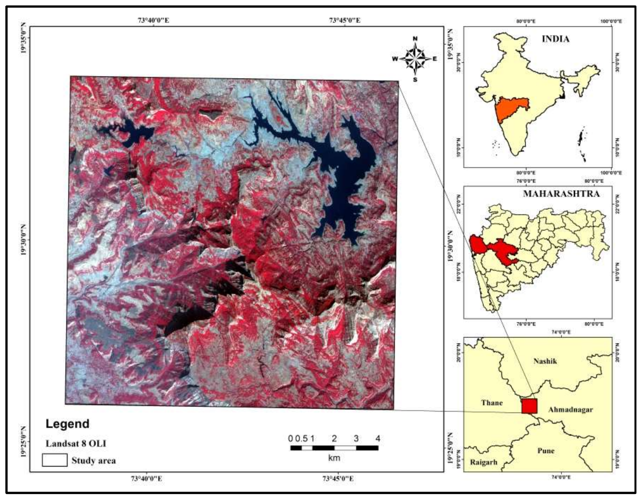

Fig. 1. Study area

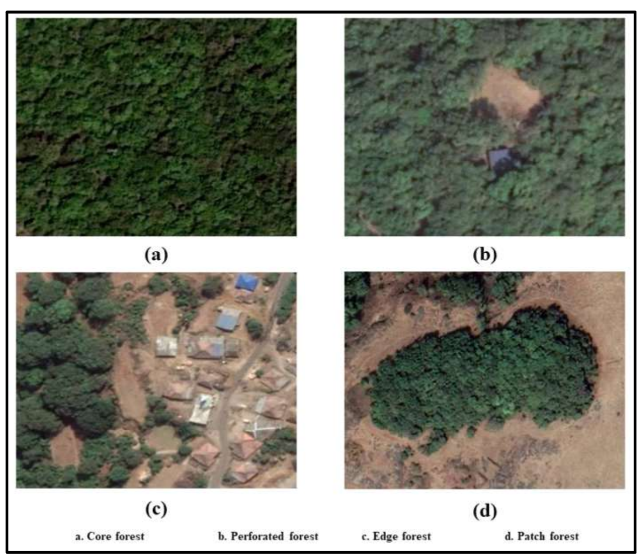

Fig. 2. Classes of forest fragmentation: a. Core Forest, b. Perforated Forest, c. Edge Forest, d. Patch Forest

LFT, was necessary to reclassify the LULC into non-forest and forest classes using spatial analyst tools in ArcGIS for identification (Table 1). Agriculture, barren land, fallow land, scrubland, settlement and water body were excluded from the analysis as the non-forested area only dense vegetation and open vegetation will remain as core forest.

RESULTS AND DISCUSSION

The land use land cover classification was done for the years 1991 and 2020. For the year 1991 Landsat 5 TM image was analysed by using a combination of bands 4, 3 and 2. For understanding contemporary LULC pattern, Landsat 8 OLI satellite image of the year 2020 used by a combination of bands 5, 4 and 3. Image classification for LULC was done based on supervised image classification, ISO cluster unsupervised classification using ArcGIS and ERDAS imagine 14 software. During the supervised image classification process of pattern recognition prior ground knowledge was used. The identified pattern of these LULC of the selected period was validated in a cross-examination manner to recognize the change notified over the period.

Table 1. Reclassification of LULC

LULC categories	Reclassified class
Agriculture	Non-forest
Barren land	Non-forest
Dense vegetation	Forest
Fallow land	Non-forest
Open vegetation	Forest
Scrub land	Non-forest
Settlement	Non-forest
Water body	Non-forest

LULC pattern of the study area in 1991: In the year 1991 based on LULC classification, most of the study area was occupied by forest area. The area under the forest was about 13582.71 ha (Hectare) (60.40 %) of total land and the remaining 8906.31 ha (39.60 %) of the land occupied by non-forest land use land cover pattern (Table 2). Among the non-forest land use activity, agriculture is the dominant activity, as covered nearly 2859.84 ha (12.72 %) of the area. The remaining LULC classes among the non-forest area have occupied in descending manner such as fallow land 2161.89 ha (9.61 %) and barren land 1601.82 ha (7.12 %), water bodies (5.73%), scrubland (3.88%), and settlements (0.54%). The forest area is shown by light green and fir green patches on the LULC maps of the two selected periods. Land cover classes, agriculture, barren land, fallow land, scrubland, water bodies and settlements are shown respectively by yellow, light sienna, pale brown, grey, red, and blue colour (Fig. 3a).

The LULC map has been distributed into forest and non-forest to understand forest fragmentation (Fig. 3b). The study area covered 13582.71 ha of forest land in 1991, accounting for 60.40% of the total area and is seen in shades of green colour on the map. The forest fragmentation categories were generated using the LFT are patch, edged, perforated and core is shown by dark orange, yellow, light orange and green colour respectively (Fig. 3c). Forest fragmentation map of year 1991 reveals that 40% area among total forest land was occupied by core forests, 28% by perforated forests, 24% by edge forests and only 8% by patch forest area (Fig. 3d). To identify fragmentation, edge pixels are coded yellow and identify the external edge of core forest areas where non-forest areas intersect (Fig. 3c). The highest disturbing

Table 2. LULC classes and distribution

Major class	Sub-classes	Area in 1991		Area in 2020	
		(ha)	(%)	(ha)	(%)
Non-forest (a)	Agriculture	2859.84	12.72	3614.67	16.07
	Fallow land	2161.89	9.61	2053.44	9.13
	Barren land	1601.82	7.12	2101.14	9.34
	Water body	1289.70	5.73	2123.55	9.44
	Scrub land	871.47	3.88	1304.19	5.80
	Settlement	121.59	0.54	139.77	0.62
Total (a)		8906.31	39.60	11336.76	50.41
Forest (b)	Patch	1026.90	4.57	1010.52	4.49
	Edge	3300.84	14.68	4007.97	17.82
	Perforated	3855.42	17.14	2109.87	9.38
	Core	5399.55	24.01	4023.90	17.89
Total (b)		13582.71	60.40	11152.26	49.59
Grand total (a+b)		22489.00	100.00	22489.00	100.00

classes are edge and perforated pixels and that shown in map respectively by yellow and light orange colour indicate that this region has the maximum fragmented forest and that maximum of the forest fragmentation zones are susceptible to shift into non-forest classes.

LULC pattern of the study area in 2020: For the year 2020, the LULC classification of Landsat 8 OLI image of the study area has been carried out. The derived LULC result for the year 2020, forest and non-forest areas have almost occupied the equivalent quantity of land. It almost covered 50 % of each of them i.e. non-forest land use covered about 11336.76 ha (50.41 %) of land and forest land use occupies a remaining 11152.26 ha (49.59 %) of land (Table 2).

Other than forest area, land use patterns show some minor changes during the three decades in the categories of non-forest land-use patterns. The agriculture category remained dominant by increasing its area up to 3614.67 ha (16.07 %). The other categories of land use land cover among the non-forest area as given in descending manner. The water bodies comprising approximately 9.44 % of the total area and covering 2123.55 ha of the area was the second-highest category (Table 2). The remaining LULC classes such as barren land occupied 2101.14 ha (9.34%) of total land, fallow land covered 2053.44 ha (9.13%) and scrubland 1304.19 ha (5.80%) and settlements 139.77 ha (0.62%) are covered (Fig. 4a).

The temporal satellite image analysis of the study area shows that the forest area had substantial forest fragmentation over the last three decades (Fig. 4b). The study area covered 13582.71 ha of forest land in 1991, representing 60.40 % of the total area, and reduced up to 49.59 % of forest land in the year 2020 (Table 2). The forest fragmentation categories were generated using the LFT are patch, edged, perforated and core is shown by dark orange, yellow, light orange and green colour respectively (Fig. 4c). Forest fragmentation map of the year 2020 revealed that 36% of the total forest land was occupied by core forests, 36% by edge forests, 19% by perforated forests and only 9% by patch forest area (Fig. 4d). Growing patches in the study area mean forest condition has disturbance and it leads to increase forest fragmentation.

Changing LULC from 1991 -2020: The changing scenario

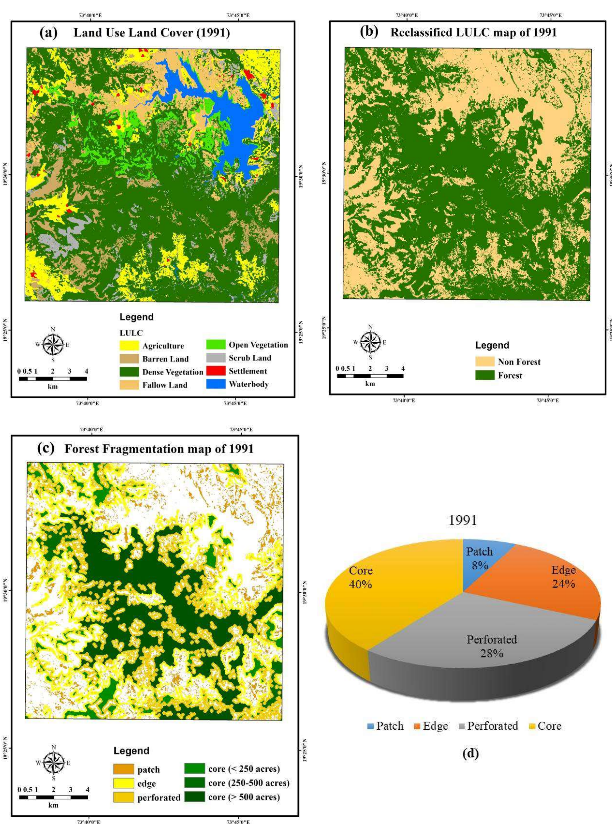

Fig. 3. a. Land use map of Study area-1991, b. Reclassified LULC (forest Non-forest) map -1991, c. Forest Fragmentaion map- 1991 d. Forest fragmentation classes cover in 1991

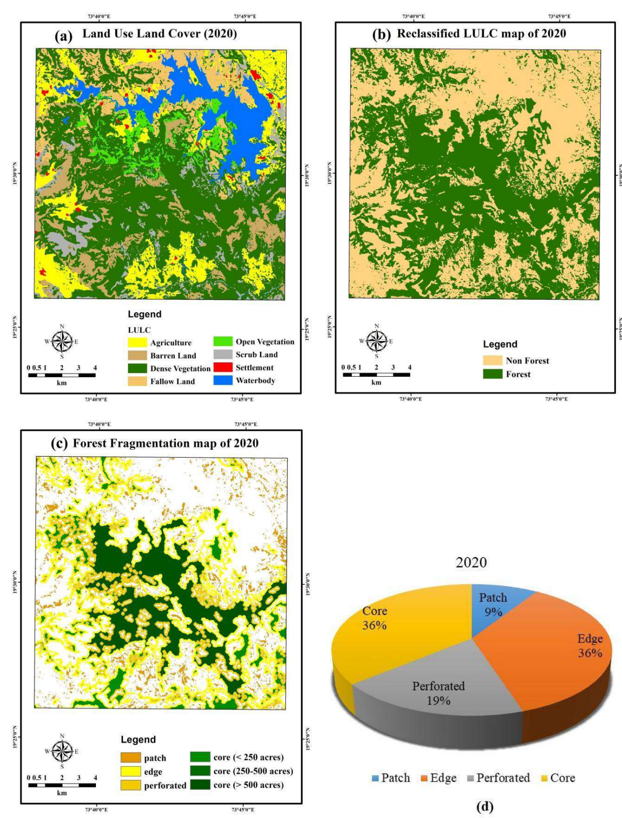

Fig. 4. a. Land use map of Study area-2020, b. Reclassified LULC (forest Non-forest) map -2020, c. Forest Fragmentaion map- 2020. d. Forest fragmentation classes cover in 2020

of LULC shows that forest area has been considerably reduced by 2430 ha area from the year 1991 to 2020. Thus, the forest areas have been fragmented and are converted into other non-forest areas. Consequently, in the temporal range of the study, the other non-forest areas have been progressively increased. The area of water bodies, agricultural land, barren land, scrubland and settlement increased 834 ha, 755 ha, 499 ha, 433 ha and 18 ha respectively. The area under the forest region decreased due to deforestation for commercial and fuelwood and agricultural purposes. Other reasons are increasing dispersed settlements, infrastructure development such as roads, dams etc.

Forest Fragmentation from 1991-2020: In 1991, under the dense and open vegetation, there was about 13582.7 ha of forest land, holding about 60.40 % lands. But at the other edge, 8906.31 ha (39.60%) of the land was occupied by the non-forest land classes. However, forest cover area has been reduced in 2020 (11152.26 ha) and forest coverage has been swapped by other non-forest land classes. In 1991, across three forest fragmentation categories, the core area shared 5399.55 ha of land and in 2020 the core area was drastically reduced to 4023.9 ha of land. Under these spatial scales, the core area deficit was 1375.65 ha (6.12%). After the core area, the perforated area becomes less prone to forest fragmentation. The perforated area in 1991 was 3855.42 ha and the area was 2109.87 ha in 2020, resulting in a gross perforated area loss of 1745.55 ha (7.76%). The edge field, on the other hand, increased from 3300.84 ha to 4007.97 ha, resulting in an overall growth of around 707.13 ha (3.14%). Finally, the patches appeared mostly the same. In 2020, the study region lost about 2430.45 ha of forest land to a variety of non-forest uses. Core forest losses were around 1375.65 ha and the core region is not only affected but other categories are affected as well. If we are not concerned about it, there will be bitter consequences for both the present and future generations. The outcome of the study suggests that the cease of forest fragmentation become a primary concern for biodiversity sustainability.

CONCLUSION

The main problem is deforestation which consequently leads to the decreasing area under forest and results in the increasing area under other land use land cover categories. The research work has a temporal range of three decades and quantified the change of deforestation through the measuring process of fragmentation from 1991 to 2020. The result revealed that non-forest types like water bodies, agriculture land, barren land, scrubland and settlement has been increased by 3.71%, 3.36%, 2.22%, 1.92% and 0.08%, respectively. Fragmentation analysis reveals increasing edges by 3.14% (707 ha) and a decrease in the core forest by 6.12% (1376 ha). The main drivers of forest fragmentation are agriculture expansion, commercial logging, fuelwood, settlement expansion, forest fire and infrastructure development like road and dam construction etc. The other form of forest fragmentation such as patch edged and perforated resulting a serious threat to the local biodiversity. The work has relevance to make aware about future generations regarding sustainable human-environment interaction. It suggests executing existing indigenous sustainable practices through government initiative with effective people participation.

ACKNOWLEDGMENTS

The authors are thankful to the Savitribai Phule Pune University, Pune under the Rashtriya Uchchatar Shiksha Abhiyan (RUSA/CBS/TH1.3) programme, for providing financial support to carry out this research.

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Received 21 November, 2021; Accepted 12 March, 2022

Indian Journal of Ecology (2022) 49(2): 559-563
DOI: https://doi.org/10.55362/IJE/2022/3561

Manuscript Number: 3561
NAAS Rating: 5.79

Seed Characteristics and Germination of *Quercus leucotrichophora* A. Camus Tree along the Elevation Gradient in Central Himalaya, India

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Abstract: *Quercus leucotrichophora* seeds were analyzed for color changes, seed size, weight, moisture content and germination along the elevation gradient. The seed germination was between 51.2 and 55.2 percent when the seed moisture content was between 35.9 and 38.8 percent .The change in mean weight of 100 seeds varied between 64.4 and 164.2 g at low elevation and the change in mean seed size was in between 31.2 and 222.6 mm^2, respectively. The change in mean weight of 100 seeds ranged between 74.7 and 63.3 g at middle elevation, and the change in mean seed size was in between 79.6 and 219.3 mm^2. Similarly at high elevation change in mean weight of 100 seeds was i between 63.6 - 90.2 and g and seed size was between 146.1 and 227.6 mm^2, respectively. The change in seed color was from dark green to dark brown, and the mean seed size was larger at the lower elevation than that of middle elevation, and the seed moisture content between 35.9 and 38.8 % during the first and second week of December considered to be a reliable indicator of maturity.

Keywords: Maturity, Moisture content, Germination, Himalaya, *Quercus leucotrichophora*

The Himalayan region is witnesses to various anthropogenic disturbances and vulnerable to climate change phenomenon, which degrading the ecosystems and make regeneration difficult. In the life cycle of forest trees, seed ripening is an important part. The variations in maturation time of seeds are a recommended way to study the effect of climatic variations on forest tree species (Bhatt and Ram 2015). Change in seed maturity period may influence the regeneration, development and hence impact stand composition and structure. Determining exact time of seed maturation is essential for the collection and regeneration of seeds. Physical attributed of seeds have been related to seed maturation in several species (Chauhan and Verma 1995; Tewari et al 2016). Climate change influences seedling dynamics of species by influencing seed germination and longevity of seeds in the soil banks. Young seedlings are more sensitive than adults to climatic irregularities. The oak forests of the region are broad leaved with approximately one year leaf life span and concentrated leaf drop during spring/summer. These forests have been placed under low to mid-montane hemi-sclerophyllous broadleaf forests. The genus *Quercus* includes has more than 400 species and is one of the most important tree species in temperate and subtropical plant communities is *Q. leucotrichohora* A. Camus (Banj Oak) is a major forest forming tree species in Uttarakhand Himalaya. The continued anthropogenic disturbances in this region create an early succession environment which makes the regeneration of the species difficult. Banj oak forest is an important component of Himalayan ecosystem from biodiversity conservation view-point; the local people generally relate oaks with water and soil conservation and in sustaining rural livelihoods (Purohit et al 2009). However, the species is under severe biotic pressure on account of its multiple uses as fodder, fuelwood, small timber, and charcoal. Due to its multiple uses, the pressure on these oak forests is relentless. Thus, the species is failing to regenerate in its natural environment for which climatic irregularities and anthropogenic pressure have been highlighted as the biggest culprits. Maturation time of seeds/acorns might shift due to global climate change phenomenon which further aggravating the regeneration issue. The aim of the present study was to determine the seed maturation period for conservation and management of *Q. leucotrichophora* species across an elevation transect and to observe the impact of climate change on seed maturation period.

MATERIAL AND METHODS

The study sites are located between 29°22'-29°24′ N Latitude and 79°25′-79°27′ E Longitude along an elevational transect of 1400 to 2200 m in Kumaun Himalaya, India. After a thorough survey, three elevations i.e., low elevation (1400-

1600 m), mid elevation (1700-1900 m) and high elevation (2000-2200 m) spread over 0.5 ha area each was selected during study period. The rocks of the study area are mainly sandstones, conglomerates, lime stones, quartzite, schist, granites and geniuses. The soil of the study area mainly sandy (40 to more than 60 % sand particles) with small amount of clay. The natural distribution of *Q. leucotrichophora* mainly between 1000-2200 m elevations and towards lower elevation associated with *Pinus roxburghii* Sarg. (chir Pine), a dominant tree species in the lower elevation of Uttarakhand Himalaya. *Q. leucotrichophora* grows either in pure stands and/or mixed with other broad-leaved and coniferous tree species. Among broad-leaved species, the main associates are *Myrica esculenta* Ham. Ex. D. Don, *Pyrus pashia* Buch. Ham, *Quercus glauca* Thunb at lower to middle elevations and *Lyonia ovalifolia* (Wall) Drude, *Quercus floribunda* Lindl, *Rhododendron arboreum* Smith, *Cedrus deodara* (Roxb.) G. Don at mid to high elevations. The mean tree diameter varies from 121.2 ± 1.9 cm at low elevation to 133.2 ± 3.2 cm at mid elevation while tree height ranged between 17.9 ± 0.8 m at high elevation to 23.1 ± 1.1 m at low elevations (Table 1).

Seeds collection and germination: Five phenotypically superior mature trees with well-developed crown of *Q. leucotrichophora* were randomly selected and marked for seed collection at each elevation. Height and CBH (at 1.37 m) of each selected tree were measured with Ravi Multimeter and measuring tapes, respectively. Collection of acorns (with involucre) of *Q. leucotrichophora* commenced from first week of October till the last week of December at all the elevations. The involucre (outer seed-based cap) was removed to determine the seed characteristics. The seeds were collected from the selected trees at each elevation and mixed to form a composite seed sample. For maturity indices seeds collection was made at an interval of 14 days till the seeds were available on marked trees. Five replicated of 25 seeds each, from the seed lot were used for determining various seed parameters. Seed size was taken as the product of length and width as mm^2 and measured with digital vernier caliper. Number of seeds per 100 gm was also determined. The seeds moisture content was expressed on the basis of fresh weight by drying at 103 ± 2°C for 16 ± 1 hr (Shah et al 2006, Tewari et al 2015) and then reweighted. Five replicates of 25 seeds each were used to determine germination percent. Seeds collected at each date were germinated on top of the seed germination paper in a dual door seed germinator at 25 ± 1°C. 2 mm radical emergence in seeds was the criteria followed for considering the seeds as germinated. Water was added as required during the experiment. Germination percent was calculated as the sum of total germinated seeds out of tested seeds for each elevation and each collection date within the test period. At the end of germination test, un-germinated seeds were percentage of seeds that had germinated at the end of the test was calculated following Paul (1972). The data were subjected to analysis of variance with a 95% confidence level using SPSS version 2007.

Table 1. Site and tree characteristics of *Quercus leucotrichophora* forests

Elevation (m)	Latitude and longitude	Tree characteristics	
		Diameter (cm)	Height (m)
Low (1400-1600)	29°20.994′ N 079°26.921′ E	121.2 ± 1.9	23.1 ± 1.1
Mid (1700-1900)	29°21.713′ N 079°27.580′ E	133.2 ± 3.2	20.1 ± 1.4
High (2000-2200)	29°23.350′ N 079°27.077′ E	126.6 ± 2.9	17.9 ± 0.8

RESULTS AND DISCUSSION

Seeds characteristics: The seed color changed from dark green at initial collection dates to dark brown at final collection dates during the study period (Table 2). The mean seed size increased from 131.2 mm^2 in first week of October to 228.4 mm^2 in third week of December at low elevation while at mid elevation, seed size increased from 79.6 mm^2 in first week of October to 239.3 mm^2 in second week of December. Similarly, at high elevation increased from 146.1 mm^2 in first week of October to 251.9 mm^2 in first week of December (Table 2). The mean weight of 100 seeds increased from 64.4 g in first week of October to 175.9 g in third week of December at low elevation, while at mid elevation, increased from 74.7 g in first week of October to 136.6 in third week of November. Similarly, at high elevation weight increased from 90.2 g in first week of October to 144.2 g in first week of December (Table 2). The mean number of seeds/100g decreased from 130.2 to 61.3 in fourth week of December at low elevation while at mid elevation, mean number decreased from 123.4 in first week of October to 56.9 in fourth week of December. Similarly, at high elevation, number of seeds decreased from 133.0 in first week of October to 30.5 in fourth week of December (Table 2). The correlation coefficient between seed size and moisture content and indicated that moisture content and indicated that moisture content was negatively correlated with seed size ($p < 0.01$) at low, mid, and high elevations (Fig. 1). The correlation coefficient was determined between moisture content and germination and indicated that germination was negatively correlated with moisture content at low and mid elevations (Fig. 2).

The percent moisture content of seeds decreased from

50.7 in first week of October to 31.1 in fourth week of December at low elevation while at mid elevation moisture content of seeds decreased from 57.8 in first week of October to 32.5 in fourth week of December. Similarly, at high elevation decreased from 61.6 (first week of October) to 27.2 per cent (fourth week of December) (Table 3). The germination was 55.2 per cent in first week of December when moisture content was 38.8 ± 1.3 % at low elevation; while at mid elevation the per cent germination was 36.6 in second week of December when moisture content was 36.6 ± 0.9 % in second week of December. Similarly at high elevation the germination was 51.2 per cent in second week of December when moisture content was 35.9 ± 3.8 % (Table 3). A significant variation was observed in seed germination behavior along an elevation gradient. The delay in germination was because of hard seed coat. The germination was significantly higher at low elevation compared to high elevation.

Various researchers have proposed seed color as an indicator of seed maturity. The color of oak seeds changed from dark green to dark brown at maturity indicated by the ease with which the seeds could be separated from the acorn cap with the commencement of browning of acorns. The seeds could be easily separated from the acorn cap from third week November onwards at lower and middle elevation and from first week of December on higher elevation site. The weight of seeds was significantly high at higher elevation compared to lower and middle elevation site. For fodder purpose, repeated lopping and cutting of trees has been carried out at lower elevation and middle elevation, which leads to decrease in weights of seed and seeds size. The mean seeds size was larger at lower elevation compared to middle elevation. These variations may be due to environmental condition operating at the same time of seed development (Chauhan and Verma 1995).

Across the sites, per cent moisture content of seeds ranged from 61.6 to 27.2 per cent during the study period and declined with each collection. Initial moisture content was significantly high at high elevation site compared to mid and low elevations. The maximum germination occurred when moisture content across all sites ranged between 35.9 and 38.8 ± 1.3 per cent. The best seed germination between 39.1

Table 2. Effect of collection dates on seeds characteristics of *Q. leucotrichophora* at different elevations

Collection dates	Seed color	Mean wt. of 100 seeds (g)			Mean no. of seeds/100g			Mean seed size		
		Low	Mid	High	Low	Mid	High	Low	Mid	High
W1O	Dark green	64.4±0.5	74.7±1.0	90.2±3.0	130.2±2.7	123.4±0.6	133.0±0.9	131.2±5.4	79.6±2.3	146.1±9.9
W3 O	Dark green	77.7±0.6	119.4±1.1	115.0±1.4	110.9±1.1	114.4±1.5	87.9±0.6	139.8±1.3	126.2±1.5	177.8±0.7
W1 N	Yellowish green	91.5±2.0	129.9±0.6	129.7±1.3	101.3±10.7	73.1±0.8	76.4±0.7	151.9±3.0	183.6±0.9	204.9±1.7
W3 N	Yellowish green	120.6±2.4	136.6±1.5	139.6±2.0	93.9±1.0	70.2±0.6	67.8±0.7	174.5±2.5	226.9±2.6	232.4±1.3
W1 D	Dark brown	143.1±1.6	124.9±0.8	144.2±1.0	90.7±1.8	68.8±0.9	53.1±0.7	190.1±2.1	234.9±3.3	251.9±0.6
W2 D	Dark brown	170.5±3.0	116.1±0.8	114.3±2.9	73.3±0.9	63.8±0.8	45.7±0.4	214.1±3.3	239.3±4.5	239.5±1.0
W3 D	Dark brown	175.9±1.6	70.7±1.8	64.7±0.6	67.5±0.4	62.0±0.4	33.8±2.3	228.4±2.4	232.7±1.1	236.8±2.7
W4 D	Dark brown	164.2±2.7	63.3±1.0	63.6±1.4	61.3±0.5	56.9±1.3	30.5±0.9	222.6±1.9	219.3±1.2	227.8±1.1

* W1 O signifies 1st week October; W3 O signifies 3rd week October; W1 N signifies 1st week November; W3 N signifies 3rd week November; W1 D signifies 1st week December; W2 D signifies 2nd week December; W3 D signifies 3rd week December; W4 D signifies 4th week December

Table 3. Effect of moisture content on various germination parameters of *Q. leucotrichophora* across the collection dates

Date of collection	Moisture content (%)			Germination (%)			Germination capacity (%)		
	Site I	Site II	Site III	Site I	Site II	Site III	Site I	Site II	Site III
W1O	50.7 ± 1.5	57.8 ± 1.3	61.6 ± 1.2	16.8 ± 0.6	7.2 ± 0.4	10.4 ± 0.5	52.8 ± 0.4	20.0 ± 0.5	47.2 ± 1.2
W3 O	48.3 ± 1.5	55.6 ± 0.8	56.1 ± 2.5	26.4 ± 1.1	14.4 ± 0.3	31.2 ± 0.7	57.6 ± 0.7	23.2 ± 0.4	52.8 ± 1.7
W1 N	42.3 ± 0.6	45.5 ± 2.8	48.9 ± 0.1	37.6 ± 0.7	17.6 ± 0.5	36.8 ± 0.7	36.8 ± 1.2	32.0 ± 0.5	53.6 ± 1.0
W3 N	40.4 ± 2.2	41.8 ± 0.2	46.3 ± 0.3	47.2 ± 1.5	27.2 ± 0.6	40.8 ± 0.6	61.6 ± 1.0	44.8 ± 0.9	55.2 ± 0.8
W1 D	38.8 ± 1.3	39.8 ± 0.3	42.2 ± 0.6	55.2 ± 1.2	32.8 ± 0.4	44.8 ± 0.2	64.8 ± 1.0	48.0 ± 0.9	56.8 ± 9.3
W2 D	34.7 ± 2.1	36.6 ±0.9	35.9 ± 3.8	53.6 ± 1.1	36.8 ± 0.5	51.2 ± 0.8	67.2 ± 0.8	44.0 ± 1.1	58.4 ± 0.8
W3 D	33.1 ± 2.5	34.0 ± 0.4	30.2 ± 0.2	42.4 ± 0.7	26.4 ± 0.5	41.6 ± 0.6	55.2 ± 0.4	39.2 ± 0.6	54.4 ± 1.1
W4 D	31.1 ± 0.8	32.5 ± 0.7	27.2 ± 1.5	39.2 ± 0.5	24.0 ± 0.5	27.2 ± 0.6	48.8 ± 0.4	36.8 ± 0.9	47.2 ± 0.5

* W1 O signifies 1st week October; W3 O signifies 3rd week October; W1 N signifies 1st week November; W3 N signifies 3rd week November; W1 D signifies 1st week December; W2 D signifies 2nd week December; W3 D signifies 3rd week December; W4 D signifies 4th week December

and 41.7 per cent moisture content has also previously been reported by Bhatt and Ram (2005). Moisture content of oak acorns has been proposed a useful indicator of viability retention and germination (Griffin 1971, Schopmeyer 1974). Rao (1984), recorded that peak seed fall in *Q. leucotrichophora* at a site located at 1818 m elevation commenced from January and continued upto March-April. The maximum germination under laboratory conditions at 25°C and 30°C ranged between 80-100%. The seed size was 272.5 mm and seed weight 2034.5 mg (fresh) and 1463.2 (dry) mg seed^{-1}. In the present study, the maximum

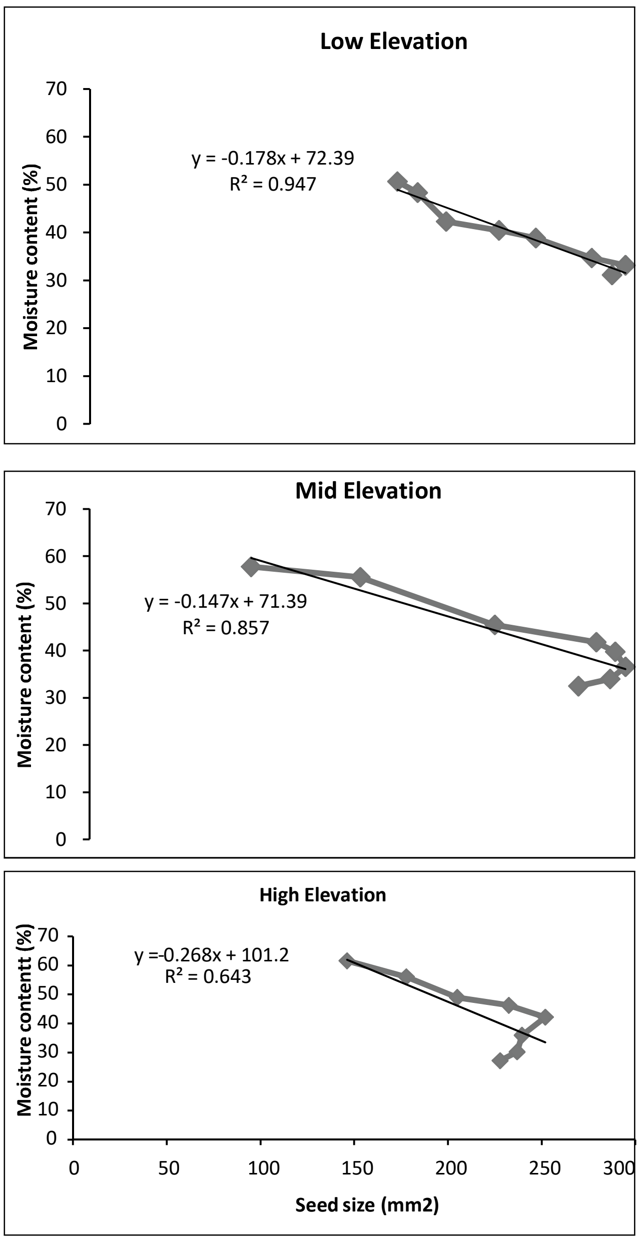

Fig. 1. Relationship between seed size (mm^2) and moisture content (%) of *Q. leucotrichophora* at low, mid and high elevation

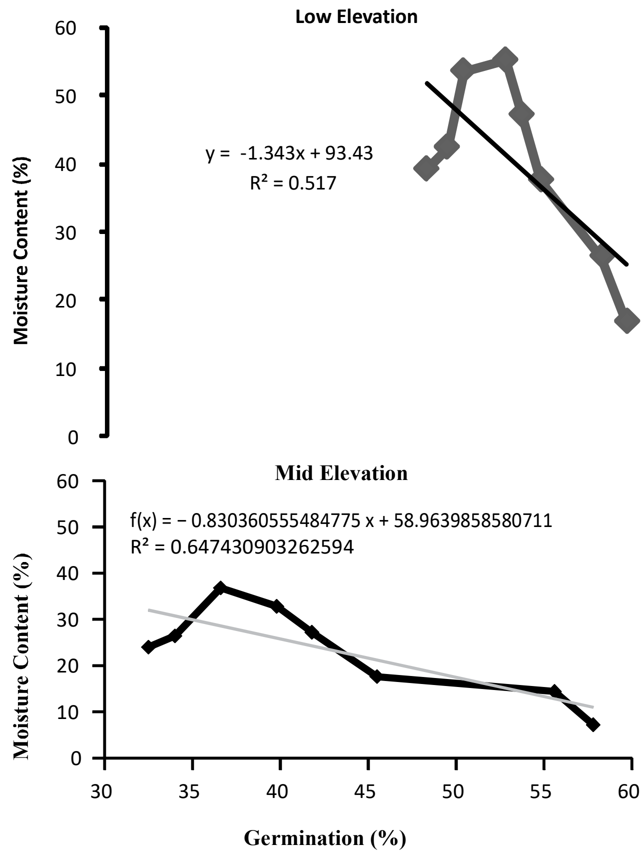

Fig. 2. Relationship between moisture content (%) and germination (%) of *Q. leucotrichophora* at low and mid elevation

germination was much lower (30-40%) under similar conditions and time of commencement of natural seed fall earlier by 45 days starting from November 2nd week and attaining a peak by December end. The study highlights that conservation of slow growing banj-oak is the biggest challenge against continuous anthropogenic disturbances as well as changing climatic conditions.

CONCLUSION

The color change of seeds from dark green to dark brown resulted in the ease of separation of acorns from the cap and the moisture content range between 35.9 and 38.8 percent appear to be reliable indicators of maturity in *Q. leucotrichophora* along its elevation range. The time of seed maturation in *Q. leucotrichophora* was earlier when compared with earlier studies and germination declined due to excessive lopping and infestation of seeds. This could also be a yearly variation impacted by climatic irregularity.f

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Indian Journal of Ecology (2022) 49(2): 564-569
DOI: https://doi.org/10.55362/IJE/2022/3562

Manuscript Number: 3562
NAAS Rating: 5.79

Changes in the Structure of Microarthropods Population in Relation to Edaphic Factors in a Managed Ecosystem of Cachar District, North East India

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Abstract: Micro-arthropods are important bio-indicators of soil health and are an integral part of food web in soil ecosystems. The present study elucidates the extent to which the various soil parameters influence the structure of soil microarthropod community. Soil sampling was done on monthly intervals and modified Berlese Tullgren funnel method was applied for the extraction of soil microarthropods. Soil temperature was noted on the study sites while other parameters of soil were analyzed. Results showed that the Collembola was the most dominant microarthropod and the density of microarthropods was recorded highest in July 2016 and lowest in September 2016. Soil organic carbon showed a significant positive correlation while other parameters revealed a weak correlation with the microarthropods density. CCA analyses revealed the occurrence of the different microarthropod groups in correspondence with the various abiotic variables and were discussed based on the microarthropods position in the CCA plot. The relation of the different edaphic variables with the microarthropods indicates that the potential contribution of all these variables should be considered for assessing the different aspects of microarthropods ecology.

***Keywords*:** Correlation, CCA, Edaphic, Rubber, Soil microarthropods

Soil microarthropods are very much essential and plays indispensable role in the soil ecosystems. They are mainly responsible for the litter decomposition and nutrient mineralization (Cole et al 2006, Kaneda and Kaneko 2008, A'Bear et al 2012). Microarthropods inhabiting in soil are well known for maintaining the soil health and react very quickly to the different changes occurred in the soil environment thereby considered them as an excellent bio-indicator of the soil environment (Lavelle et al 2006, Aspetti et al 2010). Different groups of microarthropods are exists in soil such as mites, Collembola, Diplura, Chilopoda, Symphyla (Manu et al 2016) and amongst them, Collembola and Oribatid mites are the most dominant ones (Santos-Roch et al 2011). The overall density, diversity, reproduction and development of soil microarthropods were mostly affected by the various abiotic factors such as soil moisture, precipitation, drought, soil pH, soil temperature etc. (Choi et al 2002, Ke et al 2004, Salmon et al 2008). Likewise, different climatic variables were also responsible in the seasonal fluctuation of the soil dwelling micro arthropod population. Rubber (*Hevea brasiliensis*) is a well-known low input plantation crop with a unique economic value and importance. In the East, India is the first country to launch the commercial cultivation of rubber. Currently, these plantations support various industries all over the world. The latex extracted from the rubber plant is used for numerous purposes such as in the production of equipment in sports, weatherproofing garments, etc. (FAO 2013). Moreover, the rubber plant is also used as timber for making plywood and wooden furniture that indirectly lowers the pressure imposes on forest thereby helps in carbon sequestration (Diana 2007, Ziegler et al 2009, Sturgeon 2010). Rubber plant is grown in a closed environmental system with a regular uptake of nutrients from the soil and vise versa (Hammond and Zagat 2006). Different soil types nurtures different microarthropod communities with its unique abundances and diversities which in turn helps to regulate the soil nutrient values and supports the vegetation in it. Therefore, the present study intended to explore the microarthropod population in the selected rubber plantation. The variation in the soil microarthropod population with respect to different soil parameters (soil moisture content, temperature, pH, organic carbon, N, P and K) were also analyzed to validate the microarthropods as a bio-indicator of soil environment.

MATERIAL AND METHODS

Study site: The study area lies in the North Eastern part of India which is globally recognized as biodiversity hotspot. The studied rubber plantation (*Hevea brasiliensis* Muell. Arg.) belongs to Cachar district of Assam and lies between 92°45'34°E longitude and 24°57'35°N latitude with an approximate altitude of 174 feet above mean sea level.

Cachar district falls under the conditions of subtropical warm humid climate with an annual rainfall of approximately 3874.5mm (GWIBCA 2013, Singh and Ray 2015). The soil of the plantation site has high dominance of sand percentage and is mostly sandy loam in nature.

Sampling, extraction, and identification of soil microarthropods: Soil samples from the selected ecosystem were collected at monthly intervals over a period of one year (April 2016 to March 2017) from a depth of 0-10 cm in the morning hours between 8am-9am by using simple random technique methods. On each survey, ten soil replicates were collected for the microarthropods extraction whereas five replicates for the preparation of composite soil mixture. Altogether 120 samples were collected during the study period and all the samples were kept in the modified Berlese Tullgren funnel apparatus for the purpose of microarthropods extraction. The samples were kept in the Tullgren funnel under 25-watt of electric bulb for more than 72 hours depending upon the moisture content of the soil (Murphy 1962). The vials containing 75% ethanol were fixed beneath each funnel. The extracted microarthropods were than identified under the stereoscopic binocular microscope (10x X 40x).

Analyses of edaphic variables: Soil samples of the composite mixture were air-dried and grinded for further physico-chemical analyses except in case of soil moisture content and soil temperature. Various methods were undergoes for the analyses of the edaphic variables such as temperature, moisture content, pH, organic carbon, nitrogen (N), phosphorus (P), and potassium(K) . A digital soil thermometer was inserted directly in the sampling plots (0-10cm depth) for the measurement of the soil temperature. Soil moisture content was estimated by following the oven-dry method while soil pH of the studied ecosystem was determined by a digital pH meter (Systronics). For the determination of soil organic carbon, the Walkley and Black's rapid titration method (Jackson 1958) was followed while parameters like N, P, K were assessed by Kjeldahl method, molybdenum blue and flame photometer method, respectively (Allen et al 1974).

Statistical analyses: The microarthropod population along with the different edaphic variables was subjected to statistical analysis by using various statistical software. The microarthropods density was calculated by following Singh et al (1978) in MS Office Excel-2007 software while the diversity index and regression analysis were estimated by using the PAST (version 3.05) and SPSS® (version 18.0), respectively. Canonical correspondence analysis (CCA) was performed using CANACO for windows 4.5 to illuminate the relationships between species and their environmental variables (Leps and Smilauer 2003). CCA is used as a method to find out the relationship between soils parameters with the microarthropods groups.

RESULTS AND DISCUSSION

Percent contribution of the extracted soil microarthropod groups: From the overall soil samples, a total number of 16 groups of soil microarthropods were extracted during the study period. Collembola (28.33%) and Oribatid mites (25.78%) were the most dominated groups and representing almost half of the total population sampled throughout the year. Other microarthropod groups such as Hymenoptera (13.66%), Mesostigmatid mites (10.52%), Prostigmatid mites (5.87%) were also shared a maximum contribution. Conversely, the least percentage was contributed by Isopoda with 0.05% (Fig. 1). Many pedologist reported similar findings although their studied ecosystem were different as observed in paddy field (Pator and Ray 2020), urban environment (Mcintyre et al 2001), agricultural field (Shakir and Ahmed 2015) and forest-steppe ecotone (Zhu et al 2010). Mcintyre et al (2001) observed that Collembola, Acarina, and Hymenoptera were extremely ubiquitous and almost represents 92% of the total microarthropods found in soil. Their dominancy was linked with the resistant capacity to different stress of water and temperature in the soil and litter environment (Lavelle and Spain 2001).

Density and diversity of microarthropod population: Effect of the climatic variations was clearly visible in the studied ecosystem. The maximum numbers of soil microarthropod populations were observed during May to

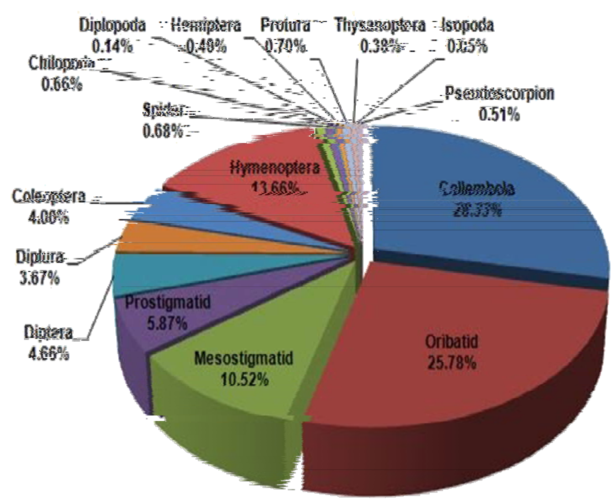

Fig. 1. Pie chart representing the percent contribution of the soil microarthropod groups during the study period (April 2016-March 2017)

August 2016 showing their more abundance in July 2016. The calculated population density for the month was 3.73 No.m^{-2}X100^2. The lowest population was in September 2016 (0.33 No.m^{-2}X100^2) (Table 1). Many reports were consistent with the findings of the present study, however, the sampling sites were different (Singh et al 2012, Singh and Ray 2015, Lakshmi and Joseph 2016, Pator and Ray 2020). Zhu et al (2010) observed that the soil microarthropods population was enhanced in the middle of the rainy season as compared to the early or late periods. Ali-Shtayeh and Salahat (2010) reported that the higher air temperature may be associated with the higher arthropod population during the summer season while the lower temperature was linked with the lower population in the winter months. At the end of August, the effect of the seasonal variation was observed on the soil inhabiting arthropod community that leads to a shifting in the community structure.

The diversity index of the microarthropod groups was highest in April 2016 (2.01) with lowest in November 2016 (1.51) (Fig. 2). Yang and Tang (2004) also observed the richness, abundance, and diversity of the soil dwelling arthropods communities were mostly higher in the dry or early rainy season as compared to the middle of the rainy season. The April is basically a wet month as dominated by high precipitation which in turn provides a suitable environment for the growth of the microarthropod population.

Edaphic factors and their correlation with soil microarthropods: During the study period, various soil parameters (soil moisture content, temperature, pH, organic carbon, N, P and K) were analyzed and correlated with the soil-dwelling microarthropods population. Depending on the climatic variation, the edaphic variables were fluctuated in a regular pattern. The moisture content of the soil samples showed a wide range of variation, highest in the June 2016 (24.30%) and lowest in January 2017 (19.45%). However, soil temperature ranged between 18.3ºC (January 2017) to 28.8ºC (July 2016). The soil pH of all the samples was acidic and did not show any wide range of variation lies between 4.61 (September 2016) to 5.15 (July 2016). The amount of soil organic carbon was varied between 0.59% (December 2016) to 0.95% (April 2016). Soil total nitrogen ranged between 0.04% (October 2016) to 0.11% (July 2016) while potassium showed a broad range of 46.32 kg ha^{-1} (November 2016) to 308.69 kg ha^{-1} (April 2016). The amount of phosphorus content in the soil varied between 13.37 kg/ha (November 2016) to 30.09 kg/ha (April 2016). Soil moisture content revealed a positive correlation with the microarthropod population but without any significant effect (Table 2). Shakir and Ahmed (2015) also reported a positive correlation between soil moisture with the microarthropod population but the data obtained were insignificant. Soil microarthropods showed a positive correlation with the temperature of the soil but the correlation was insignificant. Similar observation was reported by Asif et al (2016) in wheat crops, Pator and Ray (2018) in paddy field. They reported that the abundance of Collembola showed an insignificant positive correlation with the soil temperature. Shakir and Ahmed (2015) observed that the soil temperature had a

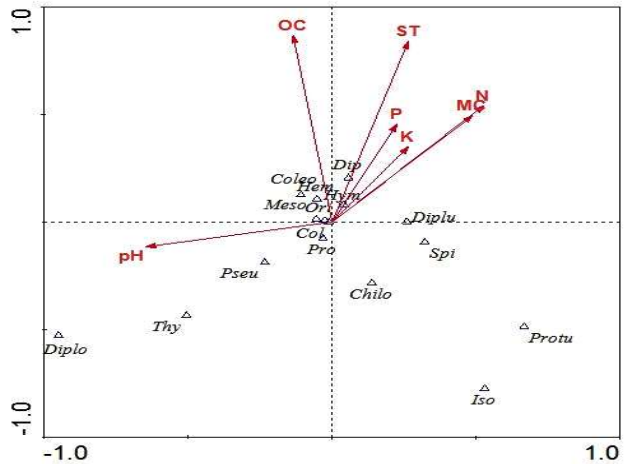

Fig. 3. Canonical correspondence analysis (CCA) biplot ordination graph of rubber plantation. MC-Moisture content, ST-Soil temperature, OC-Organic carbon, pH-Soil pH, N-Nitrogen, P-Phosphorous, K-Potassium, Ori-Oribatid mites, Col-Collembola, Meso-Mesostigmatid mites, Pro-Prostigmatid mites, Dip-Diptera, Hym-Hymenoptera, Diplu-Diplura, Protu-Protura, Chilo-Chilopoda, Diplo-Diplopoda, Iso-Isopoda, Spi-Spider, Pseu- Pseudoscorpion, Hem-Hemiptera, Thy-Thysanoptera, Coleo-Coleoptera

Table 1. Population density of total microarthropod groups in the soil samples of rubber plantation

Months	Rubber plantation (TM)
April, 2016	1.55±0.42
May, 2016	2.22±0.75
June, 2016	1.63±0.23
July, 2016	3.73±0.23
August, 2016	2.41±0.47
September, 2016	0.33±0.07
October, 2016	1.96±0.36
November, 2016	1.41±0.31
December, 2016	0.82±0.24
January, 2017	0.51±0.18
February, 2017	2.20±0.23
March, 2017	1.85±0.26

TM: Total micro arthropod population extracted month wise (April 2016-March 2017) Values are the population density (No./m^2x100^2)

positively significant correlation with the density of micro arthropods. Soil organic carbon was found as the most influencing factor in the density of microarthropods. Here, a strong significant positive correlation was observed in between the soil organic carbon and microarthropod population (Table 2). Similar observations regarding organic carbon with the microarthropod population were also reported earlier by Klausman (2006) and Ghosh (2018). All the physical, chemical and biological properties of soil were closely attached with the soil organic carbon and thereby their concentration in the soil environment affects the microarthropods population dwelling in the soil. Soil pH in the study sites was positively correlated although the correlation was weak. In support of these findings, weak positive correlation between collembola abundance and soil pH in a cotton crops was reported by Asif et al (2016). A contradictory result of negative weak correlation of soil pH was observed by Shakir and Ahmed (2015) and Klausman (2006) in soil and litter microarthropods, respectively.

Other parameters like total nitrogen (N), phosphorous (P), and potassium (K) also revealed a weak positive correlation with the microarthropods population (Table 2). A similar observation of all the three chemical parameters (NPK) having positive correlation with the microarthropods was reported by Gope and Ray (2012) but with a significant effect. The result of nitrogen is in line with the findings of Parwez and Abbas 2012, Verma et al 2014 whose work also reveals a positive non-significant correlation with the soil microarthropods. Ray et al (2012) and Islam et al (2018) analyzed the effect of potassium and phosphorous on soil microarthropods, respectively and observed an insignificant correlation between the population and selected chemical parameters.

Table 2. Correlation and regression values of different soil parameters in relation to microarthropods population

Soil parameters	Rubber plantation		
	r value	p value	Regression equation
Moisture	0.243	0.447	y = 0.1408x - 1.363
Temperature	0.470	0.123	y = 0.1198x - 1.2293
Organic carbon	0.634	0.027*	y = 5.1618x - 2.3553
pH	0.289	0.363	y = 1.5361x - 5.7353
Nitrogen	0.113	0.727	y = 8.249x + 1.3735
Phosphorous	0.205	0.523	y = 0.0386x + 1.0026
Potassium	0.550	0.064	y = 0.0058x + 0.8354

Values are significant at $p<0.05$ (*)

Table 3. Canonical Correspondence Analysis (CCA) for rubber plantation

System	Rubber plantation	
Axes	1	2
Eigenvalues	0.084	0.060
Species-environment correlations	0.976	0.964
Cumulative percentage variance of species data	19.3	33.1
Cumulative percentage variance of species-environment relation	30.1	51.8
Sum of all eigenvalues	0.435	
Sum of all canonical eigenvalues	0.278	

Canonical correspondence analysis between soil parameters and microarthropods groups: Microarthropod groups were subjected to Canonical Correspondence Analysis (CCA), a direct gradient analysis method that summarizes the relationship between the soil parameters with the microarthropods groups (Table 3). The eigenvalues for axes 1 and 2 were 0.084 and 0.060, respectively. Cumulative percentage variance of species-environment relation for axes 1 and 2 were depicted as 30.1 and 51.8. Moreover, the species environment correlations for both the axes1 and axes 2 were found as 0.97 and 0.96 respectively, indicating that the arthropods group data were strongly correlated with the soil parameters (Table 3).

In this multivariate analysis, the multicolinearity between the studied parameters was checked by applying the sign rule. In the produced CCA diagram, the length of the arrows of the given soil parameters indicates the importance on CCA plot. Microarthropod groups plotted close to the soil parameters have a strong relationship with them. Taking account of these relationships, the CCA ordination diagram revealed that the soil organic carbon (OC), soil temperature (ST), nitrogen (N), pH and moisture content (MC) were the most important variables for soil-dwelling microarthropod populations. The CCA graph showed that the axes 1 mainly correlated with the soil pH while axes 2 with the soil temperature (ST) and organic carbon (OC). Coleoptera, Oribatid, and Mesostigmatid mites were showed a strong correlation with soil organic carbon (OC) whereas Collembola, Pseudoscorpion, and Prostigmatid mites showed towards the soil pH. However, the groups such as Protura, Isopoda, and Chilopoda showed a negative relation with the soil organic carbon. Among all the soil parameters, Potassium (K) and Phosphorous (P) were the two least contributing factors that showed a weak correlation with the soil microarthropods population (Fig. 3).

The CCA revealed that soil moisture content was positively correlated with Oribatid and Hymenoptera groups. A contradictory result of the negative correlation of soil moisture with Oribatida and Hymenoptera was reported by

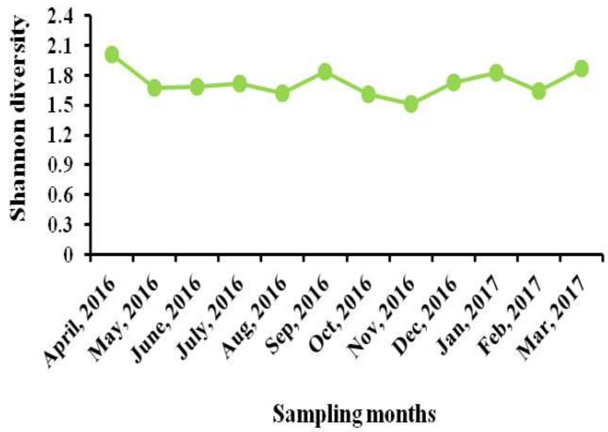

Fig. 2. Soil microarthropod diversity across the year

Duyar and Makineci (2016). CCA diagram also revealed that the arthropods groups such as Protura, Pseudoscorpion, and Thysanoptera had a negative correlation with the soil temperature. Similar observations were also reported by Duyar and Makineci (2016) from a Bornmulleriana forests in Turkey. In the study site, the biplot ordination graph also revealed that the Oribatid mites and Diptera were correspondence towards the soil temperature (Fig. 3). The results were in consistent with the findings of Pator and Ray (2020) and reported that both these groups were in close association with the soil temperature. The multivariate analysis showed that Chilopoda and Diplopoda were negatively correlated with soil temperature and soil organic carbon. A conflicting result of Myriapoda closely associated with soil temperature and soil organic matter reported by Shakir and Ahmed (2015). The CCA diagram also revealed a negative correlation between the microarthropods population and soil pH which is contradictory with the findings reported by Shakir and Ahmed (2015).

CONCLUSION

Soil microarthropods and their function in the soil ecosystem are vital for the global functioning. This paper provides a conceptual outline to understand the role of soil microarthropods and their responses to different abiotic factors. From the study, it was clearly observed that the Collembolans and Oribatid mites were highly dominant groups in the studied ecosystem and the soil parameters have exerted an impact on the microarthropods population and control their diversity, distribution and overall density of the soil microarthropods. Parameters like soil organic carbon were suitable and showed a positive significant effect on the microarthropods while other parameters in a collective way also play a major role but not proved statistically. CCA revealed that all the correlations between the microarthropods groups and abiotic variables are specific. Thus, it can be concluded that the edaphic factors either directly or indirectly exert impact on the density and diversity of soil microarthropods thereby play a vital role in maintaining the microarthropods community in the soil.

ACKNOWLEDGEMENT

The authors acknowledge the University Grant Commission, Govt. of India for providing the Basic Scientific Research fellowship during the study period.

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Received 15 September, 2021; Accepted 21 January, 2022

Indian Journal of Ecology (2022) 49(2): 570-581
DOI: https://doi.org/10.55362/IJE/2022/3563

Manuscript Number: 3563
NAAS Rating: 5.79

Documentation of Plant Species in Homegardens of Three Physiographic Regions of Hassan District, Karnataka

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***Abstract*:** The study was conducted in homegardens of the villages in three physiographic regions, Malnad, Semi-Malnad, and Maidan region of Hassan district, to document information on plant species in home gardens. In total, 299 plant species (96 trees, 82 shrubs, 70 herbs, and 52 climbers) belonging to 86 families and 232 genera were found growing naturally or cultivated from the homegarden. The family Fabaceae had the highest number of species, followed by Cucurbitaceae, Euphorbiaceae and Apocynaceae. The most common of the plants were ornamental (94 spp.), followed by medicinal (68 spp.), edible fruit (44 spp.) and vegetable (56 spp.), and other uses (38 spp.). The findings of the study, home gardens are a type of production system that is kept for the purpose of collecting a variety of products and are key avenues for species conservation and food.

Keywords: Hassan, Homegardens, Malnad, Semi-Malnad, Maidan region, Western Ghats

The home garden is a typical area of land surrounding a house where several species of plants are cultivated with a diverse mixture of perennial and annual plant species, arranged in a multilayered vertical structure and primarily tended by members of the household, with their products primarily for household consumption (Watson and Eyzaguirre 2002, Kumar and Nair 2004). A traditional home garden, on the other hand, is a significant part of a farmer's farming system and an addition to the land, where a variety of trees, shrubs, and herbs are grown for edible products and cash income, as well as a variety of outputs with both production and service values, such as aesthetic and ecological benefits. Species diversity and composition of home gardens are influenced by ecological, socioeconomic, and cultural factors (Kumar and Nair 2004). Traditional home garden practices are thought to be influenced by the form of human culture, history, desires, beliefs; and are places that have long been regarded as symbols of prestige and pride (Tangjang and Arunachalam 2009). Many countries recognize the role of home gardens in the production of food, medicine, and other useful items, as well as nutritional protection and human livelihoods (Watson and Eyzaguirre 2002, Galhena et al 2013). Home gardens act as living seed banks and a repository for plant genetic resources, ensuring the survival of rare and endangered plants as well as extinction-threatened species (Eyzaguirre and Linares 2001). Home gardens are suitable for the in situ conservation of plant genetic resources because of the high and sustained diversity of cultivated and wild plant species (Watson and Eyzaguirre 2002). Home gardens, mostly operated by women, provide essential daily inputs for the household in the form of vegetables, tubers, medicinal plants, fruit and flower-bearing plants, so improving household food security, nutrition, and well-being. Traditional agricultural types and beneficial plants are preserved in these 'living gene banks,' which are mostly maintained by women's. Home gardens have been reported mainly from the tropical and sub-tropical regions in India, primarily concentrated in high rainfall areas in the Western Ghats region of Kerala (Kunhamu et al 2015, George and Christopher 2020), and Uttara Kannada district of Karnataka (Bhat et al 2014, Bhat and Rajanna 2016). The current study attempted to collect and document information on the use of plant species in village home gardens in three physiographic regions, the Malnad, Semi-Malnad, and Maidan region of Hassan district Karnataka, India.

MATERIAL AND METHODS

Study area: Hassan district is located in the south-western part of Karnataka state in India. It lies between 12° 13´ and 13° 33´ North latitudes and 75° 33´ and 76 º 38´ East longitudes. The district begins at the base of the steep Western Ghats and continues into the gently rolling Deccan Plateau and is divided into three physiographic regions, viz. the high hilly region 'Malnad' undulating to rolling lands

'Semi-Malnad' and the plain region 'Maidan' (Fig. 1). The Malnad area, located in the western part of the district, lies on the crest of the Western Ghats. Agriculture is the main occupation of the people, cereals and potatoes are the main crops, with coffee and cardamom plantations in the 'Malnad' region. The population of this region is predominantly Hindus, and a few Muslim and Christian families and tribal community such as Hakki Pikki and Meda. The majority of rural families spend time at home tending to their gardens.

Data collection: The 36 home gardens were chosen for inventorying the floristic composition in 12 villages across three physiographic regions: 13 home gardens from Malsavara, Hegadde, Karadigala, Hondravalli in the Malnad area, 12 home gardens from Hallimysore, Kattaya, Halebeedu, Madihalli in the Semi-Malnad region, and 13 home gardens from Gowdagere, Nuggehalli, Gandasi, Arakere in the Maidan region (Fig 1). A systematic survey of plant species was conducted in each home garden during different season. The household was interviewed to know about the local names and uses of the plant species growing in their backyard gardens. Plants were identified using local flora (Saldhana and Nicolson 1976, Saldhana 1984 and 1996). To prevent taxonomic inflation, the plant names were rechecked and authenticated using the plant list (www.theplantlist.org), and the synonyms were removed.

RESULTS AND DISCUSSION

In the current study, a variety of plant species were grown and maintained in the home gardens survey from three physiographic regions; 299 plant species distributed in 232 genera and under 86 families were recorded growing naturally or cultivated in the home gardens. There were 96 species of trees, 82 species of shrubs, 70 species of herbs, and 52 species of climbers (Table 1). The most dominant family is the Fabaceae with 19 species followed by Cucurbitaceae Euphorbiaceae, Amaranthaceae. These findings are in conformity with Kerala (182 species, George and Christopher 2020), Jharkhand (101 species, Sinku et al 2021), and Karnataka, the home gardens of Honnavara (193 species, Bhat and Rajanna 2014), Karwar (210 species, Bhat et al 2014), and Halakki Vokkaliga community in Uttara Kannada District (231 species, Bhat and Rajanna 2016).

Home gardens, according to local perceptions, have the following major use categories: ornamental (94 species) followed by, medicinal, edible fruit and vegetable (Fig. 2). Ornamental plants are the most important use category with the recorded 94 species. The presence of more ornamental and commercial plants in home gardens has been identified as a sign of high urbanisation and modernization among home gardening families. The most frequently grown ornamentals, cultivated in more than 50% of all home gardens, were *Codiaeum variegatum Caladium bicolor, Crossandra infundibuliformi, Catharanthus roseus, Chrysanthemum indicum, Hibiscus rosa-sinensis, Nerium oleander,* and *Tagetes erecta.* There were fewer variations in ornamental plant diversity between the three physiographic areas. Nonetheless, the Malnad region had a high number of ornamentals (94 species), while the Semi-Malnad region had a low number of ornamentals (90 species), and the Maidan region (79 species). The majority of the species, however, were in all of the regions. Ecologically, the Malnad and Semi-Malnad regions were more similar than the Plains or Maidan regions. In addition, the Maidan region has fewer species than the other two regions. Many plants are used as medicine in home remedies by a large number of rural

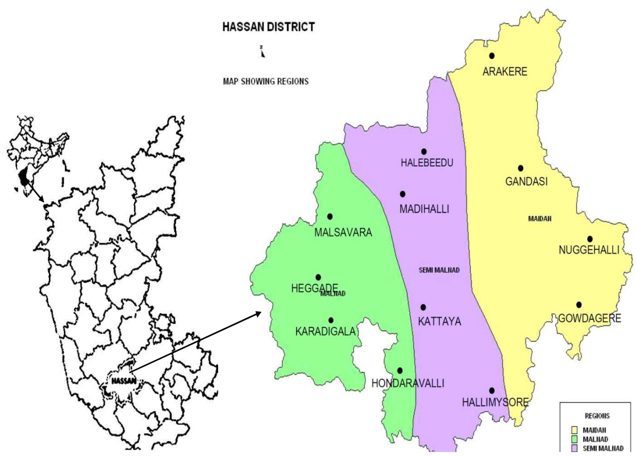
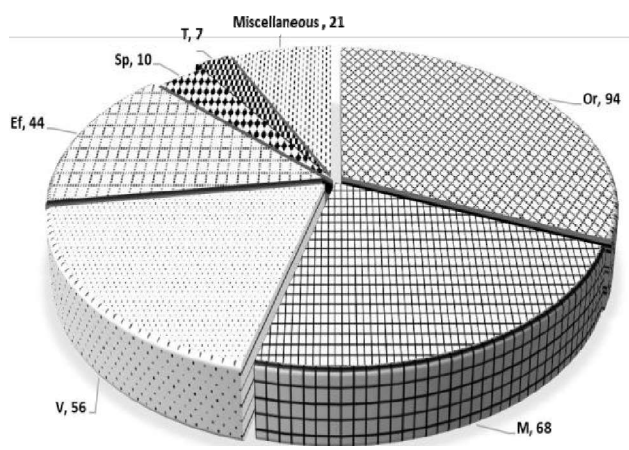


Fig. 1. Hassan district showing the three physiographical regions of villages of the study area



Or-Ornamental, M-Medicinal, V-Vegetables, Ef-Edible fruit, Sp-Spices, T-Timbers, Miscellaneous (Beverages, drinks, dye, fencing, seasonings and shade tree)

Fig. 2. Uses of home garden plant species in Hassan District

Table 1. Useful plant species in home gardens of three physiographic regions in Hassan, Karnataka, India

Sl No	Family / Botanical name	Habit	Physiographic regions			Uses
			Malnad	Semi-Malnad	Maidan	
Acanthaceae						
1.	*Asystasia gangetica* (L.) T.Anderson	H	+	+	+	Or
2.	*Barleria cristata* L.	S	+	+	+	Or
3.	*Barleria prionites* L.	S	+	+	+	Or
4.	*Crossandra infundibuliformis* (L.) Nees	S	+	+	+	Or
5.	*Eranthemum pulchellum* Andrews.	S	+	+	-	Or
6.	*Justicia adhatoda* L.	S	+	+	+	M
7.	*Thunbergia alata* Bojer ex Sims	C	+	+	+	Or
8.	*Thunbergia erecta* (Benth.) T. Anderson	S	+	+	+	Or
9.	*Thunbergia grandiflora* (Roxb. ex Rottl.) Roxb.	C	+	+	+	Or
Acoraceae						
10.	*Acorus calamus* L.	H	+	+	+	M
Agavaceae						
11.	*Agave americana* L.	S	+	+	+	Fe
Amaranthaceae						
12.	*Achyranthes aspera* L.	H	+	+	+	M
13.	*Aerva lanata* (L.) Juss.	H	+	+	+	M
14.	*Alternanthera bettzickiana* (Regel) G.Nicholson	H	+	+	+	Or
15.	*A. dentata* L.	H	+	+	+	Or
16.	*A. sessilis* (L.) R. Br. ex DC.	H	+	+	+	V
17.	*A. caudatus* L.	H	+	+	+	V
18.	*A. hybridus* L.	S	+	+	+	V
19.	*Amaranthus spinosus* L.	H	+	+	+	V
20.	*A. tricolour* L.	H	+	+	+	V
21.	*A. viridis* L.	H	+	+	+	V
22.	*Beta vulgaris* L.	H	+	+	+	V
23.	*Celosia argentea* L.	H	+	+	+	V
24.	*Gomphrena globosa* L.	H	+	+	+	Or
Amaryllidaceae						
25.	*Allium cepa* L.	H	+	+	+	V
26.	*Crinum viviparum* (Lam.) R.Ansari & V.J.Nair	H	+	+	+	Or
27.	*Hippeastrum puniceum* (Lam.) Voss	H	+	+	-	Or
28.	*Hymenocallis littoralis* (Jacq.) Salisb.	H	+	+	+	Or
29.	*Scadoxus multiflorus* (Martyn) Raf.	H	+	+	-	Or
Anacardiaceae						
30.	*Spondias pinnata* (L. f.) Kurz	T	+	+	+	Ef
31.	*Anacardium occidentale* L.	T	+	+	+	Ef
32.	*Mangifera indica* L.	T	+	+	+	Ef
33.	*Spondias dulcis* Parkinson	T	+	-	-	Ef
Annonaceae						
34.	*Annona muricata* L.	T	+	+	-	Ef
35.	*A. reticulata* L.	T	+	+	+	Ef

Cont...

Table 1. Useful plant species in home gardens of three physiographic regions in Hassan, Karnataka, India

Sl No	Family / Botanical name	Habit	Physiographic regions			Uses
			Malnad	Semi-Malnad	Maidan	
36.	*A. squamosa* L.	T	+	+	+	Ef
37.	*Polyalthia longifolia* (Sonn.) Thwaites	T	+	+	+	Or
Apiaceae						
38.	*Anethum graveolens* L.	H	+	+	+	V
39.	*Centella asiatica (*L.) Urb.	H	+	+	+	M
40.	*Coriandrum sativum* L.	H	+	+	+	Sp
41.	*Eryngium foetidum* L.	H	+	+	+	V
42.	*Foeniculum vulgare* Mill.	H	+	+	+	V
Apocynaceae						
43.	*Allamanda blanchetii* A.DC.	C	+	-	-	Or
44.	*A. cathartica* L.	C	+	+	+	Or
45.	*Alstonia scholaris* (L.) R.Br.	T	+	+	+	M
46.	*Cascabela thevetia* (L.) Lippold	T	+	+	+	Or
47.	*Catharanthus roseus* (L.) G.Don	S	+	+	+	Or
48.	*Holarrhena pubescens* Wall. ex G.Don	S	-	+	+	M
49.	*Nerium oleander* L.	S	+	+	+	Or
50.	*Plumeria obtusa* L.	T	+	+	+	Or
51.	*P. rubra* L.	T	+	+	+	Or
52.	*Rauvolfia serpentina* (L.) Benth. ex Kurz	S	+	-	-	M
53.	*R. tetraphylla* L.	S	+	-	-	M
54.	*Tabernaemontana alternifolia* L.	S	+	-	-	Or
Araceae						
55.	*Alocasia macrorrhiza* (L.) G.Don	S	+	+	-	V
56.	*Amorphophallus bulbifer* (Roxb.) Blume	S	+	+	-	V
57.	*A. commutatus* (Schott) Engl.	S	+	-	-	V
58.	*A. paeoniifolius*	S	+	+	-	V
59.	*Caladium bicolor* (Aiton) Vent.	H	+	+	-	Or
60.	*Colocasia esculenta* (L.) Schott	S	+	+	-	V
61.	*Pistia stratiotes* L.	H	+	+	+	Or
Arecaceae						
62.	*Areca catechu* L.	T	+	+	+	M
63.	*Arenga wightii* Griff.	T	+	-	-	M
64.	*Caryota urens* L.	T	+	+	-	D
65.	*Cocos nucifera* L.	T	+	+	+	D
Aristolochiaceae						
66.	*Aristolochia tagala* Cham.	C	+	+	-	Or
Asclepiadaceae						
67.	*Calotropis gigantea* (L.) Dryand.	S	+	+	+	M
68.	*Gymnema sylvestre* (Retz.) R.Br. ex Sm.	C	+	+	+	M
69.	*Hemidesmus indicus* (L.) R.Br. ex Schult.	H	+	+	+	M
Asparagaceae						
70.	*Asparagus racemosus* Willd.	C	+	+	+	M

Cont...

Table 1. Useful plant species in home gardens of three physiographic regions in Hassan, Karnataka, India

Sl No	Family / Botanical name	Habit	Physiographic regions			Uses
			Malnad	Semi-Malnad	Maidan	
71.	*Dracaena terniflora* Roxb.	S	+	+	+	Or
72.	*Sansevieria roxburghiana* Schult.f.	H	+	+	+	Or
Asteraceae						
73.	*Chrysanthemum indicum* L.	H	+	+	+	Or
74.	*Cosmos sulphureus* Cav.	S	+	+	+	Or
75.	*Dahlia pinnata* Cav.	H	+	+	+	Or
76.	*Eclipta prostrata* (L.) L.	H	+	+	+	M
77.	*Emilia sonchifolia* (L.) DC. ex DC.	H	+	+	+	V
78.	*Sphagneticola trilobata* (L.) Pruski	C	+	+	+	Or
79.	*Tagetes erecta* L.	S	+	+	+	Or
80.	*Tithonia rotundifolia* (Mill.) S.F. Blake	S	+	+	+	Or
Balsaminaceae						
81.	*Impatiens balsamina* L.	H	+	+	+	Or
82.	*I. walleriana* Hook.f.	H	+	+	+	Or
Basellaceae						
83.	*Basella alba* L.	C	+	+	+	V
Bignoniaceae						
84.	*Pyrostegia venusta* (Ker Gawl.) Miers	C	+	+	+	Or
Bixaceae						
85.	*Bixa orellana* L.	S	+	+	-	Dy
Boraginaceae						
86.	*Cordia dichotoma* G.Forst.	T	+	+	+	Ef
Brassicaceae						
87.	*Brassica juncea* (L.) Czern.	H	+	+	+	Se
88.	*Raphanus raphanistrum subsp. sativus* (L.) Domin	H	+	+	+	V
Bromaliaceae						
89.	*Ananas comosus* (L.)Merr.	T	+	+	+	Ef
Cactaceae						
90.	*Cereus repandus* (L.) Mill.	S	-	+	+	Ef
Caesalpiniaceae						
91.	*Caesalpinia pulcherrima* (L.) Sw.	T	+	+	+	Or
92.	*Cassia fistula* L.	S	+	+	+	M
93.	*Saraca asoca* (Roxb.) Willd.	T	+	+	+	Or
Cannaceae						
94.	*Canna indica* L.	S	+	+	+	Or
Caricaceae						
95.	*Carica papaya* L.	T	+	+	+	Ef
Casuarinaceae						
96.	*Casuarina equisetifolia* L.	T	+	+	+	Or
Clusiaceae						
97.	*Calophyllum inophyllum* L.	T	+	-	-	M
98.	*Garcinia gummi-gutta* (L.) Roxb.	T	+	-	-	Ef

Cont...

Table 1. Useful plant species in home gardens of three physiographic regions in Hassan, Karnataka, India

Sl No	Family / Botanical name	Habit	Physiographic regions			Uses
			Malnad	Semi-Malnad	Maidan	
Combretaceae						
99.	*Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guillem.	T	+	+	+	T
100.	*Combretum indicum*(L.) DeFilipps	C	+	+	+	Or
101.	*Terminalia bellirica*(Gaertn.) Roxb.	T	+	+	-	Ef
Commelinaceae						
102.	*Commelina benghalensis*L.	H	+	+	+	V
Convolvulaceae						
103.	*Ipomoea batatas* (L.) Lam.	C	+	+	+	V
104.	*I. hederifolia* L.	C	+	+	+	Or
105.	*I. purpurea* (L.) Roth	C	+	+	+	Or
106.	*I. quamoclit* L.	C	+	+	+	Or
Costaceae						
107.	*Cheilocostus speciosus* (J.Koenig) C.D. Specht	S	+	+	-	M
Crassulaceae						
108.	*Bryophyllum pinnatum* (Lam.) Oken	H	+	+	+	M
109.	*Echeveria runyonii* Rose	H	+	+	+	Or
Cucurbitaceae						
110.	*Benincasa hispida* (Thunb.) Cogn.	C	+	+	+	V
111.	*Citrullusl anatus* (Thunb.) Matsum. &Nakai	C	+	+	+	Ef
112.	*Coccinia grandis* (L.) Voigt	C	+	+	+	V
113.	*Cucumis melo* L.	C	+	+	+	Ef
114.	*C. sativus* L.	H	+	+	+	Ef
115.	*Cucurbita maxima* Duchesne	C	+	+	+	V
116.	*C. moschata* Duchesne	C	+	+	+	V
117.	*Diplocyclos palmatus* (L.) C. Jeffrey	C	+	+	+	M
118.	*Lagenaria siceraria*(Molina) Standl.	C	+	+	+	V
119.	*Luffaacut angula* (L.) Roxb.	C	+	+	+	V
120.	*L.cylindrica* (L.) M. Roem.	C	+	+	+	V
121.	*Momordica charantia* L.	C	+	+	+	V
122.	*M. dioica* Roxb. ex Willd.	T	+	-	-	V
123.	*Mukia maderaspatana* (L.) M. Roem.	C	+	+	+	Ef
124.	*Sechiume dule* (Jacq.) Sw.	C	+	+	+	V
125.	*Trichosanthes cucumerina* .L.	C	+	+	+	V
Cyperaceae						
126.	*Cyperus rotundus* L.	H	+	+	+	M
Dilleniaceae						
127.	*Dillenia pentagyna* Roxb.	T	+	-	-	St
Dioscoreaceae						
128.	*Dioscorea alata* L.	C	+	-	-	V
129.	*D. bulbifera* L.	C	+	+	-	V
130.	*D.pentaphylla*L.	C	+	+	-	V

Cont...

Table 1. Useful plant species in home gardens of three physiographic regions in Hassan, Karnataka, India

Sl No	Family / Botanical name	Habit	Physiographic regions			Uses
			Malnad	Semi-Malnad	Maidan	
Elaeocarpaceae						
131.	*Elaeocarpus serratus* L.	T	+	+	-	Ef
Euphorbiaceae						
132.	*Acalypha hispida* Burm.f.	S	+	+	-	Or
133.	*A. wilkesiana* Müll.Arg.	S	+	+	+	Or
134.	*Brideliaretusa (*L.) A. Juss.	T	+	+	+	T
135.	*Codiaeum variegatum* (L.) Rumph. ex A.Juss.	S	+	+	+	Or
136.	*Euphorbia cyathophora* Murray	S	+	+	+	Or
137.	*E. neriifolia* L.	S	+	+	+	Or
138.	*E. pulcherrima* Willd.exKlotzsch	S	+	+	+	Or
139.	*E. atirucalli* L.	T	+	+	+	Or
140.	*E. aumbellata* (Pax) Bruyns	S	+	+	+	Fe
141.	*Jatropha curcas* L.	S	+	+	+	M
142.	*Macaranga peltata* (Roxb.) Müll.Arg.	T	+	+	+	Or
143.	*Mallotus philippensis* (Lam.) Müll.Arg.	T	+	+	+	Dy
144.	*Manihot esculenta* Crantz	T	+	+	+	V
145.	*Ricinus communis* L.	S	+	+	+	M
Fabaceae						
146.	*Abrus precatorius* L.	C	+	+	+	M
147.	*Acacia auriculiformis* Benth.	T	+	+	+	T
148.	*Albizial ebbeck* (L.) Benth.	T	+	+	+	T
149.	*Bauhinia acuminata* L.	T	+	+	+	Or
150.	*B. purpurea* L.	T	+	+	+	Or
151.	*Cajanus cajan* (L.) Millsp.	S	+	+	+	V
152.	*Cicera rietinum* L.	H	+	+	+	V
153.	*Clitoria ternatea* L.	C	+	+	+	Or
154.	*Cyamopsis tetragonoloba* (L.) Taub.	H	+	+	+	V
155.	*Delonix regia* (Hook.) Raf.	T	+	+	+	Or
156.	*Erythrina stricta* Roxb.	T	+	+	+	St
157.	*Gliricidia sepium* (Jacq.) Walp.	T	+	+	+	St
158.	*Glycine max* (L.) Merr.	H	+	+	+	V
159.	*Lablab purpureus* (L.) Sweet	C	+	+	+	V
160.	*Pongamia pinnata* (L.) Pierre	T	+	+	+	M
161.	*Psophocarpus tetragonolobus* (L.) DC.	C	+	-	-	V
162.	*Sesbania grandiflora* (L.) Pers.	T	+	+	+	V
163.	*Tamarindus indica* L.	T	+	+	+	Ef
164.	*Vigna mungo* (L.) Hepper	C	+	+	+	V
Lamiaceae						
165.	*Mentha arvensis* L.	H	+	+	+	Sp
166.	*Ocimum basilicum* L.	H	+	+	+	M
167.	*O. tenuiflorum* L.	H	+	+	+	M
168.	*Plectranthu samboinicus* (Lour.) Spreng.	H	+	+	+	M

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Table 1. Useful plant species in home gardens of three physiographic regions in Hassan, Karnataka, India

Sl No	Family / Botanical name	Habit	Physiographic regions			Uses
			Malnad	Semi-Malnad	Maidan	
169.	*P. scutellarioides*(L.) R.Br.	S	+	+	+	Or
170.	*Pogostemon heyneanus* Benth.	H	+	+	-	M
171.	*Salvia coccinea* Buc'hoz ex Etl.	H	+	+	+	Or
Lauraceae						
172.	*Cinnamomum verum* J.Presl	T	+	+	-	Sp
173.	*Persea americana* Mill.	T	+	+	-	Ef
Lecythidaceae						
174.	*Careya arborea* Roxb.	T	+	+	+	M
175.	*Couroupita guianensis* Aubl.	T	+	+	+	M
Liliaceae						
176.	*Aloe vera* (L.) Burm.F.	H	+	+	+	M
177.	*Gloriosa superba* L.	C	+	+	+	M
Lythraceae						
178.	*Lawsonia inermis* L.	S	+	+	+	Or
Magnoliaceae						
179.	*Magnolia champaca* (L.) Baill. ex Pierre	T	+	+	+	Or
Malvaceae						
180.	*Abelmoschus esculentus* (L) Moench	S	+	+	+	M
181.	*Bombax ceiba* L.	T	+	+	+	M
182.	*Dombeya burgessiae* Gerrard ex Harv.	S	+	-	-	Or
183.	*Gossypium arboreum* L.	S	+	+	+	Fi
184.	*Grewia iliifolia* Vahl	T	+	+	+	Ef
185.	*Hibiscus mutabilis* L.	S	+	+	+	Or
186.	*H. rosa-sinensis* L.	T	+	+	+	Or
187.	*H. syriacus*L.	S	+	+	-	Or
188.	*Malva viscuspenduliflorus* Moc. & Sessé ex DC.	S	+	+	+	Or
189.	*Thespesia populnea* (L.) Sol.ex Correa	T	+	+	+	M
Marantaceae						
190.	*Maranta arundinaceae* L.	H	+	-	-	M
Meliaceae						
191.	*Azadirachta indica* A. Juss.	T	+	+	+	M
192.	*Melia azedarach* L.	T	+	+	+	M
Menispermaceae						
193.	*Tinospora sinensis* (Lour.) Merr.	C	+	+	+	M
Mimosaceae						
194.	*Adenanthera pavonia* L.	T	+	+	+	Or
Moraceae						
195.	*Artocarpus altilis* (Parkinson ex F.A. Zorn) Fosberg	T	+	-	-	V
196.	*Artocarpus heterophyllus* Lam.	T	+	+	+	Ef
197.	*A. hirsutus* Lam.	T	+	+	-	Ef
198.	*Ficus benghalensis* L.	T	+	+	+	M
199.	*F. racemosa* L.	T	+	+	+	Ef

Cont...

Table 1. Useful plant species in home gardens of three physiographic regions in Hassan, Karnataka, India

Sl No	Family / Botanical name	Habit	Physiographic regions			Uses
			Malnad	Semi-Malnad	Maidan	
200.	*F.r eligiosa* L.	T	+	+	+	M
201.	*Morus alba* L.	T	+	+	+	Ef
202.	*Streblus asper* Lour.	T	+	+	+	M
Moringaceae						
203.	*Moringa oleifera* Lam.	T	+	+	+	V
Musaceae						
204.	*Musa × paradisiaca* L.	S	+	+	+	Ef
Myristicaceae						
205.	*Myristica fragrans* Houtt.	T	+	-	-	Sp
Myrtaceae						
206.	*Callistemon viminalis* (Sol. ex Gaertn.) G.Don ex Loudon	T	+	+	+	Or
207.	*Eucalyptus globulus* Labill.	T	+	+	+	T
208.	*Psidium guajava* L.	T	+	+	+	Ef
209.	*Syzygium aromaticum* (L.) Merr. & L.M.Perry	T	+	-	-	Sp
210.	*Syzygium cumini* (L.) Skeels	T	+	+	+	Ef
211.	*S. jambos* (L.) Alston	T	+	+	+	Ef
212.	*S. samarangense* (Blume) Merr. & L.M.Perry	T	+	+	+	Ef
Nyctaginaceae						
213.	*Boerhavia iffusa* L.	H	+	+	+	M
214.	*B.glabra* Choisy	S	+	+	+	Or
215.	*B. spectabilis* Willd.	S	+	+	+	Or
216.	*Mirabilis jalapa* L.	H	+	+	+	Or
Oleaceae						
217.	*Jasminum grandiflorum* L.	C	+	+	+	Or
218.	*J. multiflorum* (Burm.f.) Andrews	C	+	+	+	Or
219.	*J. sambac* (L.) Aiton	C	+	+	+	Or
220.	*Nyctanthes arbor-tristis* L.	T	+	+	+	Or
Orchidaceae						
221.	*Vanilla planifolia* Jacks. ex Andrews	C	+	-	-	Fl
Oxalidaceae						
222.	*Averrhoa bilimbi* L.	T	+	+	-	Ef
223.	*A. carambola* L.	T	+	+	+	Ef
Passifloraceae						
224.	*Passiflora edulis* Sims	C	+	+	-	Ef
225.	*P. foetida* L.	C	+	+	+	Or
Pedaliaceae						
226.	*Sesamum indicum* L.	H	+	+	+	V
Phyllanthaceae						
227.	*Phyllanthus acidus* (L.) Skeels.	T	+	+	+	Ef
228.	*P. emblica* L.	T	+	+	+	Ef
Piperaceae						
229.	*Piper betle* L.	C	+	+	+	M

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Table 1. Useful plant species in home gardens of three physiographic regions in Hassan, Karnataka, India

Sl No	Family / Botanical name	Habit	Physiographic regions			Uses
			Malnad	Semi-Malnad	Maidan	
230.	*P. longum* L.	C	+	+	-	M
231.	*P. nigrum* L.	C	+	+	-	Sp
Plantaginaceae						
232.	*Angelonia salicariifolia* Bonpl.	H	+	-	-	Or
233.	*Russeliaequis etiformis* Schltdl. & Cham.	S	+	+	+	M
234.	*Plumbago indica* L.	S	+	+	+	M
235.	*Plumbago zeylanica* L.	S	+	+	+	M
Poaceae						
236.	*Bambusa bambos* (L.) Voss	T	+	+	+	V
237.	*Cymbopogon citratus* (DC.) Stapf.	H	+	+	+	Se
238.	*C. dactylon* (L.) Pers.	H	+	+	+	M
239.	*Saccharum officinarum* L.	S	+	+	+	D
Polygonaceae						
240.	*Antigonon leptopus* Hook. & Arn.	C	+	+	+	Or
Portulacaceae						
241.	*Portulaca grandiflora* Hook.	H	+	+	+	Or
242.	*P. oleracea* L.	H	+	+	+	V
243.	*Talinum portulacifolium* (Forssk.) Asch. ex Schweinf.	S	+	+	+	V
Proteaceae						
244.	*Grevillea robusta* A. Cunn. ex R. Br.	T	+	+	+	T
Punicaceae						
245.	*Punica granatum* L.	S	+	+	+	Ef
Ranunculaceae						
246.	*Naravelia zeylanica* (L.) DC.	C	+	+	-	Or
Rhamnaceae						
247.	*Ziziphus jujuba* Mill.	T	+	+	+	Ef
Rosaceae						
248.	*Rosa alba* L.	S	+	+	+	M
249.	*Rosa centifolia* L.	S	+	+	+	M
Rubiaceae						
250.	*Chassalia curviflora* (Wall.) Thwaites	S	+	-	-	M
251.	*Coffea arabica* L.	S	+	+	-	Br
252.	*Ixora brachiata* Roxb.	T	+	+	-	Or
253.	*I. chinensis* Lam.	S	+	+	-	Or
254.	*I. coccinea* L.	S	+	+	+	Or
255.	*Mussaenda erythrophylla* Schum. & Thonn	S	+	+	-	Or
256.	*M. frondosa* L.	S	+	-	-	Or
257.	*Neolamarckia cadamba* (Roxb.) Bosser	T	+	+	-	M
Rutaceae						
258.	*Aegle marmelos* (L.) Corrêa	T	+	+	+	M
259.	*Citrus aurantiifolia* (Christm.) Swingle	S	+	+	+	D
260.	*C. maxima* (Burm.) Merr.	T	+	+	-	Ef

Cont...

Table 1. Useful plant species in home gardens of three physiographic regions in Hassan, Karnataka, India

Sl No	Family / Botanical name	Habit	Physiographic regions			Uses
			Malnad	Semi-Malnad	Maidan	
261.	*C. medica* L.	S	+	+	-	Ef
262.	*C. reticulata* Blanco	T	+	+	-	Ef
263.	*C. sinensis* (L.) Osbeck	T	+	+	-	Ef
264.	*Murraya koenigii* (L.) Spreng.	T	+	+	+	Se
265.	*Ruta graveolens* L.	H	+	+	+	M
Santalaceae						
266.	*Santalum album* L.	T	+	+	+	M
Sapindaceae						
267.	*Cardiospermum halicacabum* L.	C	+	+	+	M
268.	*Sapindus laurifolius* Vahl.	T	+	+	+	M
Sapotaceae						
269.	*Manilkara zapota* (L.) P. Royen	T	+	+	+	Ef
270.	*Mimusops elengi* L.	T	+	-	-	Ef
Solanaceae						
271.	*Capsicum annuum* L.	S	+	+	+	Se
272.	*Cestrum nocturnum* L.	S	+	+	+	Or
273.	*Daturametel* L.	S	+	+	+	M
274.	*Lycopersicon lycopersicum* (L.) H. Karst.	S	+	+	+	V
275.	*S. americanum* Mill.	H	+	+	+	Ef
276.	*S. melongena* L.	S	+	+	+	V
277.	*S. mtorvum* Sw.	S	+	+	+	V
278.	*S. tuberosum* L.	H	+	+	+	V
Srelitziaceae						
279.	*Strelitzia reginae* Banks	S	+	+	+	Or
Theaceae						
280.	*Camellia sinensis* (L.) Kuntze	T	+	-	-	Br
Turneraceae						
281.	*Turnera ulmifolia* L.	S	+	+	+	Or
Verbenaceae						
282.	*Clerodendrum chinense* (Osbeck) Mabb.	S	+	+	-	Or
283.	*Duranta erecta* L.	S	+	+	+	Fe
284.	*Gmelina arborea* Roxb.	T	+	+	+	M
285.	*Lantana camara* L.	S	+	+	+	Fe
286.	*Stachytarpheta jamaicensis* (L.) Vahl	S	+	+	+	Or
287.	*Tectona grandis* L.f.	T	+	+	+	T
288.	*Vitex altissima* L.f.	T	+	+	+	M
289.	*V. negundo* L.	S	+	+	+	M
290.	*Volkameria inermis*L.	S	+	+	+	Or
Vitaceae						
291.	*Cissus quadrangularis* L.	C	+	+	+	V
Zingiberaceae						
292.	*Alpinia galanga* (L.) Willd.	H	+	+	-	M
293.	*Curcuma amada* Roxb.	H	+	+	-	Sp
294.	*C. aromatica* Salisb.	H	+	+	-	Sp
295.	*C. longa* L.	H	+	+	+	M
296.	*Elettaria cardamomum* (L.) Maton	S	+	-	-	Sp
297.	*Hedychium coronarium* J. Koenig	S	+	+	-	Or
298.	*Kaempferia galanga* L.	H	+	-	-	M
299.	*Zingiber officinale* Roscoe	H	+	+	+	Sp

Notes: (+) sign indicates presence of species; (-) sign indicates absence of species. **Habit**: H-Herb, S-Shrub, C-Climber, T-Tree. **Uses**: Br-Beverages, D-Drinks, Dy-Dye yielding, Ef-Edible fruit, Fe-Fencing, Fi-Fiber, Fl-Flavoring, M-Medicinal, Or-Ornamental, Se-Seasonings, Sp-Spices, St-Shade tree, T-Timbers, V-Vegetable households. The locals used a total of 68 plant species to treat various ailments. Colds, coughs, and stomach disorders are usually treated with *Acorus calamus, Curcuma longa, Ocimum tenuiflorum, Ocimum basilicum* and *Zingiber officinale*. *Moringa oleifera* leaf, flowers, and fruits are used for edible purposes, while *Colocasia esculenta* leaf, petiole, and corm are used, and *Cucurbita moschata* tender shoot and fruits are used. Primary seasonal vegetables common in all the studied home gardens were *Abelmoschus esculentus, Coccinia grandis, Cucurbita maxima, Capsicum annum, Solanum melongena* and *Sechium edule* are the major cultivated crops round the year in most of the home gardens.

Tubers are important components of the home garden and are consumed as vegetables by villagers in the Malnad area. The common tubers crops in the home garden are *Amorphophallus bulbifer, Colocasia esculenta, Dioscorea bulbifera, Ipomoea batatas* and *Manihot esculenta*. Green leafy vegetables rich in micronutrients, such as *Alternanthera sessilis, Amaranthus spinosus, Portulaca oleracea,* are also abundant in home gardens (Ray et al 2020). The edible fruit yielding plants such as *Artocarpus heterophyllus, Carica papaya, Citrus aurantiifolia, Mangifera indica, Psidium guajava*, and *Punica granatum* were usually planted in the front yard of the house so that the gardeners can keep an eye on them. *Garcinia gummi-gutta, Grewia tiliifolia, Mimusops elengi, Spondias pinnata, Syzygium jambos,* and *Ziziphus jujube* are just a few examples of underutilized edible plants that can be found in home gardens. Organically grown home garden crops, herbs, and fruits provide safe and nutritious food for households.

CONCLUSION

The purpose of the study is to inventory the plant diversity of home gardens in Hassan. The home garden is an integral component that provides vegetables, fruits, fuel wood, small timber, herbs, and spices, etc. There is an urgent need of such type of study that may be helpful in developing appropriate strategy for effective management of these valuable biological resources. The homegardens ensure crop diversification, provide diversified products through low in amount but nutritious in nature and conserve plant genetic resources.

Received 15 October, 2021; Accepted 22 February, 2022

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Indian Journal of Ecology (2022) 49(2): 582-589
DOI: https://doi.org/10.55362/IJE/2022/3564

Manuscript Number: 3564
NAAS Rating: 5.79

Socio-Economic Progress of Shrimp Farming in Punjab

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Abstract: COVID-19 pandemic devastated the world with unprecedented economic crisis, leaving everyone confused and apprehended, including the livestock sector. As a resilience measure, shrimp farmers of Punjab were advised some remedial adaptations. Expecting good results, socio-economic evaluation of shrimp farmers from 3 south west districts (Fazilka, Sri Muktsar Sahib and Mansa) of the state was carried out. With enthusiastic participation of young (56.7% ≤ 35 years of age) and educated (50% graduates) farmers, overall 86.6% of the farmers followed the advisories. The pandemic delayed stocking of ponds, however 66.7% of farmers harvested 6.5 to 8.75 t shrimp ha^{-1} $crop^{-1}$. Non-availability of water testing facility within approachable distance emerged as the major constraint (80%), while only 6.66% farmers each reported marketing and seed related problems. With culture period of 101-120 (40%) and >120 (36.7%) days, 66.7% farmers obtained feed conversion ratio <1.2. Further, 43.3 and 36.7% farmers harvested shrimp with an average body weight of 31-35g and 26-30g, respectively and 100% farmers marketed shrimp at the farm site @ Rs. 301-400 (53.3%) and >Rs. 400/- (40%) kg^{-1}, corresponding to net profit of >12.5 lakh (60%) and 7.6-12.5 lakh (26.7%) ha^{-1}. The adopted resilience plan helped the farmers to realize optimal economic returns from shrimp farming in Punjab.

Keywords: COVID, Inland, Performance, Punjab, Saline, Shrimp, Vannamei

Inland salt affected areas in Punjab, Haryana and Rajasthan are being potentially utilized for aquaculture, including fresh water carp culture in low saline areas and shrimp farming in low to high saline waters, due to innovative research and development (R&D) drive of Guru Angad Dev Veterinary and Animal Sciences University (GADVASU) in Punjab and Regional Center of ICAR- Central Institute of Fisheries Education (CIFE) in Haryana (Pathak et al 2013, Dhawan et al 2016, Ansal and Singh 2019, Bist 2019 and Debroy et al 2020). It has converted underproductive/ unproductive zero earning salt affected waste lands into a remunerative resource, converting adversity to prosperity in the region. Since 2014, when first pilot shrimp farming commercial trial was conducted in Punjab in Village Painchawali (district Fazilka), area under Pacific white shrimp (*Litopenaeus vannamei*) farming increased from 0.4 hectare (ha) in 2014 to 130 ha in 2019 (Ansal and Singh, 2019). Unlike coastal states, cold sensitive shrimp/prawn species are cultured only during the summer months (April to October) in north-western region of the country. Farmers in Punjab generally stock their ponds during April to June for rearing 100-120 days crop. Some farmers also retain their stock for > 120 days to harvest bigger sized shrimp as per market demand (Singh et al 2020). However, owing to COVID-19 lockdown led suspension of international flights and restricted interstate transport, import of SPF (specific pathogen free) shrimp brood stock by shrimp hatcheries in India was adversely affected (CIBA 2020). Consequently, production and supply of shrimp seed by the coastal states hatcheries was impeded and stocking got delayed, especially in the non-coastal states including Punjab, Haryana and Rajasthan. Under the said unprecedented condition, shrimp farmers of Punjab felt apprehensive, fearing financial losses owing to unforeseen marketing problems, being predominantly dependent on export to the United States, China and Europe (Ravishankar et al 2018). Eventually an estimated total area of 158.6 ha was stocked in 3 south west districts (Fazilka, Sri Muktsar Sahib and Mansa) with adaptive measures (delayed stocking at lower stocking density), recommended by the GADVASU, Ludhiana (Punjab) to curtail unforeseen economic hardship. No socio-economic survey has been conducted so far to appraise the socio-economic condition of shrimp farming in Punjab. Hence, the present study was taken up to evaluate the socio-economic status of shrimp farmers and to assess impact of COVID pandemic on the economic performance of shrimp farming in the above listed districts of the State during 2020.

MATERIAL AND METHODS

During the present study, 30 shrimp farmers were selected, including 10 each from Fazilka, Sri Muktsar Sahib and Mansa districts (Table 1), where shrimp farming has developed very fast in last 4-5 years (Ansal and Singh 2019, Singh and Ansal 2021), and socio-economic profile of shrimp farmers was recorded with the help of predesigned questionnaire-based survey and group discussions (Holloway 1997), by visiting the farmers personally at their farms. The socio-economic profile of farmers, including name, location, gender, age, educational profile, family size, total land holdings, land under shrimp farming, occupation, training, farming skills, labour and finance was recorded. The technical information in terms of water source, salinity, bio-security measures, seed quality, stocking, aeration, water quality monitoring, feeding management, health management, survival, disease outbreak, culture period, feed conversion ratio (FCR), consultancy, harvest size, post-harvest management, marketing, effluent management etc. was collected to evaluate technological gaps, constraints and output. Economic estimation in terms of capital investment, production (operational/recurring) cost, productivity, gross income, net profit and benefit cost (BC) ratio was carried out to assess economic viability of shrimp farming in inland saline water of the State. A total of 22 independent socio-economic variables were measured and analysed, by classifying the respondents into categories. Adoption level and performance efficiency of shrimp farmers was estimated through 25 dependent management practice variables, ranging from pond preparation to culture, harvesting and marketing. The respondents were classified into suitable categories for each variable depending on respective range recorded during the survey. Statistical techniques like percentage analysis and cumulative frequency were used for analysis of data.

RESULTS AND DISCUSSION

Gender, age and education status: The demographic profile is given in Table 2.

Land holdings and occupation: Out of the total land holdings, <0.8, 0.8-2.0 and >2.0 ha was used for shrimp farming by 10.0, 53.3 and 36.7% farmers, respectively. In terms of total land of surveyed farmers under shrimp farming, Sri Muktsar Sahib was the top district (34.6 ha) followed by Mansa and Fazilka (Table 2). In terms of ownership, 70, 90 and 50% farmers developed shrimp farms in their own land in Fazilka, Sri Muktsar Sahib and Mansa districts, respectively, while rest were on lease. As compared to southern states, more percentage of farmers in Punjab (70%) reared shrimp in their own farms. The said percentage in Maharashtra, Andhra Pradesh (Nellore district) and Tamil Nadu (Nagapattinam district) has been documented as 35.59, 11.66 and 0.67%, respectively (Naik et al 2020, Swathilekshmi et al 2005). The differences among the States may be attributed to availability of salt affected waste lands with the farmers of the south west districts of the state. Among all, only 1 shrimp pond (3.33%) was poly-lined to prevent seepage in Sri Muktsar Sahib. In contrast, most of the farmers in Haryana (Rohtak), Rajasthan (Churu) and Western UP (Mathura & Hathras) have poly-lined their ponds with HDPE 50 µ thick poly-sheet to prevent seepage loss (Bist 2019). Overall percentage of farmers in the 3 districts involved in aquaculture; agriculture and aquaculture; and business and aquaculture were 10, 83.3 and 6.7%, respectively. Shrimp farming appeared as second major occupation after agriculture for Punjab shrimp farmers (83%), with 73.3% having total land holdings between 2-8 ha; and 53.3% and 36.7% farmers rearing shrimp in 0.8-2.0 and > 2.0 ha of farm area, respectively. As compared to Punjab, percentage of farmers having shrimp farming as primary occupation in coastal states is high i.e., 100% in A.P., 83.33% in T.N. and 34.3% in Gujarat (Vadher and Manoj 2014 , Swathilekshmi et al 2005). Chittem and Kunda (2018), observed that 61.06% of shrimp farmers in A.P. are only engaged in shrimp farming; while 20.5% were involved in both shrimp farming and agriculture; and remaining 12.2% were engaged in other aquaculture practices along with shrimp farming, indicating dependence of over 70% shrimp

Table 1. GPS coordinates of selected shrimp farmers in different districts

Fazilka	Sri Muktsar Sahib	Mansa
30.332830°N 74.311125°E	30.264501°N 74.502707°E	29.835667°N 75.299683°E
30.117833°N 74.157999°E	30.263978°N 74.501741°E	29.868070°N 75.27895°E
30.905751°N 75.813065°E	30.264412°N 74.503781°E	29.860855°N 75.403290°E
30.075570°N 74.05600°E	30.287234°N 74.415714°E	29.867371°N 75.205635°E
30.104062°N 74.363053°E	30.292122°N 74.384201°E	29.864113°N 75.403397°E
30.135650°N 74.185870°E	30.073023°N 74.255659°E	29.860255°N 75.242790°E
30.104255°N 74.364191°E	30.291287°N 74.385320°E	29.868807°N 75.278950°E
30.142377°N 74.113811°E	30.201366°N 74.568040°E	29.871283°N 75.246816°E
30.107869°N 74.355824°E	30.287125°N 74.416010°E	29.866270°N 75.271210°E
30.104619°N 74.363551°E	30.111378°N 74.322471°E	29.876900°N 75.346092°E

farmers on aquaculture for their livelihood. While in South Konkan region of Maharashtra and Gujarat, aquaculture and business is reported as the major occupation in case of 76.27 and 65.7% of shrimp farmers, respectively (Vadher and Manoj 2014, and Naik et al 2020). Hence, unlike Punjab, majority of shrimp farmers in the southern part of the country are either involved in other aquaculture activities or are having any other business for financial security. These regional occupational differences are attributed to regional agriculture, livestock and industrial requirements in reference to available resources and historic expertise.

Start-up initiative and financial assistance: Although, majority of farmers-initiated shrimp farming during 2018-19 in Fazilka (60%), Sri Muktsar Sahib (70%) and Mansa (80%) districts. However, district Sri Muktsar Sahib was the first to adopt shrimp farming (before 2017), followed by Fazilka and Mansa; with 40, 20 and 40% farmers availing start-up financial assistance (subsidy and loan) under various promotional schemes, respectively (Table 2). In general, successful adoption of technology by the farmers serves as a chain reaction to motivate others to follow the footsteps. In Punjab, the progressive farmers also inspired about 80% of the farmers/entrepreneurs to adopt shrimp farming. According to the farmers of Fazilka (50%) and Sri Muktsar Sahib (80%) districts, shrimp farming helped in economic utilization of their salt affected waste lands, while in district Mansa, 100% farmers adopted shrimp farming as an opportunity for higher income, as explained further on. All the shrimp farms surveyed in district Mansa were developed in economically utilized agriculture land (18.4 ha) by extracting underground saline water available at the depth of 100-200 feet.

Training and skills in shrimp farming: With an overall percentage of 96.7%, all the farmers (100%) surveyed in Fazilka and Sri Muktsar Sahib Districts and 90% farmers in district Mansa had acquired practical training for capacity building in shrimp farming (Table 2). High investment cost involved in shrimp farming had been the prime factor that

Table 2. Socio-economic profile of shrimp farmers in different districts

Variable/ Categories		Fazilka	Sri Muktsar Sahib	Mansa	Total
Gender	Male	100	100	100	100
	Female	0	0	0	0
Age (yrs.)	<25	10	0	10	6.7
	26-35	30	50	70	50.0
	36-50	50	50	20	40.0
	>50	10	0	0	3.3
Education status	< Matric	10	10	0	6.7
	Matric	40	30	60	43.3
	Graduate	50	60	40	50.0
Total land holdings (ha)	<2	20	0	0	6.7
	2-4	40	30	40	36.6
	>4	40	70	60	56.7
Land under shrimp farming (ha)	<0.8	0	30	0	10.0
	0.8-2.0	80	10	70	53.3
	>2.0	20	60	30	36.7
Occupation	Aquaculture	30	0	0	10.0
	Aquaculture + Agriculture	70	90	90	83.3
	Aquaculture + Business	0	10	10	6.7
Training/Capacity building	Yes	100	100	90	96.7
	No	0	0	10	3.3
Exposure visits	A.P./T.N./Haryana/Gujarat	10	10	10	10.0
	Haryana	30	40	70	46.7
	No Visit	60	50	20	43.3
Access to technologies	Department of Fisheries	0	20	0	6.7
	GADVASU	70	40	90	66.7
	GADVASU & Media	30	30	10	23.3
	Any Other	0	10	0	3.3
Year of shrimp adoption	Before/During 2017	30	30	10	23.3
	2018	20	50	30	33.3
	2019	40	20	50	36.7
	2020	10	0	10	6.7
Reason of adoption	Utilization of Waste Land	30	70	0	33.3
	Higher Income	50	20	100	56.7
	Both	20	10	0	10.0
Credit source	Own Resources	60	80	60	66.7
	Subsidy/Loan	40	20	40	33.3

farmers attained technical skills to rear shrimp without any management failure. Since, farmers had acquired technical skills through trainings (96.7%), exposure visits (56.7%), interaction with shrimp farmers (100%) and consultancy with R&D institutes like GADVASU (73.3%), no farm manager or technician has been deployed on their farms. At 86.7% of farms skilled labor was hired, including 76.7% permanent manpower, to manage the shrimp farms in a scientific manner as per recommended BMPs.

Bio-security awareness and management: Biosecurity measures, including seed quality (SPF), net fencing, foot/hand dips and farm entry restrictions, were adapted by 93.3-100% of farmers in all the districts, while nylon thread network over the pond (protection against predatory birds) was used only by 40, 90 and 60% farmers in Fazilka, Sri Muktsar Sahib and Mansa districts, respectively. Overall, majority of the farmers were well aware and vigilant of bio-security measures, so as to prevent any kind of disease outbreak leading to mortality or quality compromise. Anticipating pandemic driven marketing problems and stringent quality control for export, the farmers were more watchful to prevent any added financial loss due to disease or poor quality of harvest. In contrast, only 14% farmers in the neighboring states (Haryana, Rajasthan and Western UP) were using bird nets, which was less than reported in the present study (Bist 2019).

Seed and stocking: All the farmers procured shrimp seed from the hatcheries in Andhra Pradesh and Tami Nadu registered with Coastal Aquaculture Authority (CAA) of India. In terms of seed supply, A.P. and T.N. supplied 90 and 70% seed in Mansa and Sri Muktsar Sahib districts, respectively, while no specific dominance was observed in case of district Fazilka (Table 3). Owing to COVID-19 pandemic, stocking of ponds got delayed by 2 to 3 months in all districts and 83.3% farmers procured seed (PL) @ Rs. 0.61-0.80 PL^{-1} (43.33% @ Rs. 0.71-0.80 PL^{-1}). Overall, 76.7% of the farms were stocked in the month of June and rest in July, 2020. Vannamei seed was however, procured on an average seed rate of Rs. 0.65

Table 3. Management profile of shrimp farms in different districts

Variable/ Categories		Fazilka	Sri Muktsar Sahib	Mansa	Total
Water depth (Feet)	4-5	100	100	20	73.3
	>5	0	0	80	26.7
Seed source	A.P.	50	30	90	56.7
	T.N.	50	70	10	43.3
Stocking size	<PL10	70	90	30	63.3
(PL size)	PL10-12	30	10	70	36.7
	>PL12	0	0	0	0.0
Seed cost	<0.60	20	10	0	10.0
(Rs. PL^{-1})	0.61-0.70	50	40	30	40.0
	0.71-0.80	20	50	60	43.3
	>0.80	10	0	10	6.7
Stocking rate	< 1.00	0	20	10	10.0
(Lakh PL per m^2)	1.00-1.25	50	20	30	33.3
	1.26-1.50	40	40	50	43.3
	>1.50	10	20	10	13.3
Seed survival (%)	<70	30	60	70	53.4
	71-80	40	20	10	23.3
	>80	30	20	20	23.3
Feed used	<7.5	50	0	20	23.3
(t ha^{-1} $Crop^{-1}$)	7.6-10	50	90	80	73.3
	>10	0	10	0	3.3
Feed cost	70-75	0	20	0	6.6
(Rs. kg^{-1})	76-80	0	80	60	46.7
	81-85	100	0	40	46.7
Health management	Aeration	100	100	100	100.0
	Disinfection	90	100	100	96.7
	Sanitizers	80	70	60	70.00
	Mineral Supplements	100	100	100	100.0
Farm management	Permanent Labor	80	70	80	76.7
	Hired labor	20	10	0	10.0
	Self- Management	0	20	20	13.3
Farm labor	Skilled	100	80	80	86.7
	Non-Skilled	0	20	20	13.3
Farm technician	Yes	0	0	0	0
	No	100	100	100	100

PL^{-1} in Haryana, Punjab, Rajasthan and Western U.P during the previous years (Bist 2019), indicating significant hike in seed cost (up to 23%) during 2020. Similar seed hike was recorded in the southern states during 2020 (CIBA 2020), where the seed prices increased by 15-30% affecting production cost significantly and the farmers had to spend Rs. 62,500-75,000/- more on every ha of stocking.

The districts also differed in terms of PL stocking size. In Fazilka and Sri Muktsar Sahib, 70% and 90% farmers stocked their ponds with PL size <10, while in district Mansa 70% farmers stocked PL size 10-12. Available database indicates that PL 10-14 was commonly stocked in Haryana, Rajasthan and Western U.P (Bist 2019), while in Punjab PL 10-12 sized seed was stocked during 2019 (Singh et al 2020). About 43.3% farmers followed the GADVASU advisory to restrict stocking between 20-30 PL per m^2 (<2.5 – 3.0 lakh ha^{-1}) to mitigate any unforeseen marketing issues owing to COVID -19 pandemic restrictions on international flights and export. Maximum seed survival (>70%) was reported from district Fazilka, while it was only 40% and 30% in Sri Muktsar Sahib and Mansa districts, respectively. It can be attributed to differences among the districts in respect to seed quality, seed size and stocking rate. With only 13.3% farmers exceeding stocking limits of 3.5 lakh ha^{-1}, most of the farmers (76.7%) were able to retain the stock for an extended period and sell the produce in a phased manner at competitive prices. According to early reports, in Mansa (Punjab), Rohtak (Haryana), Churu (Rajasthan) and Hathras and Mathra (Western UP) districts, shrimp seed stocking @ 25-50 PL per m^2 had been a common practice during previous years (Bist 2019, and Singh et al 2020). Besides seed quality, both seed size and stocking density affects seed survival in relation to carrying capacity of the pond, which in turn depends on water depth, water quality and management. Differences in respect to listed factors are hence, responsible for lower survival rates recorded in Sri Muktsar Sahib and Mansa districts.

Water quality and health management: As per scientific recommendations, 100% farmers in all the districts had installed wheel aerators in their ponds @ 10 aerators ha^{-1} to keep the ponds well aerated and overall water depth between 4-5 feet was maintained by 73.3% farmers, while 26.7% maintained it >5 feet (Table 3). Shrimp farmers of neighboring inland states (Haryana, Rajasthan and U.P.) have also been reported to maintain 5 feet water depth with 10 wheels aerators installed ha^{-1} (Bist 2019). Salinity of water of shrimp ponds varied from 7-16, 9-16 and 12-15 ppt in Fazilka, Sri Muktsar sahib and Mansa districts, respectively. Majority of farmers in Fazilka (90%) and Sri Muktsar Sahib (100%) districts got their samples tested from ICAR-CIFE Centre, while in district Mansa majority of the farmers (90%) got the water samples tested from GADVASU. Although, many chemicals and supplements were used by farmers for maintaining the water quality, but application of salts (calcium, magnesium and potassium), soil/water sanitizers and disinfectants like BKC (Benzalkonium Chloride), $KMnO_4$ (Potassium Permanganate) were most commonly used by the farmers in all the districts. However, the most common chemicals/ supplements used in other inland states like Haryana, Rajasthan and Western UP (Bist 2019) are reported as mineral supplements, zeolite, oxygen enhancers, ammonia reducing compounds, disinfectants and probiotics.

Feed and feeding management: Different brands (total 6 brands) of commercial feed were used in different districts. Mansa and Sri Muktsar Sahib had specific preferences for feed brands, while no such preference was observed in Fazilka district. The crude protein content (dry matter basis) in the said feed brands varied between 35 to 38%, which is expected to effect shrimp growth and productivity and is discussed in the following section. The BMPs in respect to feed check-tray, feeding rate, feeding frequency and feeding methods were followed by 96.7% of the farmers (Table 3). Overall, 73.33%, farmers used 7.6-10 t feed ha^{-1} for rearing one crop of shrimp, with maximum no. of farmers recorded in Sri Muktsar sahib (90%) followed by Mansa and Fazilka. As compared to Fazilka, more feed was used by the farmers of Sri Muktsar Sahib and Mansa districts, which is attributed to higher seed stocking rate and subsequent higher feed requirement of standing crop biomass in these districts. Further, culture period (<100 to >120 days) differences also played a major role in quantity of feed used in different districts, as discussed in following section. Cost of feed varied with the feed brand, costing Rs. 76-80kg^{-1} (46.7%) and Rs. 81-85kg^{-1} (46.7%) to most of the farmers, which was 7-9% higher than previous years (Singh et al 2020) owing to pandemic affected supply chain. However, little less hike (6-7%) was reported in case of coastal states during 2020 (CIBA 2020), probably due to added transport charges for feed supply to the northern states.

Culture period, weight gain and productivity: Culture period varied among different districts, which is attributed to delayed stocking due to seed procurement hassles faced by the farmers amidst COVID-19 pandemic. In district Fazilka, 60% of farmers harvested shrimp after 101-120 days of culture. In district Sri Muktsar Sahib, 40% farmers harvested the crop in less than 100 days of culture, while 50% reared the stock for > 120 days (Table 4). However, in district Mansa 50 and 40% farmers reared shrimp for 101-120 and > 120 days, respectively. Due to differences in crop duration, shrimp harvested in different districts differed in terms of size and count (no. kg^{-1} of shrimp). In district Fazilka, 50 and 30% of farmers harvested shrimp weighing 26-30g and >30g, respectively. In Sri Muktsar Sahib 40 and 60% and in Mansa 20 and 50% farmers harvested shrimp weighing 26-30g and >30g, respectively (Table 4). Higher average shrimp weight in districts Sri Muktsar Sahib and Mansa is attributed to higher percentage of farmers rearing the shrimp crop for > 120 days (40-50%) as compared to farmers in district Fazilka (20%) and maintenance of water depth >5 feet by 80% farmers in district Mansa.

Productivity of the shrimp farms in different districts also appeared to vary in respect to salinity, stocking size, stocking rate, survival, feed quality and management differences at farmer's level. In terms of productivity, 70, 60 and 70% farmers in Fazilka, Sri Muktsar Sahib and Mansa districts harvested 6.5 to 8.75 t shrimp ha^{-1}, respectively; while one farmer in district Sri Muktsar Sahib harvested > 8.75 t shrimp ha^{-1}. Although, the shrimp productivity recorded in all the districts was less as compared to previous years, probably due to low stocking rates (Singh et al 2020), but as per recent report (MPEDA 2021), it was still higher than the average productivity (t ha^{-1}) reported in most of the southern states during 2020-21 viz., A.P. (8.82), T.N & Pondicherry (5.20), Kerala (2.67), Karnataka (2.25), Maharashtra (3.59), W.B. (5.84), Odisha (4.10) and Gujarat (5.60). Among all, productivity of 7.5 t ha^{-1} was achieved by 40% of the shrimp farmers in Punjab, indicating the potential of shrimp farming in inland saline areas and its prospective role in food security and export earnings for the State.

With an overall percentage of 66.7%, Fazilka appeared at the top in terms of FCR (90% farmers achieving FCR < 1.2), followed by Mansa and Sri Muktsar Sahib. This can be attributed to differences in type of feed used by the farmers, besides variations in stocking rate (<2.5 to > 3.75 lakh PL ha^{-1}) and crop period (<100 to >120 days). The feed conversion efficiency decreases with progress of culture period with increase in size of shrimp (Lee and Lee 2018) and hence, higher FCR values were recorded in Sri Muktsar Sahib, where 50% farmers reared shrimp for > 120 days and 100% farmers produced bigger sized shrimp (26-40g), followed by Fazilka and Mansa. Garza de Yta et al (2004) recorded FCR of 1.97, 2.03 and 2.12 during nursery rearing of *L. vannamei* for 1-10 days, 10-20 days and 20-30 days, respectively. Lee

Table 4. Economic performance of shrimp farms in different districts

Variable/ Categories		Fazilka	Sri Muktsar Sahib	Mansa	Total
Culture period (Days)	<100	20	40	10	23.3
	101-120	60	10	50	40.0
	>120	20	50	40	36.7
Disease outbreak	Yes	0	0	10	3.3
	No	100	100	90	96.7
Average shrimp Wt. Harvested (g)	<25	20	0	30	16.7
	26-30	50	40	20	36.7
	>30	30	60	50	46.6
Productivity ($t\ ha^{-1} Crop^{-1}$)	<5	10	0	20	10.0
	5.1-6.25	20	30	10	20.0
	6.3- 8.75	70	60	70	66.7
	>8.75	0	10	0	3.3
FCR	<1.2	90	40	70	66.7
	1.3-1.5	10	50	10	23.3
	>1.5	0	10	20	10.0
Marketing	On-Farm	100	100	100	100
	Market	0	0	0	0
Operational cost ($Lakh\ ha^{-1} Crop^{-1}$)	<7.5	10	0	0	3.3
	7.6-12.5	10	40	10	20.0
	12.6-17.5	70	50	80	66.7
	>17.5	10	10	10	10.0
Post-harvest management/ Marketing	On-Farm Sale	100	100	100	100
	Processing	0	0	0	0
	Storage	0	0	0	0
Average sale rate ($Rs.\ kg^{-1}$)	<300	0	0	20	6.7
	301-400	70	60	30	53.3
	>400	30	40	50	40.0
Net income ($Lakh\ ha^{-1}\ Crop^{-1}$)	<7.5	10	0	30	13.3
	7.6-10.0	20	10	10	13.3
	10.1-12.5	20	10	10	13.3
	>12.5	50	80	50	60.0

and Lee (2018) reported FCR of 1.32 in *L. vannamei* juveniles (0.65g) fed for 36 days and 1.55 in adult (10.5g) fed for 48 days on same diet (CP 35%) and recorded reduced FCR with increase in diet CP level from 35 to 40%. CP levels of feeds used by the farmers of the state is also expected to have played a significant role in combination to culture period and size of shrimp in respect to FCR recorded in the 3 districts during the present study.

Post-Harvest management and marketing: All the farmers marketed their produce directly to traders at the farm site and could fetch competitive prices for every size they harvested from < 15 g to >40 g (65-25 count kg^{-1}). Overall, 93.3% farmers could sell their produce @ >Rs. 300 kg^{-1} (including 40% @ > Rs. 400 kg^{-1}), while as per NABARD report (Bist 2019), shrimp produced in inland states was sold @ Rs. 250-400 kg^{-1} during previous years, depending on size and quality (Table 4). No farmer was involved in any kind of processing or storage activities. Shrimp harvest was lifted by traders from A.P., Haryana, New Delhi and Gujarat, but stock from maximum farms (83.3%) was lifted by traders/lifting parties from A.P., indicating strong linkages of the farmers with the processing industry and demand of shrimp, which attracted traders/processors to Punjab from a far of state.

Operational cost and income: Operational cost of majority of farms (66.7%) ranged between 12.6 to 17.5 lakh ha^{-1} $crop^{-1}$ and with 90% farmers spending >12.5 lakh ha^{-1} $crop^{-1}$, Mansa emerged as the top district (Table 4) followed by Fazilka and Sri Muktsar Sahib, which is attributed to higher stocking rates and subsequent higher feed requirement, overuse of chemicals and additives for water quality management and power charges thereof. The 60% of the farmers earned a net profit of > 12.5 lakh ha^{-1} $crop^{-1}$ and Sri Muktsar Sahib was the top district with 80% farmers in the said net profit category. In district Fazilka, 40% farmers recorded BC ratio of more than 1.00 (1.28-1.32), while 30% achieved BC ration 0.96 to 0.99. In district Sri Muktsar Sahib, 50% of farmers recorded BC ratio > 1.00 (1.03 – 1.33) and 30% achieved BC ratio 0.91-0.96. Further, in district Mansa, 40% farmers recorded BC ratio > 1.00 (1.15- 1.35) and only 10% achieved BC ration 0.9-1.0. However, 20% farmers in district Mansa suffered loss due poor survival of seed and outbreak of black gill disease. Shrimp farming is a 'High Cost High Risk' aquaculture practices, involving about 10-15 lakh of operational or production cost ha^{-1} $crop^{-1}$of about 100-120 days. Market price of shrimp varies with size and quality, being an export commodity. Hence, net earnings of the farmers depend on both quantity and quality of shrimp harvested from their pond.

No economic study in respect to shrimp farming in inland saline areas of Punjab has been conducted so far. However, in Haryana, Rajasthan and Western UP, productivity levels ranging from 6.25 to 12t ha^{-1} (Bist 2019) were recorded during 2019. While, Joshi (2019) reported shrimp productivity of 13 and 10t ha^{-1} in Haryana, at salinity levels of 13-15 ppt and 0.5-2.0 ppt, respectively. Earlier, Singh et al (2020) reported shrimp productivity of 8.35 t ha^{-1} in district Mansa (Punjab), with stocking rate of 50 PL per m^2 and culture period of 140 days.

Further, if compared with southern states having about 2.40 lakh ha area under brackish water aquaculture (Ravisankar et al 2018), with an average shrimp productivity of 6.85t ha^{-1}, Punjab performed equally well with 66.7% farmers achieving productivity range of 6.5-8.75 t ha^{-1} during 2020.

As compared to inland state Punjab, shrimp farming in southern part of the country witnessed more difficulties and losses due COVID-19 lock down (CIBA 2020) i.e., 15-30% increase in seed cost, 6-7% increase in feed cost, 40% reduction in area, 15-20% increase in production cost. As per latest reports, total shrimp production of India dropped by 29% in 2020 with an estimated loss of 40% (Chase 2021), while world production dropped by 13% (Kumaran et al 2021).

However, in Punjab majority of the farmers could harvest their crops with profit owing to delayed stocking (June-July) at restricted stocking densities (25-30 PL per m^2), with 21.92% increase in area. This could only be possible because complete stocking was done after the lock-down period.

CONCLUSION

Although, COVID-19 pandemic and subsequent restrictions delayed stocking of ponds, besides affecting seed and feed cost in Punjab, but farmers could fare well under the resilience advisory issued by GADVASU and majority of farmers harvested 6.5-8.75 t (66.7%) shrimp ha^{-1}, with net earnings of Rs. 7.6-12.5 lakh (26.7%) and >12.5 lakh (60%) ha^{-1}, without any disease outbreak and major marketing curtailment. The adopted resilience plan helped the farmers to realize the economic benefits of low-density stocking, which enabled them to retain their stocks for an extended period over 120 days (36.7%) and earn more through phased marketing strategy. Although, shrimp farming in Fazilka and Sri Muktsar Sahib has been adopted to utilize under or unproductive salt affected lands, but conversion of good agriculture land for shrimp farming by extraction of underground water (100-200 feet depth) is a matter of great concerns as it may cause serious environmental impact through salinization of adjoining areas.

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Indian Journal of Ecology (2022) 49(2): 590-595
DOI: https://doi.org/10.55362/IJE/2022/3565

Manuscript Number: 3565
NAAS Rating: 5.79

Landscape Fragmentation Analysis in and around Rajaji National Park, Uttarakhand, India

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***Abstract*:** The study was conducted to figure out the landscape fragmentation in and around Rajaji National Park using landscape indices viz., total Class area (CA), number of patches (NP), patch density (PD), interspersion and juxtaposition Index (IJI) and largest patch index (LPI) over the classified LULC map of the study area during 1993 and 2015. Landsat imageries through spatial analyst programme FRAGSTATS 4.2.Comparative study of the landscape indices inside the protected area (2000 m buffer) and innermost protected area (excluding 2000 m buffer area) during 1993 and 2015 indices such as NP, PD, LPI decreased over time while, IJI got increased with respect to forest patch, which means interspersion is more and patch adjacency is getting increased during the analyzed period, which means inside the protected area fewer disturbances were observed. Meanwhile, comparison of landscape indices outside protected area (2000 m buffer outside PA) during 1993 and 2015 revealed that NP, PD increased overtime while, LPI and IJI decreased over time. Lower values of IJI characterize landscapes in which the patch types are poorly interspersed, means the outer side of protected area are more fragmented with respect to the inside boundary.

***Keywords*:** Landscape fragmentation, Digital image processing, Patch density, Largest Patch Index

In global scale, land use changes are cumulatively transforming land/ forest cover at an alarming and accelerating pace, especially in the tropical region. So, the time demands a quick and accurate assessment of the changes happening or happened to the natural resources like forest both in present as well as past respectively. Vegetation is an essential and fundamental aspect of general biodiversity, hence knowledge of its spatial distribution patterns can help in conservation (Rashid et al 2013). Moreover, forest cover changes have an impact on the supply of crucial ecosystem services such as biodiversity, climate control, carbon storage, and water supplies (Hansen et al 2013). Landscape structure and composition can also use to analyze ecological processes, which aids in landscape management (Reddy et al 2013a). Deforestation, commercial logging, and other human effects have all been monitored and assessed via geospatial analysis, which is frequently employed in the area of ecology (Wang et al 2010, Hou et al 2013). Due to the wide availability of Landsat satellite data, it has also received attention in detecting land use change and forest fragmentation (Rajani and Smitha 2017). Remotely sensed data, also with GIS tools and ground observations, is essential for cost-effective monitoring, and the generated information aids in smart planning and decision-making (DeFries et al 2007, Carranza et al 2014). Landscape ecology is largely founded on the notion that environmental patterns strongly influence ecological processes. A disruption in landscape patterns may therefore compromise its functional integrity by interfering with critical ecological processes necessary for population persistence and the maintenance of biodiversity and ecosystem health. For these and other reasons, much emphasis has been placed on developing methods to quantify landscape patterns, which is considered a prerequisite to the study of pattern-process relationships. The landscape consists of patches of different land covers. Patch characterization is the best method to analyses patch size, shape, and arrangement. The patches are the representation of past and present environmental conditions and human dimensions. Disturbance zones have also been investigated using factors such as patch density, porosity, fragmentation, and juxtaposition (Reddy et al 2013b). The present study aims at evaluating the landscape in and around the protected area. Spatial pattern analysis program FRAGSTATS 4.2 is used here for quantifying the structure (i.e., composition and configuration) of landscapes (Mcgarigal 2015).

MATERIAL AND METHODS

Study area: Rajaji National Park is situated in the state of

Uttarakhand. In the year 1983, Rajaji Wildlife Sanctuary of Uttaranchal was merged with Motichur and Chilla wildlife sanctuaries and made into Rajaji National Park is situated along the hills and foothills of Shiwalik ranges in the Himalayan foothills and represent the Shiwalik eco-system (Fig. 1). Combining three sanctuaries viz. Chilla, Motichur and Rajaji National Park is spread over the Pauri Garhwal, Dehradun, and Saharanpur districts of Uttarakhand. The Motichur and Rajaji sanctuaries are contiguous and are separated from the Chilla Sanctuary to the south-east by the Ganges River and the Chilla River. Motichur and Rajaji wildlife sanctuaries lie to the north and south of the Siwalik Ridge and are dissected by many ravines carrying water which descend from the main ridge, becoming broad pebble/boulder filled streams in the plains. These streams remain dry for most of the year but become raging torrents during the monsoon. The area is covered with diverse forest types ranging from semi-evergreen to deciduous and from mixed broad-leaved to Terai grassland and has been classified as Indus-Ganges Monsoon Forest type. Lofty strands of sal dominate in many parts. The study area falls in the following forest ranges of Rajaji National Park division viz., Dholkhand West, Dholkhand East, Chillawali and Haridwar ranges.

Methodology: Monitoring and evaluating the land cover change in and around protected area (Rajaji National Park) via bi-temporal change analysis of the study area within the addressed periods of 1993 and 2013, inside protected area (in 2000 m buffer inside PA), outside protected area (in 2000 m buffer outside PA) and innermost protected area (excluding 2000 m buffer area) using 1993 and 2015 datasets. Firstly, Acquisition of bi-temporal imageries (1993 and 2015) from USGS Earth Explorer web portal (https://earthexplorer.usgs.gov/) were made (Fig. 3). The entire image related activities viz. processing, analysis and extraction etc. has been done using ERDAS 2014 software and Arc Map 10.3.1. Digital image processing includes procedures for pre-processing, enhancement, and information extraction. Layers import and Layer stacking were the first step which were done after the data acquisition. Image processing requires several steps for the better identification of the image features. It is a kind of numerical manipulation of digital images including the procedures for image enhancement and information extraction. Spectral enhancement has been performed on both the images studied during the classification and interpretation steps. Layer stacking, FCC creation and image enhancement was done (Fig. 4). Supervised classification involves on-screen digitizing of polygons on training sites. Google earth synchronized training areas for Landsat TM 2015 data were used to develop signatures for different classes in the region of interest. Buffer creation and extraction (2000 m) both inside and outside the study area. Flow chart of the methodology adopted for the study are shown below (Fig. 2)

Fragmentation analysis using fragstats: A spatial pattern analysis programme for categorical maps developed by Kevin Mcgarigal and Eduard ENE (McGarigal and Marks, 1995). Through this programme, landscapes subjected to analysis are user defined and can represent any spatial phenomenon. FRAGSTATS version 4.2simply quantifies the areal extent and spatial configuration of patches within a

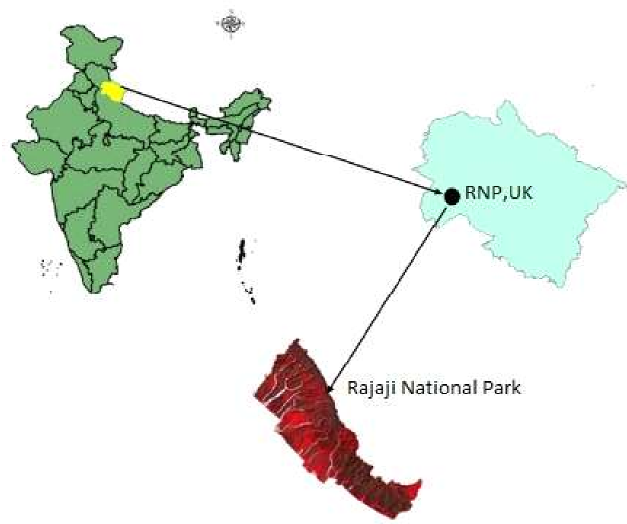

Fig. 1. Study area (30˚3' 29" N, 78˚10' 22" E)

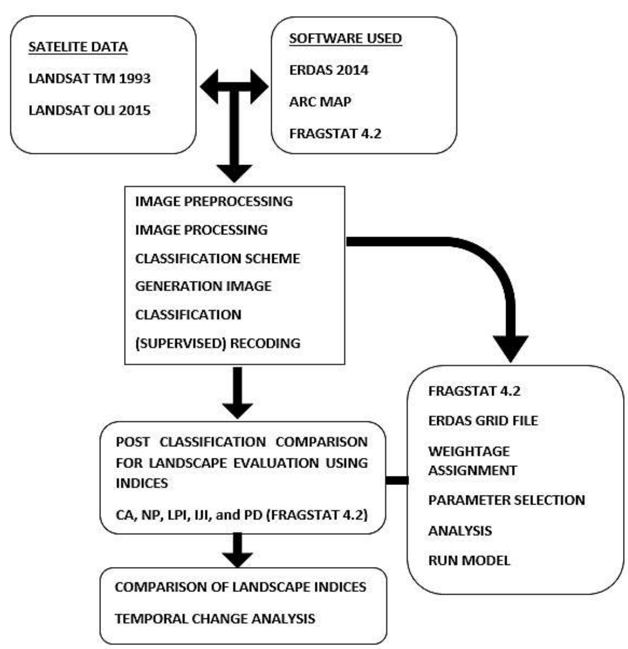

Fig. 2. Flowchart of methodology

landscape; it is incumbent upon the user to establish a sound basis for defining and scaling the landscape, including the extent and grain of the landscape and the scheme upon which patches are classified and delineated. FRAGSTATS computes 3 groups of metrics viz., *patch-level* – nature of patches - average size, size of core area, *class-level* – nature of each type - amount and distribution of each type and *landscape-level* – nature of the landscape - pattern, configuration of entire mosaic, landscape diversity and heterogeneity (Mcgarigal 2015). In this study, landscape evaluation was conducted using indices like CA (Class Area), NP (Number of Patches), PD (Patch Density), LPI (Largest Patch Index) and IJI (Interspersion and Juxtaposition Index) through FRAGSTATS version 4.2 spatial analyst programme.

Indices Used for the Present Study

Total classarea (Hectares): CA equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by 10,000 (to convert to hectares); that is, total class area.

Number of patches (unit-none): NP equals the number of patches of the corresponding patch type (class). Number of patches of a particular patch type is a simple measure of the extent of subdivision or fragmentation of the patch type. Of course, if total landscape area and class area are held constant, then number of patches conveys the same information as patch density or mean patch size and may be a useful index to interpret. Number of patches is probably most valuable, however, as the basis for computing other, more interpretable, metrics. Note that the choice of the 4-neighbor or 8-neighbor rule for delineating patches will have an impact on this metric.

Patch density (Number per 100 hectares): PD equals the number of patches of the corresponding patch type divided by total landscape area (m^2), multiplied by 10,000 and 100 (to convert to 100 hectares). If total landscape area is held constant, then PD and NP convey the same information. Like NP, PD often has limited interpretive value by itself because it conveys no information about the sizes and spatial distribution of patches. Note that the choice of the 4-neighbor or 8-neighbor rule for delineating patches will have an impact on this metric

Largest patch index (percent): LPI equals the area (m^2) of the largest patch of the corresponding patch type divided by total landscape area (m^2), multiplied by 100 (to convert to a percentage); in other words, LPI equals the percentage of the landscape comprised by the largest patch. Total landscape area (A) includes any internal background present. Largest patch index at the class level quantifies the percentage of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance.

Interspersion and juxtaposition index (percent): IJI equals minus the sum of the length (m) of each unique edge type involving the corresponding patch type divided by the total length (m) of edge (m) involving the same type, multiplied by the logarithm of the same quantity, summed over each unique edge type; divided by the logarithm of the number of patch types minus 1; multiplied by 100 (to convert to percentage). Consequently, a landscape containing 4 large patches, each a different patch type and a landscape of the same extent containing 100 small patches of 4 patch types will have the same index value if the patch types are equally interspersed (or adjacent to each other based on the proportion of total edge length in each edge type).

RESULTS AND DISCUSSION

The NP, PD, LPI decreased overtime while IJI got increased, which means interspersion was more and patch adjacency was getting increased. Inside the protected area (2000m buffer) during the study period from 1993 to 2015, there was an increase of 2355 ha in the total class area of forest class type and shown a considerable decrease in agriculture and habitation.

Moreover, there is less disturbance or fragmentation in the innermost area of the National Park. Number of Patches (NP), Patch Density (PD) and Largest Patch Index (LPI) were decreased in 2015 when compared to 1993 imagery studied (Table 1 and Fig. 5). Interspersion and Juxtaposition Index (IJI) was more with respect to forest class type which means,

Table 1. Landscape indices inside protected area (2000 m buffer) during 1993 and 2015

Class types	Total class area (Hectares)		Number of patches		Patch density (Number per 100 hectares)		Largest patch index (Percent)		Interspersion and juxtaposition index	
	1993	2015	1993	2015	1993	2015	1993	2015	1993	2015
Forest	11058.66	13413.67	1796	1278	1.78	1.27	7.69	7.64	39.50	55.94
Agriculture + Habitation	6142.77	3976.31	3549	5186	3.51	5.14	0.90	0.20	42.19	27.09
Dry river bed	898.29	239.02	1127	227	1.12	0.22	0.10	0.04	44.05	0.13
Open scrub	844.02	1182.91	1233	3154	1.22	3.13	0.18	0.20	48.88	17.45
Water	1.44	0	14	0	0.01	0	0	0	18.10	0

interspersion is more, and patch adjacency is getting increased.

Mean while, studied landscape indices outside the protected area viz. NP, PD were increased overtime and LPI decreased overtime; IJI was less which means interspersion was less and patch adjacency was getting decreased, that is more fragmented outside. Here, along with forest class type, agriculture and habitation also show a considerable increase in the total class area (Table 2).

It was quite evident that, there was more disturbance or fragmentation in the outermost buffer area of the National Park. Number of Patches (NP), Patch Density (PD) got increased in recent imagery. Largest Patch Index (LPI) and Interspersion and Juxtaposition Index (IJI) decreased in 2015 when compared to 1993 imagery (Table 2 and Fig. 6). IJI with lower values characterize landscapes in which the patch types are poorly interspersed (i.e., disproportionate distribution of patch type adjacencies).On the contrary, studied landscape indices of innermost protected area viz., NP, PD, LPI decreased overtime; while IJI was more, which means interspersion was more and patch adjacency was getting increased. In the inner most region of the protected area, agriculture and habitation decreased to a great extent and total forest class area increased (Table 3).

There was less disturbance or fragmentation in the innermost area of the National Park. Number of Patches (NP), Patch Density (PD) and Largest Patch Index (LPI) were decreased in 2015 when compared to 1993 imagery. Interspersion and Juxtaposition Index (IJI) was more with respect to forest class type which means, interspersion was more, and patch adjacency was getting increased (Table 3 and Fig. 7). The rate and extent of forest fragmentation both inside and outside of the National Park during the mentioned study period revealed that declaration and merging of Rajaji, Motichur and Chilla Wildlife Sanctuaries into National Park quite evidently helped in reducing fragmentation and augmenting vegetation cover. Increased disturbances caused by anthropogenic activities will increase fragmentation and thus indirectly decrease forest cover of the area (Aditya et al 2018). Outside the National Park clearly indicates a patch type of increased fragmentation. Similar approaches were also been adopted by several authors all over the world (Midha and Mathur 2010, Lamine et al 2018).

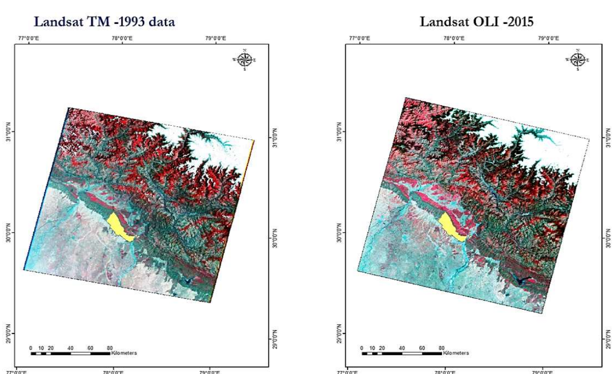

Fig. 3. Acquired Landsat Imageries of study area (Path 146, Row 039)

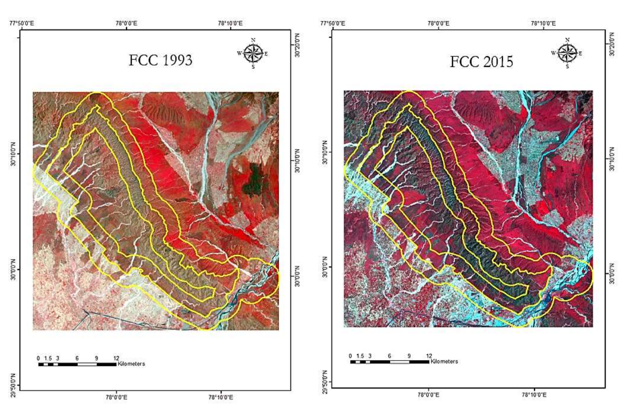

Fig. 4. FCC and image enhancement of study area

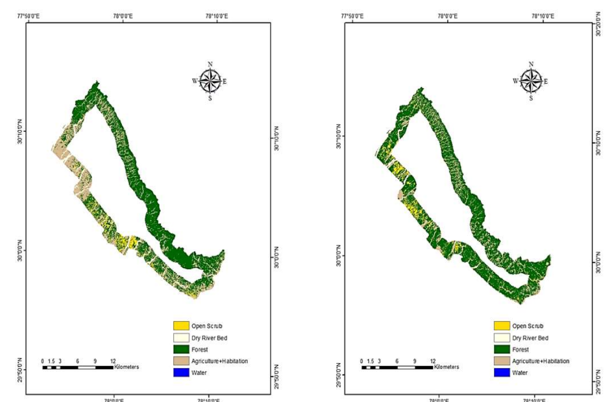

Fig. 5. Comparison of classified buffer area of 2000 m (Inside protected area)

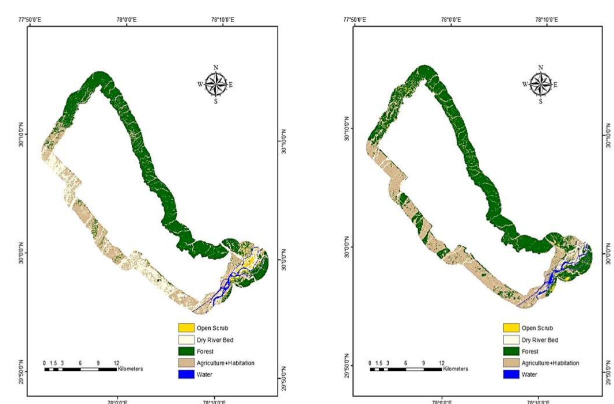

Fig. 6. Comparison of classified buffer area of 2000 m (Outside protected area)

Table 2. Comparison of landscape indices of outside the protected area (2000 m buffer) (1993 and 2015)

Class types	Total class area (Hectares)		Number of patches		Patch density (Number per 100 hectares)		Largest patch index (Percent)		Interspersion and juxtaposition index (Percent)	
	1993	2015	1993	2015	1993	2015	1993	2015	1993	2015
Forest	11460.96	12691.64	1376	1768	0.96	1.23	6.50	5.93	41.88	33.92
Agriculture + habitation	8063.01	10443.06	3004	3639	2.09	2.53	0.97	3.49	71.50	55.72
Dry river bed	4524.39	848.52	1759	915	1.22	0.64	0.93	0.04	31.32	2.83
Open scrub	405.36	320.60	579	1630	0.40	1.13	0.04	0.02	62.60	13.01
Water	441	452.14	34	180	0.02	0.13	0.25	0.27	37.20	12.60

Table 3. Comparison of landscape indices of innermost protected area (excluding 2000 m buffer area) during 1993 and 2015

Class types	Total class area (Hectares)		Number of patches		Patch density (Number per 100 hectares)		Largest patch index (Percent)		Interspersion and juxtaposition index (Percent)	
	1993	2015	1993	2015	1993	2015	1993	2015	1993	2015
Forest	8125.11	10030.43	1544	1124	2.35	1.72	4.54	3.61	31.76	57.40
Agriculture + Habitation	4977.18	2963.07	2646	3854	4.04	5.89	3.07	0.74	35.17	35.91
Dry river bed	754.92	225.9	581	240	0.89	0.37	0.25	0.11	35.17	0
Open scrub	3.24	0	18	0	0.03	0	0	0	49.18	0
Water	433.44	1023.97	806	2496	1.23	3.82	0.29	0.15	41.89	22.57

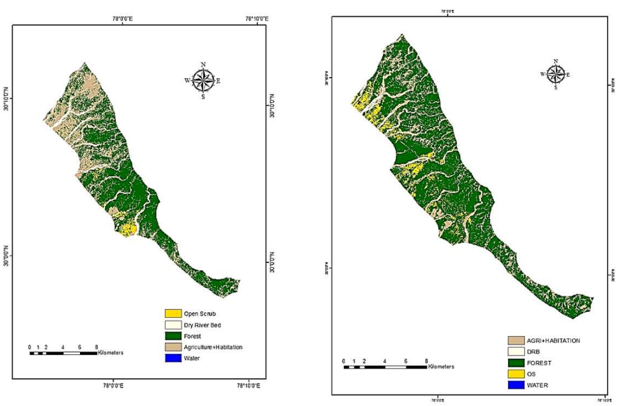

Fig. 7. Comparison of classified innermost protected area (Excluding buffer)

CONCLUSION

Landscape evaluation via bi-temporal image analysis revealed that there was considerable fragmentation in adjacent landscapes outside the protected area in the recent image when compared to historical image. While comparing landscape indices inside protected area (2000 m buffer) and innermost protected area (excluding 2000 m buffer area) during the study period (1993 and 2015). landscape indices such as NP, PD, LPI decreased over time while, IJI got increased with respect to forest patch, which means interspersion was more and patch adjacency got increased during the analyzed period. On the other hand, Comparison of landscape indices outside the protected area (2000 m buffer) during 1993 and 2015 revealed that NP, PD increased overtime while, LPI and IJI decreased over time. Lower values of IJI characterize landscapes in which the patch types are poorly interspersed (i.e., disproportionate distribution of patch type adjacencies) which means the outer side of protected area are more fragmented with respect to the inner boundary. This kind of studies figures out the significance of maintaining protected area network, especially National Parks. More studies in similar lines will surely facilitate better conservation and management of the protected area networks of the country.

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Received 25 November, 2021; Accepted 12 March, 2022

Indian Journal of Ecology (2022) 49(2): 596-602
DOI: https://doi.org/10.55362/IJE/2022/3566

Manuscript Number: 3566
NAAS Rating: 5.79

Documentation on the Floral Diversity of Rajagiri College of Social Sciences Campus, Kalamassery, Kerala

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Abstract: The present study was undertaken to document the diversity of flora in the campus of Rajagiri College of Social Sciences, Kalamassery, Ernakulam district, Kerala. The documentation of floral diversity helps to recognize the overall ecological conditions and gives profound understanding of the economic, medicinal and traditional importance of plant diversity. The campus flora of Rajagiri College of Social Sciences, Kalamassery is not yet documented, and the present paper deals with the floral diversity of the campus. A total of 164 plant species represented by 141 genera belonging to 62 different families were recorded, of which three species were represented by gymnosperms. The Asteraceae, Leguminosae, Arecaceae, Asparagaceae and Euphorbiaceae were dominant families of floristic composition of the study region. Eight threatened plant species are present in the campus namely, *Pterocarpus santalinus* L. f. (Leguminosae), *Swietenia mahagoni* (L.) Jacq. (Meliaceae), *Syzygium malaccense* (L.) Merr. and L. M. Perry (Myrtaceae), *Jacaranda mimosifolia* D. Don (Bignoniaceae), *Santalum album* L. (Santalaceae), *Dypsis lutescens* (H. Wendl.) Beentje and J. Dransf. (Arecaceae), *Dalbergia latifolia* Roxb. (Leguminosae) and *Asparagus racemosus* Willd. (Asparagaceae).

Keywords: Rajagiri College of Social Sciences, Kalamassery, Floral diversity

The Indian biodiversity is very rich with 7% of world's flora and has been included as one of the 12 mega diversity centers. The varied eco-climatic conditions coupled with unique geological and cultural features have contributed to an amazing diversity of habitats, which harbor and sustain immense biological diversity at all levels (Agrawal 2000). Biodiversity reflects total variety and variability within and among the flora and fauna and these studies are ecologically very important in the face of encroachment, habitat loss and extinction rates. The taxonomic study of flora is very crucial to the richness of biodiversity. This goal can be achieved by carrying out floristic studies and it is the main pillar of assessing plant diversity conservation management and sustainable utilization (Jayanthi and Rajendran 2013). The survey of plants in a particular area helps in understanding the overall ecological conditions which can be deciphered by classifying the recorded plants into various biological life forms. Survey of plants and trees in a particular area gives us a profound understanding and appreciation of their medicinal and economic values. It provides the authorities concerned in formulating and implementing various strategies for the sustainable management and conservation of natural resources. Moreover, floristic investigations provide reliable information about the taxonomic classification, distribution, ecology and uses of such plants and trees. Floristic surveys help in explaining the plant biodiversity providing information regarding the current status, new invasion, revision of the flora, ecosystem function and its conservation in a particular geographical area. There are 4,679 taxa of flowering plants in Kerala, belong to 1,360 genera in 212 families (Sasidharan 2004). Various forest, mangrove and campus floral diversity studies were conducted for exploring the whole plant diversity in the particular study area. The vegetation analysis of a particular geological area is conducted by using the quantitative characters of the plants for estimating the importance of various plant species. The information about the ecosystem structure, composition and species diversity helps to improve endemic plant protection and conservation. Documentation of biodiversity is an urgent requirement as the knowledge about the ecosystem structure, composition and diversity of species helps to improve the protection of endemic species also. The objective of the present study is the documentation of the floral diversity of Rajagiri College campus, Kalamassery, Kerala.

MATERIAL AND METHODS

Study area: The present floral study was conducted at the Rajagiri College of Social Sciences Campus and is located at Rajagiri hill, Kalamassery in Ernakulam district, Kerala, at an elevation of 23 m altitude above mean sea level. The area is geographically located at 10°03'11.47” N latitude and 76°18'55.85” E longitude.

Floristic analysis: The study was conducted between the period of 2019-2020. Weekly field observations were made for the collection and identification of different species and details such as habit, botanical name, family and uses were noted according to Bentham and Hooker's classification. Digital photographs of freshly collected plants were also taken. The flowered twigs were collected for identifying the plant species. The voucher Herbarium specimens were prepared following (Bridson and Forman 1998) and deposited at the Bio-tech Research Lab of Biosciences department for future reference. Identification of plants was carried out with the help of available Flora and other standard publications (Sasidharan 2004, Nayar et al 2006). Further, their identification was confirmed by matching with authentic specimens in Kerala Forest Research Institute (KFRI), Peechi and Jawaharlal Nehru Tropical Botanic Garden and Research Institute (JNTBGRI), Thiruvananthapuram.

RESULTS AND DISCUSSION

A large variability can be seen in the floral diversity of various ecosystems like traditional home gardens (Kunhamu et al 2015). The study on structural and floristic diversity of different landscape in Western Ghats of Kodagu region, Karanataka has been carried out (Maheswarappa and Vasudeva 2018). The present study identified 164 species of plants belonging to 141 genera under 62 families excluding the lichens, pteridophytes, bryophytes and mycoflora which were not possible during the present study (Table 1). Of these, 161 species are Angiosperms and 3 species are Gymnosperms. Out of 161 species of Angiosperms, 109 species are dicots, 44 species are monocots and 8 species are Magnoliids. Out of 138 genera of Angiosperms, 94 genera are dicots, 38 genera are monocots and 6 genera are Magnoliids (Table 2). There are 59 families of Angiosperms represented by 42 families of Dicotyledons, 13 families of Monocotyledons and 4 families of Magnoliids. The flora of Rajagiri has 68 species of herbs, 27 species of shrubs, 53 species of trees, 12 species of climbers and one parasite species in the study area (Fig. 1). Among the plant diversity in Rajagiri Hill Campus (RCSS), Araceae family rank first (11 plant species) followed by Asteraceae (10 plant species), Leguminosae (10 plant species), Arecaceae (8 plant species), Asparagaceae (7 plant species), Euphorbiaceae (7 plant species), Apocynaceae (6 plant species) and Moraceae (6 plant species). Other families represent a small share of the total number. There are 87 species of medicinal plants, 90 species of ornamental plants, 13 species of fruit plants and 16 species of wood plants are found in the Campus (Fig. 2 and 3).

There are eight threatened species plants present in the Rajagiri College of Social Sciences campus namely,

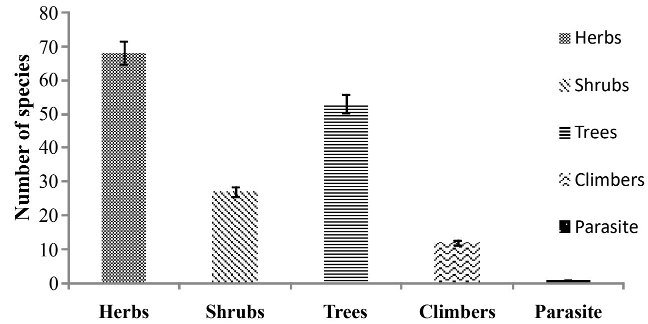

Fig. 1. Distribution of herbs, shrubs, trees, climbers and parasite plants in Rajagiri College of Social Sciences Campus, Kalamassery

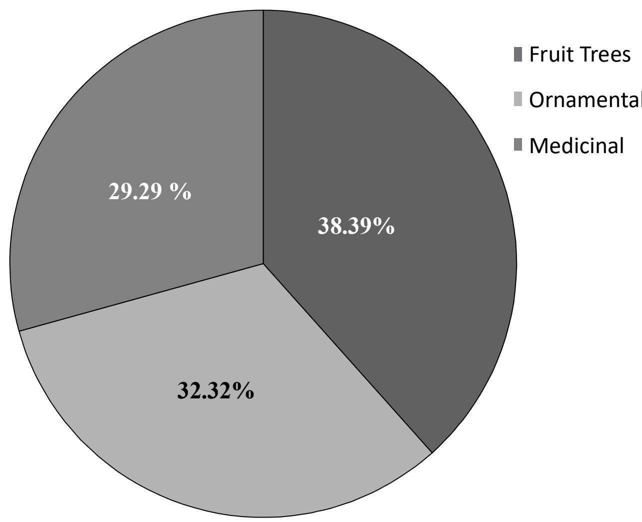

Fig 2. Distribution of trees in Rajagiri College of Social Sciences Campus, Kalamassery

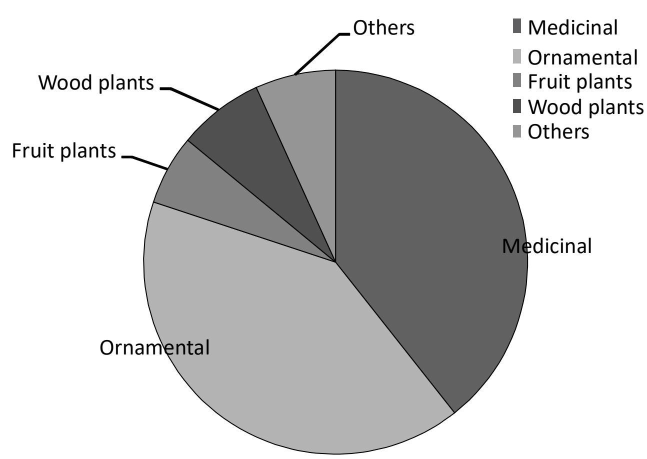

Fig. 3. Economic importance of the plant diversity at Rajagiri College of Social Sciences Campus, Kalamassery

Table 1. Plant species in the Rajagiri College of Social Sciences campus, Kalamassery

Botanical name	Family	Common name	Use
Amherstia nobilis Wall.	Leguminosae	Pride of Burma	Ornamental
Alstonia scholaris (L.) R. Br.	Apocynaceae	White Cheesewood, Devil Tree	Wood
Mangifera indica L.	Anacardiaceae	Mango Tree	Fruit Tree
Nyctanthes arbor-tristis L.	Oleaceae	Night Flowering Jasmine	Ornamental
Psidium guajava L.	Myrtaceae	The Common Guava	Fruit Tree
Syzygium malaccense (L.) Merr. & L. M. Perry	Myrtaceae	Malay Apple	Fruit Tree
Pterocarpus santalinus L. f.	Leguminosae	Red Sandalwood	Wood
Butea monosperma (Lam.) Taub	Leguminosae	Flame-of-the-Forest	Timber and Medicinal plant
Cananga odorata (Lam.) Hook. f. & Thomson	Annonaceae	Ylang-ylang	Aromatic oil from flowers
Syzygium cumini (L.) Skeels	Myrtaceae	Malabar Plum	Fruit plant, Medicinal
Artocarpus heterophyllus Lam.	Moraceae	Jack Tree	Fruit Tree
Cocos nucifera (L.)	Arecaceae	Coconut Tree	Fruit plant, all parts useful
Cyrtostachys renda Blume	Arecaceae	Lipstick Palm	Ornamental
Wodyetia bifurcata A. K. Irvine	Arecaceae	Foxtail Palm	Ornamental
Tabernaemontana alternifolia L.	Apocynaceae	Nag Kuda	Medicinal
Artocarpus hirsutus Lam.	Moraceae	Wild Jack	Fruit Tree
Macaranga peltata (Roxb.) Mull. Arg.	Euphorbiaceae	Chandada	Wood
Simarouba glauca DC.	Simaroubaceae	Paradise Tree	Medicinal Plant
Jacaranda mimosifolia D. Don	Bignoniaceae	Blue Jacaranda	Ornamental
Bougainvillea glabra Choisy	Nyctaginaceae	Paper Flower	Ornamental
Lannea coromandelica (Houtt.) Merr.	Anacardiaceae	Indian Ash Tree	Used in Plywood
Hibiscus rosa-sinensis L.	Malvaceae	China Rose	Ornamental, Medicinal
Moringa oleifera Lam.	Moringaceae	Drumstick Tree	Vegetable, Medicinal
Phyllanthus emblica L.	Phyllanthaceae	Indian Gooseberry	Fruit Tree, Medicinal
Murraya koenigii (L.) Spreng.	Rutaceae	Curry Leaf Tree	Leaves, Medicinal
Polyalthia longifolia (Sonn.) Thwaites	Annonaceae	False Ashoka	Shade tree, Medicinal
Ailanthus excelsa Roxb.	Simaroubaceae	Tree of Heaven	Softwood
Areca catechu L.	Arecaceae	Areca Nut Palm	Areca nut
Hamelia patens Jacq.	Rubiaceae	Fire Bush	Ornamental, Medicinal
Ficus elastica Roxb. ex Hornem.	Moraceae	Rubber Fig	Ornamental
Phyllanthus acidus (L.) Skeels	Phyllanthaceae	Malay Gooseberry, Star Gooseberry	Berries fruit plant
Terminalia catappa L.	Combretaceae	Indian Almond	Ornamental, Fruit Tree
Azadirachta indica A. Juss.	Meliaceae	Neem Tree	Medicinal
Magnolia champaca (L.) Baill. ex Pierre	Magnoliaceae	Champak	Fragrant flowers and timber
Bauhinia variegata L.	Leguminosae	Orchid Tree, Mountain Ebony	Ornamental
Santalum album L.	Santalaceae	East Indian sandalwood	Sandalwood and oil
Plumeria alba L.	Apocynaceae	Pagoda Tree, White Frangipani	Ornamental
Caesalpinia coriaria (Jacq.) Willd.	Leguminosae	Divi-divi	Ornamental
Brunfelsia pauciflora (Cham. & Schltdl.) Benth.	Solanaceae	Yesterday-today-and-tomorrow	Ornamental
Citrus limon (L.) Osbeck	Rutaceae	Lemon tree	Fruit Tree
Pimenta dioica (L.) Merr.	Myrtaceae	Allspice	Spice
Xylia xylocarpa (Roxb.) Taub.	Leguminosae	Burma Ironwood	Ornamental, Medicinal
Swietenia mahagoni (L.) Jacq.	Meliaceae	Mahogany	Timber
Dalbergia latifolia Roxb.	Leguminosae	Indian Rosewood	Timber
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	Combretaceae	Arjuna Tree	Medicinal, Timber
Litsea coriacea Hook. f.	Lauraceae	Leather-Leaf Litsea	Medicinal, Timber
Terminalia bellirica (Gaertn.) Roxb.	Combretaceae	Belliric Myrobalan	Medicinal, Timber

Cont...

Table 1. Plant species in the Rajagiri College of Social Sciences campus, Kalamassery

Botanical name	Family	Common name	Use
Tectona grandis L. f.	Lamiaceae	Teak	Hard Wood Tree
Roystonea regia (Kunth) O. F. Cook	Arecaceae	Cuban Royal Palm	Ornamental
Bixa orellana L.	Bixaceae	Achiote	Medicinal, Condiment
Sterculia foetida L.	Malvaceae	Java Olive Tree	Ornamental, Soft Wood
Guazuma ulmifolia Lam.	Malvaceae	West Indian Elm	Medicinal
Terminalia paniculata Roth	Combretaceae	Kindal Tree	Medicinal, Wood
Cleome rutidosperma DC.	Cleomaceae	Fringed Spider Flower	Medicinal
Euphorbia hirta L.	Euphorbiaceae	Common Spurge	Medicinal
Ficus pumila L.	Moraceae	Creeping Fig	Medicinal
Celosia argentea L.	Amaranthaceae	Plumed Cockscomb	Ornamental, Medicinal
Phoenix roebelenii O'Brien	Arecaceae	Pygmy Date Palm	Ornamental
Pseuderanthemum carruthersii (Seem.) Guillaumin	Acanthaceae	Carruthers' False face	Ornamental
Oldenlandia corymbosa L.	Rubiaceae	Diamond Flower Plant	Medicinal
Synedrella nodiflora (L.) Gaertn.	Compositae	Synedrella	Medicinal, Leaf Food
Phaius tankervilleae (Banks ex L'Hér.) Blume	Orchidaceae	Greater Swamp Orchid	Ornamental
Costus woodsonii Maas	Costaceae	Red Button Ginger	Medicinal, Ornamental
Cordyline fruticosa (L.) A. Chev.	Asparagaceae	Ti Plant	Medicinal, Ornamental
Pilea nummulariifolia (Sw.) Wedd.	Urticaceae	Creeping Charlie	Ornamental
Polyscias balfouriana (André) L. H. Bailey	Araliaceae	Balfour Aralia	Ornamental
Acalypha indica L.	Euphorbiaceae	Indian Acalypha	Medicinal
Aglaonema costatum N. E. Br.	Araceae	Spotted Evergreen	Ornamental
Dracaena reflexa Lam.	Asparagaceae	Song of Jamaica	Ornamental
Dendrophthoe falcata (L. f.) Ettingsh.	Loranthaceae	Honey Suckle Mistletoe	Parasite, Medicinal
Gomphrena globosa L.	Amaranthaceae	Globe Amaranth	Ornamental
Crotalaria retusa L.	Leguminosae	Rattle Weed Plant	Ornamental
Hemigraphis colorata (Blume) Hallier f.	Acanthaceae	Red Flame Ivy	Medicinal, Ornamental
Mimosa pudica L.	Leguminosae	Touch-me-not	Medicinal
Ocimum tenuiflorum L.	Lamiaceae	Holy Basil	Medicinal
Ixora coccinea L.	Rubiaceae	Jungle Geranium	Medicinal, Ornamental
Amaranthus viridis L.	Amaranthaceae	Slender Amaranth	Edible, Medicinal
Curcuma longa L.	Zingiberaceae	Turmeric	Edible, Medicinal
Catharanthus roseus (L.) G. Don	Apocynaceae	Madagascar Periwinkle	Medicinal, Ornamental
Aloe vera (L.) Burm. f.	Asphodelaceae	Aloe Vera	Medicinal, Ornamental
Chlorophytum comosum (Thunb.) Jacques	Asparagaceae	Spider Plant	Ornamental
Spathiphyllum wallisii Regel	Araceae	Peace Lily	Ornamental
Cyanthillium cinereum (L.) H. Rob.	Compositae	Little Ironweed	Medicinal
Peperomia pellucida (L.) Kunth	Piperaceae	Pepper Elder	Medicinal
Cyanotis cristata (L.) D. Don	Commelinaceae	Crested Dew Grass	Medicinal
Kyllinga nemoralis (J. R. Forst. & G. Forst.) Dandy ex Hutch. and Dalziel	Cyperaceae	White Water Sedge	Medicinal
Holmskioldia sanguinea Retz.	Lamiaceae	Cup-and-saucer-plant	Ornamental
Begonia malabarica Lam.	Begoniaceae	Malabar Begonia	Ornamental, Medicinal
Ageratum conyzoides (L.)L.	Compositae	Billy Goat Weed	Medicinal
Commelina diffusa Burm. f.	Commelinaceae	Climbing Dayflower	Medicinal

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Table 1. Plant species in the Rajagiri College of Social Sciences campus, Kalamassery

Botanical name	Family	Common name	Use
Sansevieria trifasciata Prain	Asparagaceae	Snake Plant	Ornamental
Antigonon leptopus Hook. And Arn.	Polygonaceae	Coral Vine	Ornamental, Medicinal
Hymenocallis littoralis (Jacq.) Salisb.	Amaryllidaceae	Beach Spider Lily	Ornamental, Medicinal
Chrysothemis pulchella (Donn ex Sims) Decne.	Gesneriaceae	Sunset Bells	Ornamental
Brachiaria reptans (L.) C. A. Gardner & C. E. Hubb.	Poaceae	Creeping Panic Grass	Medicinal, Fodder
Brachiaria ramosa (L.) Stapf	Poaceae	Brown Top Millet	Fodder
Brachiaria deflexa (Schumach.) C. E. Hubb. ex Robyns	Poaceae	Annual Brachiaria	Fodder
Chlorophytum laxum R. Br.	Asparagaceae	Bichetii Grass	Ornamental
Torenia fournieri Linden ex E. Fourn.	Linderniaceae	Wishbone Flower	Ornamental
Dypsis lutescens (H. Wendl.) Beentje & J. Dransf.	Arecaceae	Yellow Palm	Ornamental
Ruellia prostrata Poir.	Acanthaceae	Bell Weed	Medicinal, Natural dye
Urtica parviflora Roxb.	Urticaceae	Stinging Nettle	Medicinal
Tibouchina urvilleana (DC.) Cogn.	Melastomataceae	Princess Flower	Ornamental
Oxalis corniculata L.	Oxalidaceae	Creeping Wood Sorrel	Medicinal
Tridax procumbens (L.) L.	Compositae	Tridax Daisy	Medicinal, Weed
Allamanda cathartica L.	Apocynaceae	Golden Trumpet	Ornamental, Medicinal
Aerva lanata (L.) Juss.	Amaranthaceae	Mountain Knotgrass	Medicinal
Asparagus racemosus Willd.	Asparagaceae	Satavar	Medicinal
Abelmoschus moschatus medik.	Malvaceae	Musk Mallow	Ornamental, Medicinal
Piper nigrum L.	Piperaceae	Pepper	Spice, Medicinal
Piper longum L.	Piperaceae	Long Pepper	Medicinal
Piper betle L.	Piperaceae	Betel	Medicinal
Plectranthus amboinicus (Lour.) Spreng.	Lamiaceae	Mexican Mint	Medicinal
Phyllanthus niruri L.	Phyllanthaceae	Gale of the Wind	Medicinal
Euphorbia heterophylla L.	Euphorbiaceae	Wild Poinsettia	Medicinal
Spathiphyllum cannifolium (Dryand. ex Sims) Schott	Araceae	Spathe Flower	Ornamental
Cyclea peltata (Lam.) Hook. f. & Thomson	Menispermaceae	Indian Moon-Seed	Medicinal
Clerodendrum speciosum Dombrain	Lamiaceae	Bleeding Heart Vine	Ornamental
Anthurium andraeanum Linden ex André	Araceae	Painter's Palette	Ornamental
Biophytum sensitivum (L.) DC.	Oxalidaceae	Little Tree Plant	Medicinal
Talinum triangulare (Jacq.) Willd.	Talinaceae	Ceylon Spinach	Leaf vegetable
Euphorbia milii Des Moul.	Euphorbiaceae	Crown of Thorns	Ornamental, Medicinal
Lantana camara L.	Verbenaceae	Wild Sage	Ornamental, Medicinal
Epipremnum aureum (Linden and André) . G. S. Bunting	Araceae	Money Plant	Ornamental
Cissus quadrangularis L.	Vitaceae	Veldt Grape	Medicinal
Portulaca grandiflora Hook.	Portulacaceae	Rose Moss	Ornamental
Vanda testacea (Lindl.) Rchb. f.	Orchidaceae	Small Flowered Vanda	Medicinal
Ficus religiosa L.	Moraceae	Sacred Fig, Peepal	Medicinal, Wood
Codiaeum variegatum (L.) Rumph. ex A. Juss.	Euphorbiaceae	Variegated Croton	Ornamental
Hippeastrum vittatum (L'Hér.) Herb.	Amaryllidaceae	Barbados Lily	Ornamental
Heliconia psittacorum L. f.	Heliconiaceae	Parakeet Flower	Ornamental

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Table 1. Plant species in the Rajagiri College of Social Sciences campus, Kalamassery

Botanical name	Family	Common name	Use
Phyllanthus urinaria L.	Phyllanthaceae	Chamber Bitter	Medicinal
Schefflera arboricola (Hayata) Merr.	Araliaceae	Dwarf Umbrella Tree	Ornamental
Philodendron bipinnatifidum Schott ex Endl.	Araceae	Lacy Tree Philodendron	Ornamental
Centrosema pubescens Benth.	Leguminosae	Butterfly Pea	Forage, Green manure
Pothos scandens L.	Araceae	Climbing Aroid	Medicinal
Dieffenbachia exotica hort.	Araceae	Spotted Dumbcane	Ornamental
Ruellia simplex C. Wright	Acanthaceae	Mexican Bluebell	Ornamental
Rhapis excelsa (Thunb.) Henry	Arecaceae	Broadleaf Lady Palm	Ornamental
Homalomena rubescens (Roxb.) Kunth	Araceae	Homalomena Maggy	Ornamental
Ficus benjamina L.	Moraceae	Weeping Fig	Ornamental
Dracaena surculosa Lindl.	Asparagaceae	Dracaena Gold Dust	Ornamental
Tacca chantrieri André	Dioscoreaceae	Bat Flower	Ornamental
Excoecaria cochinchinensis Lour.	Euphorbiaceae	Chinese Croton	Ornamental
Tradescantia spathacea Sw.	Commelinaceae	Moses-in-the-cradle	Ornamental, Medicinal
Zinnia elegans Jacq.	Compositae	Common Zinnia	Ornamental
Mirabilis jalapa L.	Nyctaginaceae	Four O'clock Plant	Ornamental, Medicinal
Cosmos sulphureus Cav.	Compositae	Yellow Cosmos	Ornamental
Gerbera jamesonii Bolus ex Hook. f.	Compositae	Barberton Daisy	Ornamental
Impatiens balsamina L.	Balsaminaceae	Balsam	Ornamental
Turnera ulmifolia L.	Passifloraceae	Yellow Alder	Medicinal
Rudbeckia laciniata L.	Compositae	Cut Leaf Coneflower	Ornamental
Caladium lindenii (André) Madison	Araceae	Angel's Wing	Ornamental
Andrographis paniculata (Burm. f.) Nees	Acanthaceae	Green Chireta	Medicinal
Chromolaena odorata (L.) R. M. King and H. Rob.	Compositae	Siam Weed	Medicinal
Caladium bicolor (Aiton) Vent.	Araceae	Angel Wings	Ornamental
Cynodon dactylon (L.) Pers.	Poaceae	Bermuda Grass	Medicinal
Cyperus rotundus L.	Cyperaceae	Nut grass	Medicinal
Emilia sonchifolia (L.) DC. ex DC.	Compositae	Lilac Tassel Flower	Medicinal
Tabernaemontana divaricata (L.) R. Br. ex Roem. And Schult.	Apocynaceae	Crape Jasmine	Medicinal, Ornamental
Opuntia ficus-indica (L.) Mill.	Cactaceae	Prickly Pear	Ornamental
Cycas revoluta Thunb.	Cycadaceae	Sago Palm	Medicinal, Ornamental
Araucaria heterophylla (Salisb.) Franco	Araucariaceae	Andes Pine	Ornamental
Thuja occidentalis L.	Cupressaceae	Northern White Cedar	Medicinal, Ornamental

Table 2. Flora of Rajagiri College of Social Sciences campus, Kalamassery

Clade	Family	Genera	Species
Dicots	42	94	109
Monocots	13	38	44
Magnoliids	4	6	8
Gymnosperms	3	3	3
Total	62	141	164

1. *Syzygium malaccense* (L.) Merr. and L. M. Perry (Family: Myrtaceae): Rare
2. *Pterocarpus santalinus* L. f. (Family: Leguminosae): Near Threatened
3. *Jacaranda mimosifolia* D. Don (Family: Bignoniaceae): Vulnerable
4. *Santalum album* L. (Family: Santalaceae): Vulnerable
5. *Swietenia mahagoni* (L.) Jacq. (Family: Meliaceae): Endangered

6. *Dalbergia latifolia* Roxb. (Family: Leguminosae): Vulnerable
7. *Dypsis lutescens* (H. Wendl.) Beentje & J. Dransf. I. (Family: Arecaceae): Near Threatened
8. *Asparagus racemosus* Willd. (Family: Asparagaceae): Endangered

The rapid destruction of wild stock of medicinal plants is mainly due to the premature and non-scientific exploitation. These activities threaten next season's propagation and regeneration of the plant species Chaudhuri 2007.

CONCLUSION

Rajagiri College Campus consists of highly diversified flora and it is rich in the plants of economic importance. It is necessary to know the importance of the plant diversity so that the multiplication and conservation of such plants become quite imperative, especially in the context of plants which are on the verge of extinction. The documentation of campus floral diversity is very important as it is vital that native and endemic species of plants are conserved. Lack of awareness among the new generation about various plant and tree species in their surroundings which have commercial, medicinal and ritual importance is one of the problems constraining the conservation efforts of the authorities concerned. The scientific documentation and publication of the floral diversity of the campus will give an insight to the student community need for conservation and sustainable utilization of plant species.

Received 02 December, 2021; Accepted 21 February, 2022

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Indian Journal of Ecology (2022) 49(2): 603-607
DOI: https://doi.org/10.55362/IJE/2022/3567

Manuscript Number: 3567
NAAS Rating: 5.79

Identification and Mapping of Land Degradation through Remote Sensing in Budgam District of Jammu and Kashmir, India

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Abstract: The present study is to assess the land degradation in the Budgam district of Jammu and Kashmir with the use of multi temporal satellite images of Sentinel II data of three seasons of the year 2018 with the spatial resolution of 10 metres within the third, fourth, and the Eighth bands in conjunction with the ground-truthing of the study area. The evaluation was done with the utilization of visual interpretation keys like tone, texture, etc in Arc GIS 10.2 Software. Based on the severity of the land degradation the study area was mapped into categories of anthropogenic (mining), barren rocky/ stony waste, water erosion gullies and water erosion ravines. Out of 1371 square kilometres of the study area, approximately 129.20 square kilometres are degraded, out of which 118.84 square kilometres were categorized into the barren rocky stony waste class, which is due to the undulating topography (Kandi) of the realm. The decrease in the vegetation cover and also the transformation of the agricultural land into horticulture and other commercial activities is the reason for the land degradation. This paper will function as an input to the planners, district system for monitoring and management of the severity of land degradation within the area.

Keywords: Land degradation, Identification, Mapping, Budgam, Brick kilns, Visual interpretation

One of the most serious universal ecological issues that threaten the world food security, resulting in adverse effect on agricultural yield is land degradation. Principal processes of land degradation include erosion by water and wind, chemical deterioration (comprising acidification, salinization, etc), physical deterioration (comprising crusting, compaction, hard-setting etc.) and biological deterioration (reduction in total biomass carbon, and decline in land bio-diversity) . Soil erosion and biodiversity loss being the main causes of land degradation in the less populated areas, while water shortage, soil depletion and soil pollution are most typical within the most agricultural areas (Nachtergaele et al 2011). Almost 250 million people are directly affected by land degradation (UNCCI), and may be a reason of decline in the quality and quantity of freshwater supplies, soil productivity which ends up in greater food insecurities, increase in poverty and greater social costs (Aggarwal et al 2013). Land degradation being the foremost common and grave environmental issue within the world, it has affected two billion hectares (22.5%) of the world's agricultural land, grasslands, forest and woodland (Al Dousari et al 2000). Livelihood of more than 900 million people in almost 100 countries is directly and adversely affected by land degradation. Climate is one of the causes of desertification in China, but anthropogenic causes are dominant (FAO 2005). The countries in the developing world, especially, those in the arid and semi-arid regions, are much affected. Agriculture is one of the foremost environment modifying factors.While soil deterioration may be a major aspect of land degradation, processes like deforestation and lowering of the water level is also a part of land degradation (Zalidis et al 2002).

Resourcesat-1(P6) LISS was visually interpreted and therefore the area was divided into the categories of un-degraded, moderately degraded, degraded etc (Krishna et al 2008). Tagore et al 2012 delineated the Rajgarh district of Madhya Pradesh into the categories of barren rocky/ stony waste, water erosion gullies, sheet erosion categories of degraded lands by the visual interpretation of FCC of LISS III data of 23 meters resolution.Therefore the aim of this is to identify and map different categories of land degradation in Budgam District of Jammu and Kashmir using remote sensing data and to evaluate it.

MATERIAL AND METHODS

Study area : Budgam the territorial dominion of Jammu and Kashmir located within the Central part of Kashmir and covers an area of 1371 km sq. between 33° 48' 43"North to 34° 08' 43″North and 74° 31' 51″ East to 74° 55' 03'East with altitude of 1610 meters (Fig. 1). It is bound by district Baramulla in North-West and Srinagar in the North-East and South-West and Pulwama Poonch and Shopian bound this area in the South. The realm consists of the lofty Pir Panjal and flat topped Karewas which are locally known as Wudars. Karewas are the lacustrine deposits of the Pleistocene

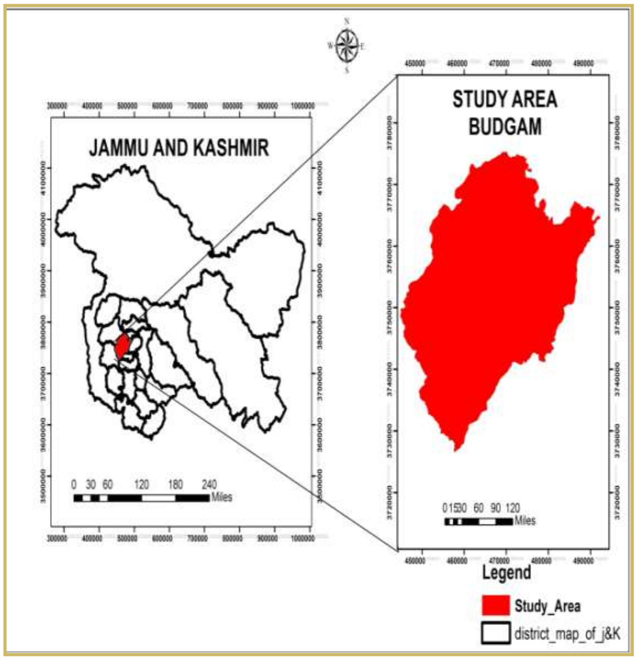

Fig. 1. Study area map

Period. Blue, grey and buff clays and silt, partly compacted conglomerates and sandstones, pebble beds and embedded moraines are some of the different kinds of lithology types.The soils within the area are generally of three types, viz., loamy soil, karewa soil and poorly developed mountain. Climate of the study area is temperate type with warm summers and cold winters.

Geo Spatial techniques were used for the assessment of land degradation within the study area. The satellite imageries employed in this study are from the United States Geological Survey (USGS) earth explorer (https://earthexplorer.usgs.gov).The initial knowledge about the study space was obtained from the false colour composite of the Sentinel II images. The spatial resolution of the image is 10 metres in band third, fourth and band eighth (RGB). The imageries of three season's viz. Kharif, Rabi and Zaid in conjunction with ground truthing was used. Since the multi temporal satellite images were used, because most of the hilly terrain is enveloped by the snow for almost two seasons which then becomes visible almost during the kharif season and therefore the images of multi seasons were being employed for mapping.The bands were layer stacked and the area of interest (AOI) was extracted from it and also various geometrical corrections were done in the images through the use of ERDAS IMAGINE software. Deductive logic approach was followed to delineate various land degradation categories in which, the areas where there is no scope for land degradation was delineated first. Subsequently, the land degradation units that are quite evident are delineated followed by areas which required more logical analysis.

Various geometrical corrections were done by the utilization of ERDAS IMAGINE software. Spatial filters like high pass filters for gullies and ravines were used. Image pre-processing is extremely important to determine a more direct association between the acquired data and biophysical phenomena. The method of visually interpreting digitally enhanced imagery attempts to optimize the congratulatory capabilities .Visual mode of interpretation (Domlija et al 2019) techniques through the use of interpretation keys like texture, tone, hue, aspect, association and aspect (Sahu 2007) through the utilization of ARC 10.2 followed by ground verification has been employed for mapping degraded lands.

Image interpretation keys (tone, size, shape, texture) were used to identify the degree and harshness of land degradation (Table 2). The interpretation was then supported by ground truthing. During the ground truthing a similarity amid the image elements and identified land degradation classes was tried to be established during the interpretation.

Assessment of classification accuracy was carried out to determine the quality of information derived from the data. A stratified random method of accuracy assessment was used to represent different Land degradation classes in the area. The accuracy assessment was carried out based on ground truth data and visual interpretation. The overall accuracy is 83.52 (Table 3). The comparison of reference data and classification results was carried out statistically using error matrices. Besides, a nonparametric kappa test was also performed to measure the extent of classification accuracy. The Kappa Statistics for the agreement are 0.78. However, a decline in accuracy could be due to difference between the ground survey and that of the resolution of remote sensing data.

RESULT AND DISCUSSION

The total area of the study space is 1371 square kilometres. Of the total study space, 129.20 square kilometres are degraded. Of this, barren rocky/stony waste cover 118.84 square kilometres (7.76%), anthropogenic activities (mining) cover 7.17 square kilometres (0.52%), water erosion gullies account for 0.24 square kilometres (0.01%) and water erosion ravines account for 2.95 square kilometres (0.13%) (Table 2). The entire degraded areas identified and mapped (Fig. 2).

Barren rocky/stony waste: This appears as light brownish or light maroons in color. They occur as discrete or continuous patches altogether, the three season data. These are mostly found in hilly areas or within the areas of rough terrain. The entire area of degraded land falling under the category of barren rocky /stony waste is 118.84 square

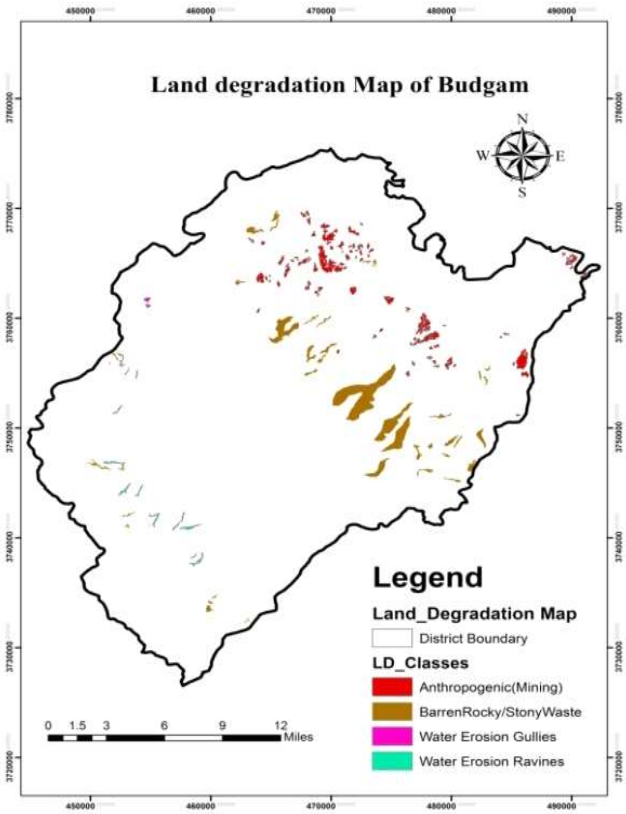

Fig. 2. Land degradation map

kilometers which is 8.66% of the entire geographical area of the district.

Anthropogenic activities (Mining): it includes stone query, surface rocks, excavations, sand and gravel pits, and excavating soil for brick kilns etc. It appears as light yellow with rectangular light bluish patches. It is clearly visible altogether season data. The anthropogenic activity mainly included in this area is excavating the soil for brick kilns. The area falling under this category is 7.17 square kilometers which is 0.52% of the entire area of the study area.

Water erosion ravines: Ravines are most intense style of erosion with complex style of networks formed by gullies with greater drainage density. Their steepness decreases because the distance increases from the system, and therefore the image texture becomes smooth. The entire area under ravines is 2.95 square kilometers which accounts

Table 2. Degraded land categories of study area

Land degradation class	Area (sq.km)	Percentage
Anthropogenic (mining)	7.17	0.52
Barren Rocky/Stony Waste	118.84	8.66
Water Erosion Gullies	0.24	0.01
Water Erosion Ravines	2.95	0.21
Total	129.20	9.4

Table 1. Visual interpretation keys for mapping of land degradation

Process	Colour	Shape	Texture	Pattern	Size	Shape	Association
Water Erosion	Slightly brighter grey to dark grey than surrounding land	Irregular	Smooth medium to course	Contiguous / Discrete Patches to Contiguous Patches	Small to Large	Irregular	Slopping cultivated land with poor vegetation in rainy season
Gullies	Brighter than surrounding land/grey in colour depending on soil colour	Irregular	Medium to slightly course	Discrete to contiguous patches	Small to medium	Irregular	First order streams
Wind Erosion	Light Grey/yellow to Pink mottles	Irregular/Regular	Smooth medium to course	Contiguous / Discrete Patches to Contiguous Patches	Large to very Large	Irregular/Regular	
Water logging	Light blue to very dark blue	Irregular/Regular	Smooth	Discrete patches	Small to large	Irregular	Depressions in inlands/ coastal plains.
Salinization/alkalization	Light grey to white	Irregular	Smooth	Discrete patches	Small to medium	Irregular	Coastal plains young alluvial plains/ stream courses/ irrigated canal commands
Acidification	Various shades of green black	Irregular	Smooth-Medium	Discrete patches	Small to large	irregular	Lateritic high rainfall region, cultivated peats/ marshes.
Anthropogenic(industrial effluent , mining, brick kilns)	Shades of white , red , black and yellow	Irregular/Regular	Smooth-Medium	Discrete	Small to medium	Irregular	Hilly/ plain areas
Barren Rocky/ Stony Waste	Light to medium; grey / yellowish white	Irregular	Smooth	Discrete/Contiguous	Small to medium	Irregular	Hilly/ plain / pediment areas.

Table 3. Error matrix of land degradation

Class name	Error Matrix of land degradation				
	Reference total	Classified totals	Number correct	Users accuracy	Producers accuracy
Anthropogenic (Mining)	23	22	19	86.36	82.6
Barren Rocky/Stony Waste	21	22	18	81.81	85.71
Water Erosion (Ravines)	21	22	18	81.81	85.71
Water Erosion (Gullies)	19	19	16	84.21	84.21
Total	84	85	71	Overall classification accuracy 83.52%	
				Overall Kappa coefficient 0.78	

for 0.21% of the entire geographic area of the study area.

Water erosion gullies: These are mostly on sloping areas. It appears lighter than the encompassing areas with fine texture. The entire area under gully erosion is 0.24 square kilometers which accounts for 0.01% of the entire geographical area of the study dominion.

Different factors were responsible for LD within the area. The population of the area increased from 6, 29,309 lakhs (Anonymous, 2001) to 7, 53,745 lakh (Anonymous 2011) with a rise of 1, 24,436 lakh persons during ten years. Most of the population being agriculture dependent clear the forests for agriculture purposes due to which land becomes devoid of vegetation and becomes susceptible to degradation. The agricultural land within the area is transformed for the most anthropogenic activity that is excavating soil for brick kilns. The DEM of the study area reveals that the area is sloped (1530-4621 DEM ranges) thus the upper reaches being highly sloped are empty of vegetation which ends up in barren rocky /stony waste style of degradation. The soils of the Karewa foot slopes and foot slopes of hills being terraced and bounded with fine texture and are to some extent erosive in nature. Gully erosion is mainly seen in steep river flow, when there are heavy rains; the surface runoff along the river washes away the debris thus affecting growth of vegetation. They are mostly common on sloping surface. Gully erosion prompts loss of topsoil which has major physical and economic presumptions (Pani et al 2011). The implications of gully erosion are not only loss of agricultural land; in several places it has also resulted in the involuntary shifting of villages (Pani et al 2001).

CONCLUSION

This study describes the procedure of identification and mapping of various categories of land degradation like, anthropogenic activities, barren rocky/ stony waste, water erosion gullies and water erosion ravines land degradation phenomena, using the visual interpretation of Sentinel II data of 10 meters resolution in third fourth and eighth band (RGB) imagery from USGS Website. The execution of this system has proven useful in determining the spatial extent of assorted categories of degraded lands within the area. The degraded area is 9.4 % of the entire study area. Within the hilly terrain the most degradation is mainly the barren rocky/ stony waste which is due to the undulating terrain of the high slopes, and account for the great degree of severity. Within the settlement area the debasement is mainly due to anthropogenic activities including excavation of soil for brick kilns. The degradation categories like gullies and ravines also can't be neglected. This work may be used as a plan to spot and prioritize potential areas for reclamation and will serve as a tool for analysis of environmental sensitivity at regional scale and the identification of hotspots of land degradation. The present study would help to identify areas vulnerable to land degradation. This would also help in achieving better results with limited investment and avoid wastage of natural resources.

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Received 21 November, 2021; Accepted 22 February, 2022

Indian Journal of Ecology (2022) 49(2): 608-615
DOI: https://doi.org/10.55362/IJE/2022/3568

Manuscript Number: 3568
NAAS Rating: 5.79

Biodiversity and Ecosystem Services of Trees Outside Forests: A Case Study from Dr. Harisingh Gour Vishwavidyalaya, Sagar, Central India

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Abstract: Alike forests, trees outside forest play a critical role in providing ecosystem services as well as biodiversity conservation. They include all those trees which has attained 10 cm or more diameters at breast height (DBH), available on land which is not notified as forest or other wooded land. Trees outside forest especially roadside trees have attracted little attention for their role in providing ecosystem services and biodiversity conservation due to their discontinuous occurrence and lack of documentation. The present study was conducted in Dr. Harisingh Gour University campus to document floristic diversity and their potential contribution towards ecosystem services. All the trees and shrubs having 10 cm or more DBH present along roads were documented and categorized for nativity, uses and ecosystem services. A total of 1252 individuals belonging to 85 species, 73 genera and 38 families were recorded. The habitat inhabits *Santalum album*, a vulnerable species and *Cordia macleodii* an endangered species escaped from natural and semi-natural forests indicating suitable habitat for them. The documented species were dominated by native flora (65 sp.) and 20 non-native species. Most of the species were food providing, ethno-medicinal, fodder, fuel wood and timber species. Further, 34 species including 4 religious species (*Aegle marmelos*, *Ficus religiosa*, *Phyllanthus emblica* and *Santalum album*) were found to provide cultural services.

Keywords: Ecosystem services, Trees outside forest (TOF), Biodiversity, Roadside trees, Native and exotic species

It is unequivocal and indisputable that climatic change and biodiversity loss are the greatest threat to humanity and all forms of life on earth. Vegetation destruction and degradation cause biodiversity loss and alteration in ecosystem functioning. Conservation and periodic assessment of diverse ecosystems and a whole range of biological diversity there in, become crucial for long term survival of humans and maintaining the conditions for existence of life on earth. Forests play a crucial role in mitigation of climate change impact through carbon sequestration (Hou et al 2019, Nunes et al 2020), providing habitat for wide variety of flora and fauna and offering a number of ecosystem services (Valdés et al 2020). Many trees growing outside forests, commonly termed as Trees outside forest (TOF), are not included in forest monitoring and inventories, although they provide services similar to those provided by forests (Chakravarty et al 2019, Shrestha et al 2018). TOF concept is defined as 'trees available on lands which are not defined as a forest or other wooded land' (FAO 2005). In India, it is defined as 'all those trees, which has attained 10 cm or more diameters at breast height, available on land which is not notified as forest' (FSI 2011). They do play a vital role in combating global climatic change and reduce biodiversity loss and can be effective component of sustainability (Albrecht and Kandji 2003, Roshetko et al 2007). TOFs are increasingly viewed as an avenue for biodiversity conservation, carbon sequestration, climatic stabilization and livelihood support in rural and urban areas (Acharya 2006). It has potential for providing ecosystem services and ensures continuous tree cover to provide benefits for current and future generations (Ajewole 2010) and therefore, has begun to attract more attention due to their economic importance (De Foresta et al 2013). TOF including agriculture land, plantations, barren lands, road side plantations, various institutional or academic landscape, built on lands including settlements and infrastructures make positive contribution towards living conditions of different towns and cities (Eludoyin et al 2014).

Evaluation of TOF and their services are important to improve our understanding and concern about the status and dynamics of all tree resources. Monitoring and management of trees in institutional landscapes is required (Ananda et al 2014, Singh et al 2017) as they are one of the major component of TOF. Number of studies had been carried out in institutional landscapes of India (Singh et al 2017, Nandal et al 2019, Tamang et al 2019) for floristic diversity and ecosystem services. The present study was conducted in the university campus to enumerate the tree diversity and their potential uses and ecosystem services provided by them.

MATERIAL AND METHODS

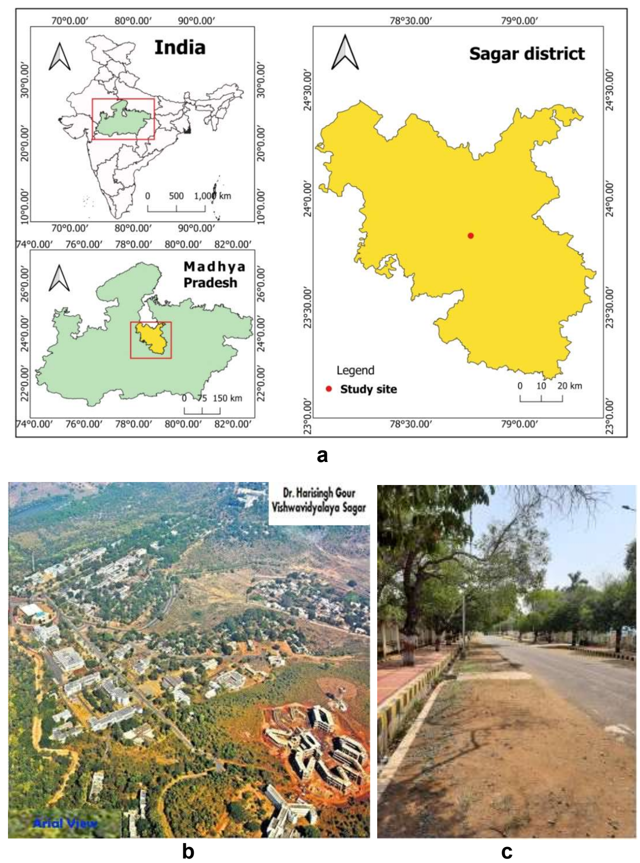
Study area: The present study was carried out in the roadside area of Dr. Harisingh Gour Vishwavidyalaya, Sagar, M.P. campus in the year of 2020-2021.This area is a part of lower Vindhyan range of Central India. The university campus is situated on the plateau of hill with an area of 1500 acre on an elevation of 420 msl. Geographically it lies 23˚49' N and 078˚46' E. Underlying rock is basalt, formed out of igneous rock, with plenty of basalt rounded boulders and with a very thin soil rich in calcium and phosphorus. The type of forests surrounding this area is classified as tropical dry deciduous type (Champion and Seth 1968). Climate of the study area is monsoonal with well-defined summer, rainy and winter seasons. Summer is hot and dry with maximum temperature of 45˚C during April to mid-June. Rainy season begins from late June up to September with average annual rainfall of 1187 mm. Winter is mild with minimum temperature of 5˚C during the month of January. General conditions of areas are dry during seven to nine months in a year. Most of the campus is inhabited by semi-natural forests in north, west and south directions and other areas include departments for different subjects, library, central office, dispensary, stadium, playground, hostels, residences etc. at the center and eastern region. Institutional areas are connected by roads and roadside plantations (Fig. 1 A, B, C).

Methodology

All roadside trees and shrubs along roads were documented. Present study considered only those trees and shrubs having 10 cm or more diameters at breast height (DBH), as they are considered as the TOF according to FSI (2011). Most of the species are identified at the spot as they were previously marked for study purpose; however, other species were mounted on herbarium sheet as per proper herbarium technique and were identified with the help of herbarium of Dr. Harisingh Gour Vishwavidyalaya and forest flora of Madhya Pradesh (BSI 1993, 1997, 2001). Complete enumeration was done for counting the individuals of all the species and classifying them in families and genera. All the areas were visited regularly to observe some of the direct benefits that local people get from the roadside plantations. Documented species were categorized for their nativity, uses and ecosystem services based on reports in literature (Gokhale et al 2011, Shukla and Chakravarty 2012, Raj et al 2018, Tamang et al 2019, Pradhan et al 2020).

RESULTS AND DISCUSSION

Floristics: In all, 1252 individuals of trees with DBH ≥ 10 cm were recorded belonging to 85 species, 73 genera and 38 families (Table 1) (Fig. 2). The contribution among number of individuals was dominated by *Tectona grandis* (11%), *Butea monosperma* (8%), *Mimusops elengi* (7%) and *Delonix regia* (6%). The overall dominant family was Mimosaceae represented by 9 species and 4 genera followed by Fabaceae (8 species and 7 genera), Rutaceae (6 species



source: University websitehttp://dhsgsu.ac.in/images/ dhsgsu_arial_view_photo.jpg

Fig. 1. (A) Study area (B) Arial views of University campus (C) Road side trees of study area

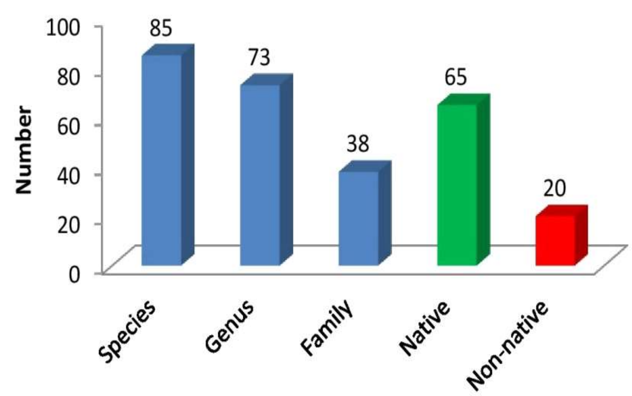


Fig. 2. Number of species, genera, families with no. of native and non-native species of the study area

Table 1. Documented species with their families, number of individuals, nativity, IUCN status, ecosystem services and utilization

Species name	Family	Indivi-duals	N/I	IUCN status	Servi-ces	Species specific benefits
Acacia auriculiformis	Mimosaceae	1	I	LC	P	Timber, fuel wood, apiculture, fodder, tannin, ornamental, gum, medicinal
Acacia catechu	Mimosaceae	1	N	NE	P, R	Medicinal, fodder, fuel, boundary/ support, nitrogen fixing, nectar source, dyeing
Acacia leucophloea	Mimosaceae	44	N	LC	P, R	Medicinal, fodder, fuel wood, nectar source, dyeing, Nitrogen fixing
Acacia nilotica	Mimosaceae	2	N		P	Fodder, food, gum, timber, medicinal
Aegle marmelos	Rutaceae	18	N	NE	P, C	Food, fodder, essential oil, medicinal, religious
Ailanthus excelsa	Simaroubaceae	2	N	NE	P, R	Fodder, fuel, gum, resin, medicine, shade, boundary, soil erosion control, trapping suspended particulate matter
Albizia lebbeck	Mimosaceae	2	N	LC	P, R	Timber, fuel wood, shade, nitrogen fixing, medicinal
Albizia odoratissima	Mimosaceae	2	N	LC	P, R	Timber, fuel wood, fodder, nitrogen fixing
Albizia procera	Mimosaceae	13	N	LC	P, R	Timber, fuel wood, shade, nitrogen fixing, soil improver, fodder
Annona squamosa	Annonaceae	20	I	LC	P	Food, fuel wood, medicinal
Anthocephalus cadamba	Rubiaceae	1	N		P, C, R	Dye food, fodder, ornamental, apiculture, tannin, intercropping
Artocarpus heterophyllus	Moraceae	1	N	NE	P, R	Food, fuel wood, fodder, shade
Azadirachta indica	Meliaceae	60	N	LC	P, C, R	Oil, medicinal, timber, religious, shade, fodder, nitrification inhibitor
Bauhinia racemosa	Fabaceae	2	N	NE	P	Fuel wood, fodder, nectar source, dyeing
Bauhinia variegata	Fabaceae	1	N	LC	P, R	Fuel wood, food, fodder, apiculture, fiber
Bixa orellana	Bixaceae	2	I	NE	C, P	Religious, food, cosmetic product, dye, medicinal
Bombax ceiba	Malvaceae	11	N	LC	P	Fibre, fodder, silk floss, medicinal
Bougainvillea	Lamiaceae	13	I	LC	C	Ornamental
Bridelia retusa	Phyllanthaceae	1	N	LC	P	Medicinal
Buchanania lanzan	Anacardiaceae	5	N	LC	P	Food
Butea monosperma	Fabaceae	97	N	DD	P, C	Aesthetic value, avenue plantation, fodder, timber, dye, resin
Callistemon citrina	Myrtaceae	1	I	NE	P, C	Herbicide, ornamental
Callistemon lanceolatus	Myrtaceae	1	I	NE	C, P	Avenue plantation, aesthetic, essential oil
Calotropis procera	Asclepidaceae	1	I	NE	C, P	Aesthetic value, medicinal
Carica papaya	Caricaceae	2	I	DD	P	Food, Medicinal
Cassia fistula	Caesalpiniaceae	19	N	NE	P, C, R	Fuel wood, fuel, medicine, aesthetic, apiculture, tannin
Casurina equisitifolia	Casurinaceae	3	N	NE	P, C	Ornamental, medicinal
Citrus lemon	Rutaceae	1	N	NE	P	Food, oil, good source of citric acid
Citrus aurantiifolia	Rutaceae	1	N	NE	P	Food, essential oil, medicinal
Cocos nucifera	Arecaceae	1	N	NE	P, C, R	Food, broom stick, lipid, soil improver, intercropping, ornamental
Cordia macleodii	Boraginaceae	2	N	EN	P	Food, medicinal, dye, glue, timber
Dalbergia sissoo	Fabaceae	33	N	LC	P, R	Shade, timber, fuel wood, nitrogen fixing, fiber, apiculture, lipid
Delonix regia	Caesalpiniaceae	71	I	LC	C, R, P	Avenue plantation, aesthetic, shade, fuel wood, gum/resin
Dendrocalamus strictus	Poaceae	32	N	NE	P	Making fence
Diospyros melanoxylon	Ebenaceae	1	N	NE	P	Leaf as Beedi wrapper
Diospyros montana	Ebenaceae	1	N	NE	P	Food, medicinal
Elaeodendron glaucum	Celastraceae	7	N	NE	P	Medicinal
Eucalyptus alba	Myrtaceae	61	I	LC	P, R	Ornamental, fencing, apiculture, fuel wood
Feronia limonia	Rutaceae	1	N	NE	P, C	Food, religious, medicinal
Ficus benghalensis	Moraceae	17	N	NE	R, C, P	Shade, religious, fodder, rubber/latex

Cont...

Table 1. Documented species with their families, number of individuals, nativity, IUCN status, ecosystem services and utilization

Species name	Family	Individuals	N/I	IUCN status	Services	Species specific benefits
Ficus glomerata	Moraceae	1	N	NE	R, P	Shade, food, fodder, timber, latex, intercropping
Ficus religiosa	Moraceae	58	N	NE	R, P, C	Shade, fodder, religious, nitrogen fixing, soil improver
Flacourtia indica	Flacourtiaceae	3	N	LC	P	Food, alcohol, medicinal, fencing, firewood
Gardenia latifolia	Rubiaceae	3	N	NE	P	Medicinal, timber
Gliricidia sepium	Fabaceae	19	I	NE	P, R, C	Fodder, apiculture, fiber, inter cropping, ornamental
Gmelina arborea	Verbinaceae	2	N	LC	R, P	Shade, timber, fuel wood, apiculture, fiber, gum/resin, soil improver
Grevillea robusta	Proteaceae	6	I	NE	C, P, R	Avenue plantation, aesthetic, timber, latex, fodder, apiculture, soil improver, intercropping
Helicteres isora	Sterculiaceae	1	N	R	P	Medicinal
Holoptelea integrifolia	Ulmaceae	19	N	NE	P	Medicinal, fuel wood
Jacaranda mimosifolia	Bignoniaceae	5	I	VU	P, R, C	Timber, shade, ornamental
Jasminum	Oleaceae	1	N		P, R	Medicinal, oil, intercropping
Kydia calycina	Malvaceae	2	N	LC	P	Fodder, medicine
Lagerstroemia parviflora	Lythraceae	35	N	NE	P, R	Food, medicinal, shade, gum, tannin, dye, fiber
Lawsonia inermis	Lythraceae	2	I	LC	P, C	Dye, medicinal, fiber, ornamental
Lannea coromandelica	Anacardiaceae	1	N	NE	P, C	Food, apiculture, tannin, alcohol, ornamental
Leucaena leucocephala	Mimosaceae	31	I	CR	P, R	Fodder, nitrogen fixation, wood for paper industry
Madhuca latifolia	Sapotaceae	1	N	NE	P	Food, oil, alcohol, fuel
Mallotus philippensis	Euphorbiaceae	1	N	NE	P	Dye, medicine
Mangifera indica	Anacardiaceae	25	N	DD	C, R, P	Shade, food, fodder, timber, fuel wood, religious, soil improver, ornamental
Manilkara zapota	Sapotaceae	1	I	NE	P, R	Fuel wood, rubber/latex, food, apiculture
Miliusa tomentosa	Annonaceae	2	N	NE	P	Food, fodder, fuel wood, timber
Mimusops elengi	Sapotaceae	87	N	LC	R, C, P	Shade, avenue plantation, aesthetic, food, fodder, fuel wood, essential oil, fiber, erosion control
Moringa pterygosperma	Moringaceae	1	N	LC	R, P	Seed cake for water purification, food, fodder, medicinal
Murraya exotica	Rutaceae	2	N	NE	C	Avenue plantation, aesthetic
Murraya koenigii	Rutaceae	1	N	NE	P	Food, medicine
Nerium odoratum	Apocynaceae	10	N	LC	C, P	Ornamental, poison
Peltophorum pterocarpum	Fabaceae	49	N	NE	P, C	Fodder, timber, ornamental
Pithecellobium dulce	Mimosaceae	3	I	LC	P	Food, medicine
Phoenix sylvestris	Arecaceae	1	N	NE	P	Food, medicine, leaves for making mats
Phyllanthus emblica	Phyllanthaceae	8	N	LC	P, R, C	Fiber, essential oil, medicine, soil improver, religious
Plumaria alba	Apocynaceae	1	I		C, P	Ornamental, medicinal
Polyalthia longifolia	Annonaceae	51	N	NE	P, C	Medicinal, aesthetic, fuel wood, ornamental
Polyalthia pendula	Annonaceae	2	N		C, P	Ornamental, wood for making pencil, match stick
Pongamia pinnata	Fabaceae	10	N	LC	R, P	Oil, medicinal, fuel wood, Timber, shade, poison
Psidium guajava	Myrtaceae	6	N	LC	P	Food, medicine, apiculture, erosion control
Roystonia regia	Arecaceae	14	I	LC	C	Avenue plantation, aesthetic
Santalum album	Santalaceae	32	N	VU	P, C	Oil, medicine, religious
Senna siamea	Fabaceae	1	N	NE	P	Fodder, medicine, timber
Syzygium cumini	Myrtaceae	1	N	NE	P, R	Food, fuel wood, shade
Tamarindus indica	Caesalpiniaceae	2	N	LC	P	Food, oil, medicine
Tecoma stans	Bignoniaceae	23	I	NE	C, P	Ornamental, medicine
Tectona grandis	Verbinaceae	140	N	NE	P	Timber, fuel wood, shade
Terminalia arjuna	Combretaceae	4	N	NE	P, R	Fodder, apiculture, tannin, fuel, timber, erosion control, shade
Terminalia catappa	Combretaceae	2	N	LC	P, C, R	Food, ornamental, shade, medicinal, dye/ tannin, resin
Ziziphus jujuba	Rhamnaceae	27	N	LC	P	Food, medicine

NE- not evaluated, LC- least concern, DD- data deficient, EN- critically endangered, VU- vulnerable, N- Native, I- Non-native, P- Provisional service
C- Cultural service, R- Regulatory service

and 4 genera) and Myrtaceae (5 species with 4 genera) (Fig. 3). Out of 73 genera, the most common was *Acacia* with 4 species followed by *Albizia* (3 sp.) and *Ficus* (3 sp.).

Despite the fact that the university campus was developed in an area having natural forests, the number of individuals with higher DBH was less. Certain species, such as *Bougainvillea spp*, *Callistemon citrina*, *Callistemon lanceolatus*, *Carica papaya*, *Casurina equisitifolia*, *Citrus lemon*, *Citrus aurantiifolia*, *Cocos nucifera*, *Grevillea robusta*, *Manilkara zapota*, *Moringa pterigosperma*, *Murraya exotica*, *Nerium odoratum*, *Psidium guajava*, *Roystonia regia* and *Terminalia catappa* were observed in the study area but were not found in the nearby natural vegetations. Out of 85 tree species, 65 were native and 20 species were non-native species (Table 1) (Fig. 2). Most of the species are neutralized in the surround vegetations. *Gliricidia sepium* shows invasive potential as it is now spreading on its own in almost every corner of the university campus.

All of the trees and shrubs are providing salutary services to local people. They are as follows:

Provisional services: Provisional service is directly assessed by people from the vegetation. Out of the total documented species, 82 species are providing provisioning services to people. Amongst the provisioning service provider species, 33 were food providing species, 31 medicinal species, 29 fodder species, 23 fuel wood species, 21 timber species, 20 oil yielding species, 11 dye yielding species, 7 tannin yielding species and 5 resin yielding species (Fig. 4). Important timber producing species are *Tectona grandis*, *Dalbergia sissoo*, *Azadirachta indica*, *Albizia lebbeck* and *Pongamia pinnata*. Local people collect fuel wood from dried parts of *Pongamia pinnata*, *Tectona grandis*, *Mimusops elengi*, *Albizia lebbeck*, *Dalbergia sissoo*, *Albizia procera* and *Mangifera indica*. The study also documented species with traditional medicinal value like *Azadirachta indica*, *Aegle marmelos*, *Feronia limonia*, *Helicteres isora*, *Phyllanthus emblica* and *Santalum album*.

34 species were found to provide cultural services. From ancient times some of the plants were worshiped by people in Indian culture and were designated as religious trees. *Aegle marmelos*, *Ficus religiosa*, *Phyllanthus emblica* and *Santalum album* are important religious species. Aesthetically important species were *Polyalthia longifolia*, *Polyalthia pendula*, *Butea monosperma*, *Roystonia regia* and *Delonix regia*. Ornamental plants were *Bougaainvillea spectabilis*, *Nerium odoratum*, *Polyalthia pendula* and *Tecoma stans* (Table 1). Cutting and damaging the religious species is prohibited as an old tradition and belief, hence, a way of conservation.

Regulatory services: These are the indirect benefit that keeps the environment congenial. They include decomposition, water purification, flood controlling and soil erosion, climate regulation, air purification, temperature regulation, reducing dust and pollutants and noise. Large and dense canopy trees with thick and fleshy leaves like *Ficus* spp., *Syzygium cumini*, *Mangifera indica*, *Manilkara zapota*, *Mimusops elengi* and *Terminalia catappa* were prominent species to reduce noise, absorb dusts and pollutants and ameliorate the environment providing relief to the visitors especially during summer time (Table 1). 34 species were found providing regulatory services. Large canopy trees such as *Ficus benghalensis*, *Ficus religiosa*, *Mimusops elengi*, *Artocarpus heterophyllus*, *Syzygium cumini* and *Azadirachta indica* were shade and refuge providing not only to humans but also to birds.

Roadside trees of Dr. Harisingh Gour campus harbors a good number of plant species (85 species) which was comparable to 95 species reported from Uttar Banga Krishi Vishwavidyalaya, West Bengal, India (Tamang et al 2019), 98 species from TFRI campus plantations, Jabalpur, M.P., India (Singh et al 2017), 66 tree species from Tripura

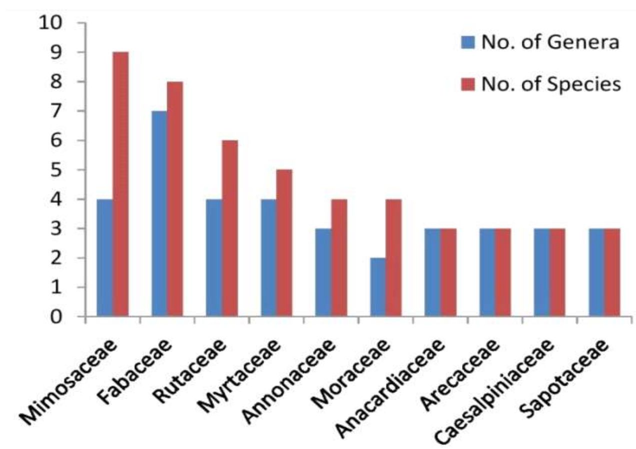


Fig. 3. Prominent families with their species and genera

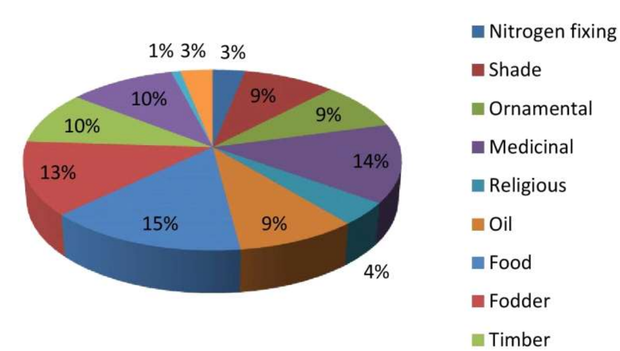


Fig. 4. Prominent ecosystem services provided by the vegetationin our study site

University campus (Deb et al 2016), 236 plant species from Adikavi Nannaya University (Rao 2016), 335 species with 55 tree species from Bharatijar university campus, India (Rajendran et al 2014) and 30 species from Sholapur university campus, Maharashtra, India (Gavali and Shaikh 2016).The difference in number of species in present study with others may be due to the fact that most of the studies have considered whole vegetational area of the campus and in addition to that some of the study considered all type of life forms, while we have considered only road side woody perennials with DBH ≥ 10 cm. Quantifying species richness is not only beneficial for comparisons among different places, but also for addressing the saturation of local communities colonized from regional source pool (Anandan et al 2014). Maximizing species richness is often explicit goal of conservation studies and background rates of species extinction (Airola and Buchholz 1984). In the present study, it was observed that roadside trees of institutional area may act as important ex-situ conservational unit comprising vulnerable and endangered species like urban green spaces studied by Pradhan et al (2020). Identification and documentation of species facing severe threats in different stages of vulnerability is necessary (Padalia et al 2004) as well as other factors influencing the existing vegetation of any region (Parthasarathy 1999). In our study, we found *Santalum album*, a vulnerable species and *Cordia macleodii* an endangered species escaped from natural and semi-natural forests of the study area.

Present study area is dominated by lower diameter class individuals. This might be due to the availability of vacant niche which adds the efficacy of regeneration potential for younger individuals. Further, soil of the present study area is thin with lower nutrient and moisture content which could be another key aspect contributing to the tree size reduction. DBH class distribution is one of the important factors which reflect the degree of stress, anthropogenic disturbance and history of development. Natural forests and public parks are well maintained, therefore, trees of these areas face limited stress and human interference. However, other green spaces like roadside plantations, institutional areas, home gardens etc. are planted for specific purposes to meet individual and community amenity values (Nero et al 2018). Trees along street and near residential areas are more susceptible to stress, hence are more dynamic in population and structure (Sæbø et al 2003, Nero et al 2018).

The flora of present study area, composed of 65 native and 20 nonnative species which was comparable to 66.31% endemic and 33.68% exotic species from institutional area of Uttar Banga Krishi Vishwavidyalaya, Cooch Behar (Tamang et al 2019), 63.35% of exotic species from Doon University campus, Dheradun (Singh et al 2017) and 183 exotic plant species from the Banaras Hindu University campus (Singh 2011). Planting non-native species has always been a debatable issue (Dickie et al 2014, Nitoslawski and Duinker 2016, Sjöman et al 2016). Tree species have been planted widely beyond their natural habitats to provide different ecosystem services. Although non-native or exotic species can provide a number of services (Dickie et al 2014, Castro-Díez et al 2019, Tamang et al 2019, Pradhan et al 2020), ecological characteristics of the habitat can be altered by introduction of exotic species and can be of significant threat to ecosystem (Singh et al 2017, Sakachep and Rai 2021) as they may neutralize and subsequently become invasive and disrupt or transform communities or ecosystems (Dickie et al 2014). It may be considered a sort of biological pollution and a critical outcome of human activities that leads to the extinction of native species (Kumar et al 2021). A well said quote by David Lodge defines them well, "These species are not inherently bad. They're just in wrong place".

TOF can be found in varying locality factors of all climates, land types, land use and regions having important economic, social and environmental implications on local, national and global scale (De Foresta et al 2013). These plantations act as a catalyst by providing microhabitats and nutrient accumulation. TOF have the potential to provide ecosystem services in the form of preventing soil erosion, nutrient and water cycling, biodiversity conservation and pest control. Therefore, the assessment of TOF and its services are important to enhance our understanding about the state and dynamics of all tree resources. Along with ecosystem services, all the 85 species are helpful for mitigating global climate change by sequestering significant amount of carbon as biomass. Planting trees is an effective tool for restoring biodiversity (Fang and Peng 1997, Zhuang 1997) and all kinds of trees (forests and trees outside forests) play an important role in the global carbon cycle.

CONCLUSION

Present study shows that all the species of study site, irrespective of native and non-native provide a number of ecosystem services to serve mankind. Old growth forests are frequently targeted for conservation since they harbor a large proportion of vulnerable species (disturbance sensitive) and species of restricted distribution. Like forests, all other terrestrial vegetation including urban green spaces, agriculture land and other TOFs are capable of providing ecosystem services and conserve rare and endangered species. Economic valuation of ES can aid assessments of the impacts of projects, programs or policies on ecosystems. A number of studies had reported the existing trade-off between ecosystem services and biodiversity conservation in the urban ecosystems.

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Received 21 December, 2021; Accepted 02 April, 2022

Indian Journal of Ecology (2022) 49(2): 616-622
DOI: https://doi.org/10.55362/IJE/2022/3569

Manuscript Number: 3569
NAAS Rating: 5.79

Chemical Composition and Biological Activities of *Marrubium vulgare L*

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***Abstract*:** The present study was conducted to evaluate the antioxidant and antibacterial activity of the extract of leaves and flowering of *Marrubium vulgare L*. The quantification of total phenols was determined using the Folin-Ciocalteu reagent, it is 2.23 mg EAG/g DM. The identification of flavonoids by the Alcl3 method, revealed the presence of anthocyanins, C-glycosides and aglycones, whose contents are 1.266mg/g, 0.385mg/g and 0.0331 mg/g, respectively. The antioxidant activity of the compounds in the methanolic extract was evaluated in vitro through two tests. In the case of DPPH test, the IC50 are 0.55, 0.97, and 1.2, 0.033 mg/ml for anthocyanins, c-glycosides, polyphenols and aglycones respectively. For FRAP assay, at a concentration of 1 mg/ml, the reducing power of iron manifested ODs of 1.389 nm; 0.752 nm, 0.496 and 0.114 nm for anthocyanins, C-glycosides, total polyphenols and aglycones respectively. The results show an excellent correlation between the two tests used, and the contents of anthocyanins and c-glycosides. The antimicrobial activity was evaluated by the agar diffusion method against *Staphylococcus aureus* (ATCC 25923), *Escherichia coli* (ATCC 25922). The antibiogram shows that anthocyanins have a very important antibacterial activity on *S. aureus* with an inhibition zone of 16.5 mm and a diameter of 13.5 for *Escherichia coli.* Anthocyanins show the lowest MIC values against the two strains *Staphylococcus aureus* and *Escherichia coli* (MIC=1/16 and 1/8 respectively). C-glycosides also have an inhibitory effect on the growth of *Escherichia coli* and particularly on *Staphylococcus aureus* (MIC= 1/32 and 1/8 respectively) which is a sensitive bacterium (gram+). Anthocyanins have marked a strong sensitivity towards the two strains. In conclusion, this work presents the compounds of *Marrubium vulgare* L as novel antimicrobial agents and as a potential source for combating bacteria, which are increasingly resistant to antibiotics.

Keywords: Antimicrobial activity. Antioxidant activity, Chemical composition, Methanolic extract, *Marrubium vulgare* L.

Oxidative stress, the cause of many diseases, is driving the search for new antioxidant remedies. For a hundred years, synthesis had defeated plant-derived drugs, except for antibiotics and anti-tumor drugs. However, development of molecular level assays, are opening up for natural products. Similarly, biotechnological, biochemical and metabolic advances are leading to a rapidly growing interest in natural resources (Reena and al 2021). This interest is also due to the realization that a significant number of secondary metabolites, which play an important role in the prevention of diseases, are present in our food (Uttara 2009, Gowhar Amin Mir and Sandeep Sehgal 2021)

The researchers also reported on the antimicrobial activity of several medicinal plants due to the emergence of multi-resistant bacteria as they are a major cause of treatment failure in many infectious diseases. Therefore, there is a need to search for alternative antimicrobial agents. One of the possible strategies to achieve this goal is to identify and characterize bioactive phytochemicals, which have antibacterial activity (Ahanjan et al 2008). *Marrubium vulgare L*. is an important medicinal plant that belongs to the Lamiaceae family, common in Mediterranean regions. Rich mainly in phenolic compounds is known for its strong antioxidant and antimicrobial power (Casanova and Tomi 2018).This family has been used for centuries as an expectorant, liquefier of bronchial secretions, antitussive, anti-infectious, stomachic, diuretic, tonic, cholagogue, anti-hepatobiliary, febrifuge (Dusser Lauge 2017).

For all these reasons, present study is in line with the perspective of valorization of local natural resources. In this context research is focused on the identification of phenolic compounds and the evaluation of the antioxidant and antimicrobial activity of the methanolic extract of the leaves and flowers of *Marrubium vulgare* L. against 2 gram positive and gram negative bacteria.

MATERIAL AND METHODS

The species *Marrubium vulgare L*.,was collected during April to May 2018, in Makouda in the region of TiziOuzou (Algeria) far from any pollution impact. The leaves and flowers of the plant were, dried in a well-ventilated place and protected from light, crushed and stored in glass bottles in the dark.

Study area: The wilaya of Tizi-Ouzou is located on the central-eastern coast of Algeria and covers an area of 2958 km2. It is limited to the South by the wilaya of Bouira, to the East by Bejaia, to the West by Boumerdès and opens to the North on the Mediterranean Sea by 85 km of coasts. The study area is located in the central part of the Tellian Atlas, in the North of Algeria, at a distance of 100km East of Algiers and West of the Djurdjura chain, between latitudes 36°20'N and 36°40'N and longitudes 3°40'E and 4°35'E.

Preparation of the methanolic extract: 10g of leaf and flower powder are macerated in 100 ml of methanol under stirring for 24 hours at room temperature. After filtration and evaporation of the solvent using a rotary evaporator, at 55°C, the extract is recovered with 5ml of methanol and stored in the refrigerator at 4°C (Djahra 2014).

Determination of total phenolic compounds: The content of total phenols was determined with the Folin-Ciocalteu reagent according to the technique of Singleton (1999) using gallic acid as standard. This determination is based on the quantification of the total concentration of hydroxyl groups present in the extract. The Folin-Ciocalteau reagent is an acidic yellow solution containing a polymeric complex of ions (heteropolyacids). In alkaline medium, this reagent oxidizes phenols into phenolate ions and partially reduces its heteropolyacids resulting in the formation of a blue complex. The absorbance of the samples and standards is measured with a spectrophotometer at 765 nm. The total phenol content is given in mg gallic acid equivalent (GAE)/g dry matter.

Determination of flavonoids: The flavonoids were estimated according to the method described by Hertog et al (1992) using quercetin as standard. The flavonoids are quantified by a colorimetric method with aluminum trichloride

Fig. 1. Location of the sample collection area (https://www.viamichelin.fr/web/Cartes-plans/Carte_plan-Tizi_Rached-_-Tizi_Ouzou-Algerie

($AlCl_3$) and soda (NaOH). Aluminum trichloride forms a yellow complex with flavonoids and soda forms a pink complex. The absorbance of the samples and standards is measured with a spectrophotometer at 430nm. The flavonoid content is expressed per mg quercetin equivalent/g dry matter.

Determination of proanthocyanins: The reading is made by measuring the absorbance at 520 nm. The absolute content of anthocyanins is calculated by the following formula with a corrective coefficient of 6 (Lebreton et al 1967):

$$T\ (mg/g) = 5{,}2\ .10^{-2}\ .DO.\ V.\ \ d/p$$

Determination of C-glycosylflavones: The reading is made by measuring the absorbance at 340 nm and the absolute content is calculated by the following formula:

$$T\ (mg/g) = 2{,}37.\ 10\text{-}2.\ DO.V.d/p$$

Determination of flavonicaglycones: To determine the content of aglycones, the differential assay method was used, which is based on two dilutions:

The 1st dilution is done in ethanol (ethereal extract + 95° ethanol). The 2nd dilution is done in AlCl3 solution (Ethereal extract + AlCl3 in 95° ethanol). The AlCl3 solution is prepared by mixing 1g of aluminum chloride in 100ml of 95° ethanol. From the dry ethereal residue taken up in 95° ethanol, 1ml of the 1% aluminum chloride solution is added. After incubation for 15 min at room temperature the absorbance of the aglycones was read between 400 and 435nm with a spectrophotometer. Concerning the determination of flavonicaglycones (420nm) and flavonols (435nm), the formula used is the following:

$$T(mg/g^{-1}) = 1{,}3.\ 10^{-2}.\ \Delta DO.\ V.\ d/p$$

Evaluation of the antioxidant power of the extract

DPPH free radical scavenging test: The scavenging activity of the DPPH radical is measured according to the protocol described by Sanchez-moreno (2002). The solution of DPPH was prepared in advance by solubilizing 1.2mg of DPPH in 50 ml of methanol. To 1 ml of DPPH is added 0.5 ml of the extract solution at different concentrations. The mixture is kept in the dark for 30 min until decoloration. The absorbance is read against a blank prepared for each concentration at 517nm.

The positive control is represented by a solution of a standard antioxidant,ascorbic acid. The negative control (blank) consists of DPPH and methanol.

The test is repeated three times and the results are expressed as percentage reduction of DPPH (%) according to the following formula:

$$I\ \% = [1 - (Abs\ contrôle - Abs\ test) / Abs\ contrôle] \times 100$$

The values of the concentrations to inhibit 50% of the initial concentration of DPPH (IC50) were determined graphically by linear or logarithmic regression of the percentages of inhibition as a function of the different concentrations of the tested compounds (Torre et al 2007).

Iron reduction test FRAP: The experimental protocol of Yildirim (2001) was used 1ml of the extract at different concentrations is mixed with 1.25ml of a 0.2 M phosphate buffer solution (pH= 6.6) and 1.25ml of a 1% potassium ferricyanide K3Fe (CN)6 solution. The whole is incubated in a water bath at 50°C for 20 min, then cooled to room temperature. 2.5 ml of trichloroacetic acid (10%) was added to stop the reaction, The mixture was centrifuged at 4000rpm for 20 min at room temperature. To 1 ml of supernatant 1 ml of distilled water and 200µl of a 0.1% iron chloride (FeCl3, 6H2O) solution was added. Solutions of reference antioxidants (Ascorbic acid) that serve as positive control and as well as the negative control (blank, with methanol) were prepared under the same conditions. The OD of the test compounds and ascorbic acid were measured spectrophotometrically at a wavelength of 700 nm.

Determination of antibacterial activity: Two reference bacterial strains from the Pasteur Institute (Algeria) are tested: *Escherichia coli* ATCC 25922 Gram negative and *Staphylococcus aureus* ATCC 25923 (Gram positive).

From young colonies, from 18 to 24 h, a bacterial suspension is made in sterile distilled water for each strain. After homogenization of the bacterial suspension with a vortex, standardization to 106 CFU/ml was performed by spectrophotometer at a wavelength of 620nm. The OD obtained is between 0.08 and 0.1 which corresponds to a concentration of 107 to 108 CFU/ml (CFU: Colony Forming Unit).

Diffusion method on solid medium: antibiogram: The evaluation of antibacterial activity was performed by the agar diffusion method (Ngameni 2009). In Petri dishes, Mueller Hinton agar medium in supercooling was aseptically poured at a rate of 15ml per dish. After solidification, a sterile swab was soaked in the bacterial suspension and spread on the surface of the agar three times, rotating the plate at about 60° after each application in order to have an even distribution of the inoculum. Sterile discs impregnated with each sample tested (10µl per disc) were placed on the agar surface. The plates were then incubated for 24 h at 37 °C. Negative control discs impregnated with an aqueous solution of antibiotic (positive control) were included in the tests. The experiment was performed in triplicate. The diameters of the inhibition zones surrounding the discs containing the test samples were measured (Sharififar et al 2007). The solid-state diffusion technique (CMI) was used. It is a method similar to the antibiogram method which consists in determining the sensitivity of a bacterial strain towards one or several metabolites at different dilutions. The MIC is defined as the lowest concentration capable of inhibiting any microbial growth visible to the naked eye. The statistical study is performed with EXCEL software. The results are repeated 3 times and are expressed as mean ± SD.

RESULTS AND DISCUSSION

Total polyphenol content: The content of phenolic compounds estimated using a linear calibration curve (Fig. 2). The total polyphenols in the methanolic crude extract of *Marrubium vulgare L* was 2.23mg gallic acid equivalent per g dry matter. A rather close value (3.42mg GAE/g extract) was observed in the methanolic extract of leaves and flowers of *Marrubium vulgare L* by Ghedadba (2014).

On the other hand, different results were obtained from the vegetative organs of the same species. A level of 18, 21mg EAG/ml of extract was found by Boudjelal (2012) and 17.08 mgEAG/gMS by Djahra (2014). Stanković (2011) observed 49.27 mg GA/g extract in total phenols on a lamiaceae *Marrubium peregrinum L*, levels that seem high compared to present extract (2.23±0.114). This variability in the results could be related to the climatic conditions of the species' biotope or to the different methods followed during extraction (Stanković, 2011).

Flavonoid content: The anthocyanins represent the most important class of flavonoids, with a value of 1.266 mg/g. C-glycosides and aglycones present at lowest values of 0.385 mg/g and 0.0331mg/g respectively (Table 1). These flavonoid contents can be affected by genotype, development and growth conditions, maturity and by the

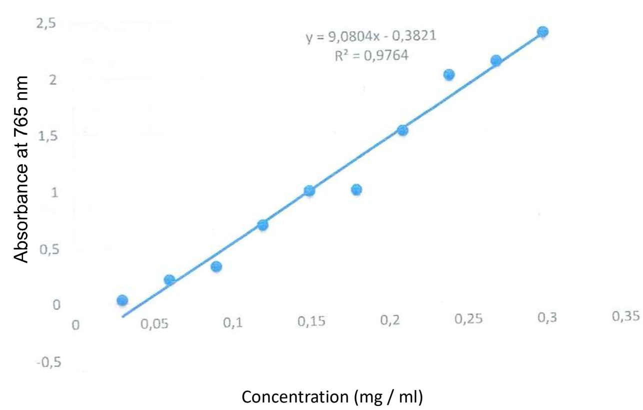


Fig. 2. Standard curve of gallic acid for the determination of total polyphenols

Table 1. Contents of the three classes of flavonoids

Phenolic compound	Content (mg. g^{-1})
Anthocyanins	1.266
C-glycosides	0.385
Aglycones	0.0331

polarity of the solvents used in the preparation of extracts (Ghedadba 201 and Bouterfas et al 2016)

Antioxidant activity

DPPH test

The percentage of free radical inhibition is proportional to the concentration of the compounds. Anthocyanins seem to have a better antioxidant activity than total polyphenols and c-glycosides. The aglycones represent the least efficient compounds in the elimination of free radicals. The antiradical activity of compounds was significantly lower than that of ascorbic acid (Fig. 3). To better characterize the antioxidant power, introduced the parameter IC50. This parameter expresses the quantity of antioxidants necessary to decrease the concentration of the free radical by 50%. The lower the IC50 value, the higher the antioxidant activity of a compound, which indicates the effectiveness of the compound (Hebi et Eddouks 2016)).

Anthocyanins and c-glycosides show antiradical properties with IC50= 0.55 and 0.97 mg/ml respectively. Total polyphenols show very low antiradical properties with an IC50 of 1.2 mg/ml. IC50 of aglycones is not determined and is probably due to its low content in the extract. The IC50 of ascorbic acid is a powerful anti-radical being 0.2 mg/ml (Fig. 4).

FRAP test

The iron reduction capacity is proportional to the increase in the concentration of the compounds (Fig. 5). These results agree well with (Haddoudi and al 2014). At the concentration 1 mg/ml anthocyanins show a maximum optical density of 1.389 nm, followed by c-glycosides and total polyphenols with optical densities of 0.752 nm, 0.496 nm respectively. Aglycones show low reducing power with absorbance of 0.114 nm. All plant compounds show antioxidant activities significantly lower than the reference product (ascorbic acid) with absorbance of 3.011 nm (Fig. 5 and 6).

Anthocyanins and c-glycosides have the best scavenging powers towards free radicals (DPPH) (with IC50= 0.55 and 0.97 mg/ml respectively) and also the best Fe^{3+} reducing capacities (anthocyanins have a maximum optical density of 1.389 nm, followed by c-glycosides whose value is 0.752 nm). This probably indicates the presence in our compounds of powerful antioxidant molecules that can intervene by two types of reaction mechanisms (FRAP test and DPPH test). These data are in line with many studies that have evaluated the reducing effect of ferrous ions from extracts of various plants. The study conducted by Rubió and al (2013) shows that the reducing power of a compound can serve as a significant indicator of its potential antioxidant activity.) Bentabet and al (2014) indicate that there is a direct

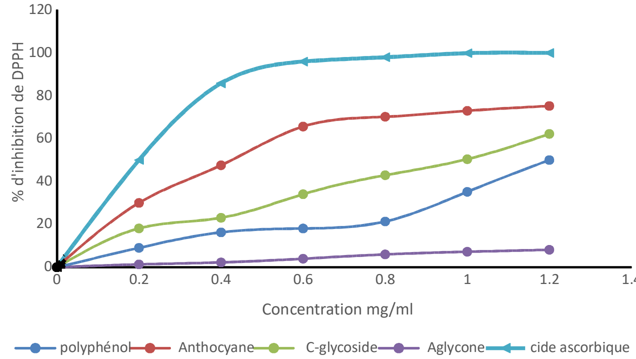


Fig. 3. DPPH uptake as a function of compound concentrations in *Marrubium vulgare* L.

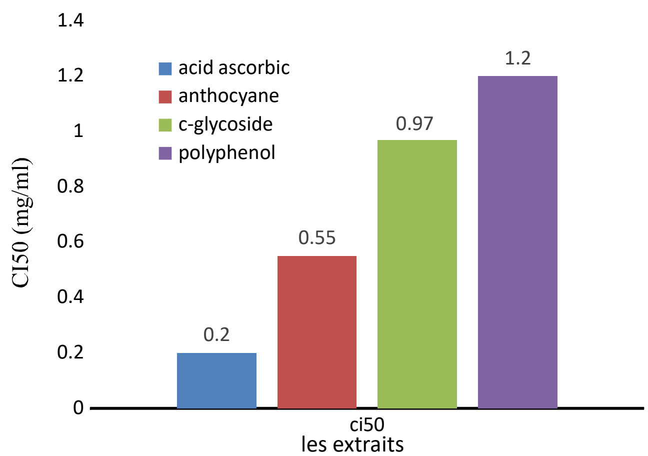


Fig. 4. Comparison of the IC50 of the different compounds

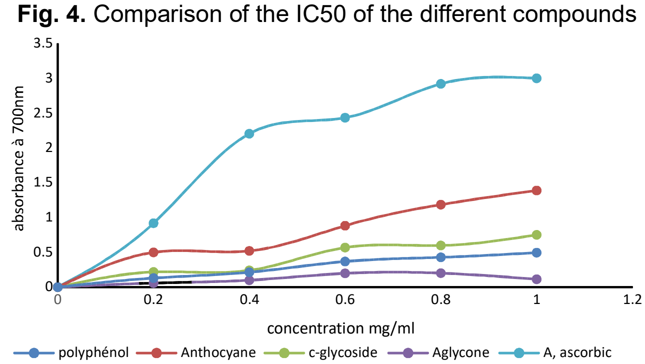


Fig. 5. Iron reducing power of the different compounds and ascorbic acid

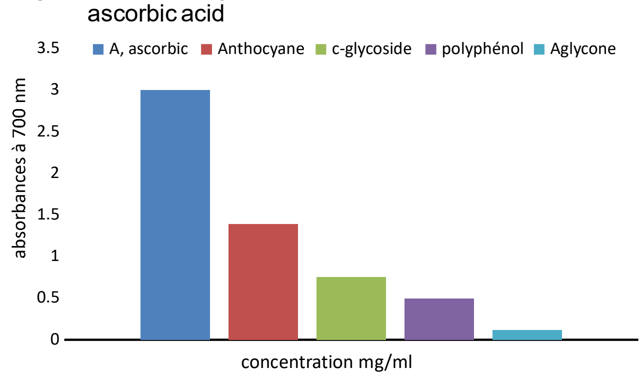


Fig. 6. Iron reducer of the different compounds and ascorbic acid at concentrations 1mg/ml

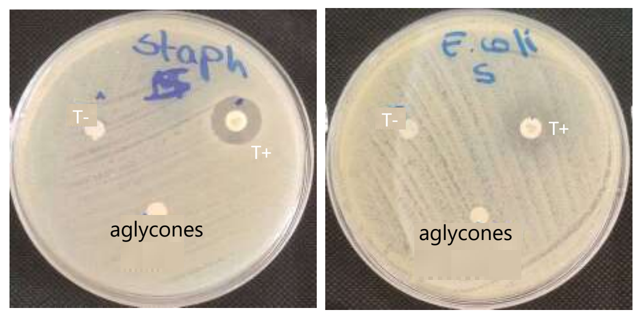
correlation between the antioxidant activities and the reducing power of the components of some plants.

Disc diffusion method (Antibiogram): The results of antibacterial activity tested on the two bacterial strains: *E. coli* and *S. aureus* are given in Figures 7 and 8, 9, 10.

The anthocyanins are the most active of all the other compounds (Fig. 7, 8, 9, 10, 11). This compound recorded the largest zones of inhibition against *Staphylococcus aureus* and *Escherichia coli* strains (16.5 mm and 13.50 mm respectively). The *S. aureus* strain was less sensitive to total polyphenols and c-glycosides (9 mm and 8.5 mm respectively). Total polyphenols and c-glycosides showed an interesting inhibitory activity towards the *Escherichia coli* strain with a diameter of 10 mm. Both strains are highly resistant to aglycones (6 mm).This inhibition activity is slightly lower than that of the reference antibiotic: Gentamicin. The negative control did not exert any inhibitory activity, the colonies develop normally in its presence and the anthocyanins marked a strong sensitivity towards the two strains.

Determination of the minimum inhibitory concentration(MIC): The bacterial growth decreases with the increase of the concentration of the compounds. The lower the MIC, the better the antibacterial activity of the compounds (Table 2). The MICs show that the *Escherichia Coli* strain is sensitive at both concentrations 1/4 and 1/2 for anthocyanins (MIC= 1/8) and also sensitive at both concentrations 1/4 and 1/8 for c-glycosides (MIC=1/32). For total polyphenols the MIC is undetermined.

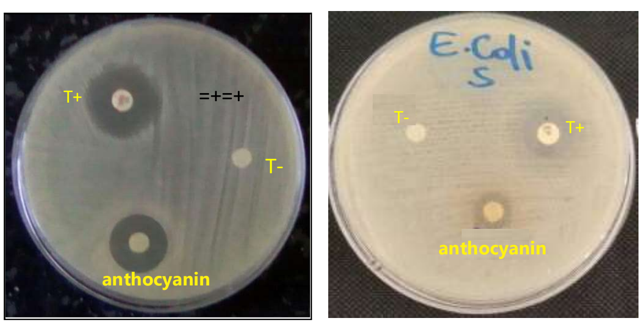
The *Staphylococcus aureus* strain seems very sensitive to concentrations 1/2 and 1/4 for anthocyanins (MIC =1/16) and moderately sensitive to concentration 1/2 for c-glycosides (MIC=1/8). *Staphylococcus aureus* is very resistant to total polyphenols (Fig. 12, 13, and 14). These results reveal that the Gram+ *Staphylococcus aureus* bacterium was more sensitive to anthocyanins and c-



Staphylococcus aureus. *Escherichia coli.*

T+: Gentamicin positive control (.antibiotic) T- : negative control (methanol)

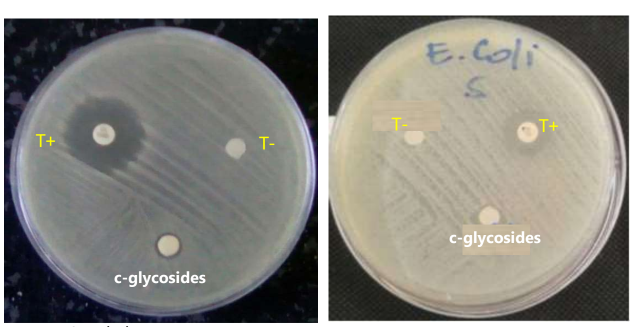
Fig. 9. Zones of inhibition of aglycones



Staphylococcus aureus *Escherichia coli*

(T+: Gentamicin; T- : Diethyl ether)

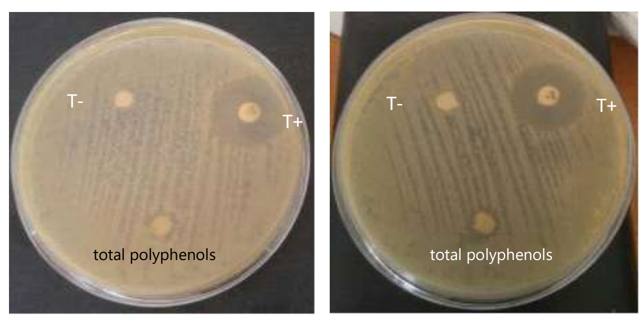
Fig. 7. Zones of anthocyanin inhibition



Staphylococcus aureus *Escherichia coli*

T+: Gentamicin positive control (.antibiotic) T- : n-butanol

Fig. 8. Zones of inhibition of c-glycosides



Staphylococcus aureus. *Escherichia coli*

T+: Gentamicin positive control (.antibiotic T- : methanol)

Fig. 10. Zones of inhibition of total polyphenols

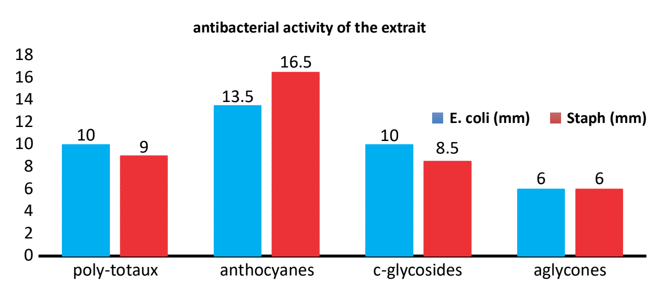
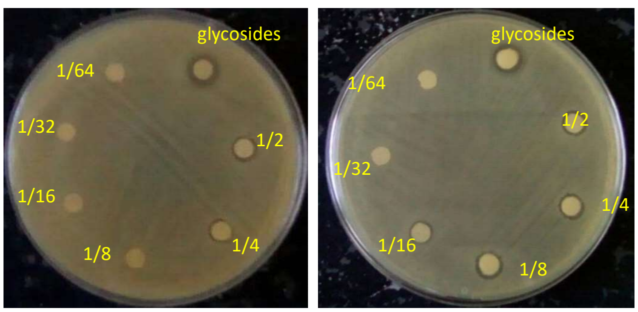


Fig. 11. Diameters of inhibition of the different compounds tested on the two bacteria

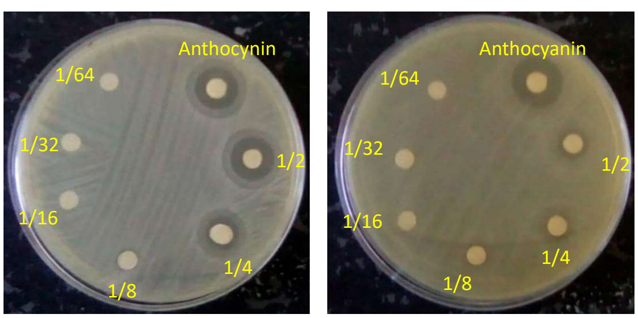
Table 2. Diameter of the inhibition zone (mm)

	Total polyphenols						
Bacteria total polyphenols	1/2	1/4	1/8	1/16	1/32	1/64	
S. aureus	00±00	00±00	00±00	00±00	00±00	00±00	
E. coli	9±0.741	9±0.741	10±0.741	9±0.741	9.5±0.741	8±0.741	
Anthocyanins							
Bacteria	anthocyanes	1/2	1/4	1/8	1/16	1/32	1/64
S. aureus	17.5±4,84	17±4.84	15.5±4.84	7.5±4.84	00±00	00±00	00±00
E. coli	15±3.90	8.5±3.90	8±3.902	00±00	00±00	00±00	00±00
C- glycosides							
Bacteria	c-glycosides	1/2	¼	1/8	1/16	1/32	1/64
S. aureus	13.5±1.75	11±1.75	10±1.75	00±00	00±00	00±00	00±00
E. coli	12±1.25	10±1.25	10±1.25	10.5±1,25	8.5±1.25	00±00	00±00



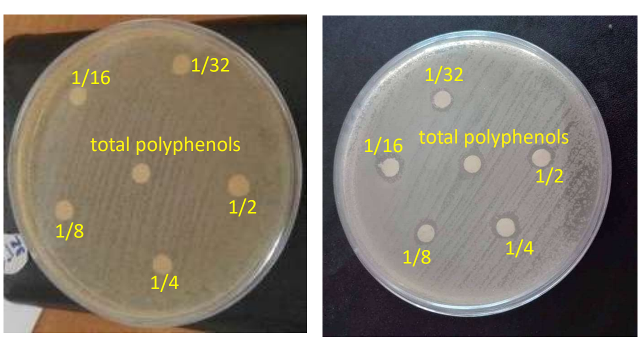
Staphylococcus aureus *Escherichia coli*

Fig.12. MIC of c-glycoside



Staphylococcus aureus *Escherichia coli*

Fig. 13. MIC of Anthocyanin



Staphylococcus aureus *Escherichia coli*

Fig.14. MIC of total polyphenols

glycosides than the Gram- *Escherichia coli* bacterium. This is consistent with recent studies on Lamiaceae that showed marked antibacterial activities against both types of bacteria with high inhibition against Gram (+) (Vijayabaskar 2012,Krichen 2015 and Bemmansour and al 2021). The resistance of Gram (-) bacteria could be explained by the presence of outer membranes that surround the cell wall and limit the diffusion of hydrophobic compounds through the covering lipopolysaccharides (David and Sudarsanam 2013).

CONCLUSION

The phytochemical study of the methanolic extract of the leaves and flowers of *Marrubium vulgare L* species revealed the presence of total polyphenols, flavonoids mainly anthocyanins, C-glycosides and aglycones. The antioxidant activity by DPPH and FRAP indicate that anthocyanins have the highest anti-radical activity followed by C-glycosides. The antioxidant activity of *Marrubium vulgare* L extract highlighted in this study could justify the traditional uses of this plant to develop new bioactive compounds. For the antibacterial activity, the most active compounds against *Staphylococcus aureus* and *Escherichica coli* are anthocyanins and c-glycosides. Therefore, these results remain promising, and could serve as a basis for further studies to confirm the antimicrobial efficacy of these natural products and to propose their use as antimicrobial agents, compensating for the side effects of antibiotics and increased bacterial resistances

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Received 20 November, 2021; Accepted 02 April, 2022

Indian Journal of Ecology (2022) 49(2): 623-628
DOI: https://doi.org/10.55362/IJE/2022/3570

Manuscript Number: 3570
NAAS Rating: 5.79

Nutritional Evaluation of Garden Cress Seeds (*Lepidium sativum*) Based Iron Enriched Recipes

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Abstract: Adolescence is a vulnerable period in human life cycle when nutritional requirements increases due to rapid growth spurt. More than 60 per cent of adolescent girls have been reported to be affected by iron deficiency anemia. Garden cress seeds (*Lepidium sativum*) are locally available inexpensive seeds which are excellent sources of iron, protein and β–carotene. The present study was planned to develop iron enriched four recipes viz. *ladoo, mathri*, s*hakkarpare* and biscuits for adolescent girls using garden cress seeds as the main ingredient. Three formulations of each recipe, i.e., control (no garden cress flour), variant-1 (unprocessed garden cress flour) and variant-2 (processed garden cress flour) were developed. The developed recipes were analysed for proximate composition, selected mineral content and *in-vitro* iron bioavailability. The variant-2 of *ladoo and mathri*, was higher in ash (2.10 and 2.27 %), crude fat (23.97 and 36.24 %), crude fibre (1.43 and 6.95 %) and crude protein (9.55 and 10.44 %). The selected mineral content was also higher in variant-2 of *ladoo* and *mathri*. Processing of seeds had significant effect on total iron, ionisable and soluble iron as well as per cent bioavailability of iron that enhanced after the treatment. Thus, among various developed recipes, variant-2 of, *ladoo* and *mathri* were highly nutritive.

Keywords: Garden cress, Proximate, Minerals, *in-vitro* iron bioavailability

Anemia is the most common nutritional deficiency disorder worldwide. According to DLHS-3 survey in Himachal Pradesh, 43% women and 55% children are anemic. Adolescence is a vulnerable period in human life cycle when nutritional requirements increases due to rapid growth spurt. Iron deficiency not only reduces work productivity but also accentuates the problem further during pregnancy because, they are just on threshold of marriage and motherhood (Gwatkin et al 2003). Thus, nutritional pattern in these years has special significance. Garden cress (*Lepidium sativum*) is an annual herb, belonging to *Brassicaceae family*, which is native to Egypt and Asia (Malleshi and Guo 2004). In India, it is mainly cultivated in UP, Rajasthan, Gujarat, Maharashtra and Madhya Pradesh (Kirtikar and Basu 2004). It is also cultivated in Himachal Pradesh but awareness regarding its health and nutritional benefits is very less and therefore the crop is mainly raised as fodder crop for animals. Garden cress helps to regulate menstrual cycle, increases milk production and secretion in lactating mothers and prevents post-partum complications. It is an effective medicine for general weakness in girls (Doke and Guha 2014) .Garden cress seeds are therefore packed with the power of nutrients which can combat malnutrition, anemia and other micronutrient deficiencies. So, the idea of incorporating this crop (seeds) into sweet and salty food preparations for supplementation also catches attention. Strategies for improving anemia include supplementation, fortification and improvement in the diet. But, there is an interest turning to approach of diet intervention that has higher potential for achieving far-reaching and long lasting benefits for the control of iron deficiency. Therefore, it is essential that locally available materials which are inexpensive but highly nutritious bemused as a vehicle to improve the nutrition status for adolescent girls. Study was done to develop and standardize iron rich recipes for adolescent girls by modification of recipes that are popular among them with the incorporation of iron rich garden cress seeds.

MATERIAL AND METHODS

Garden cress seeds were collected in bulk from local market and were processed. The whole garden cress seeds were sorted and cleaned to remove impurities and were ground in mixer and stored in airtight container. Treated garden cress seeds were sorted and cleaned to remove impurities. Seeds were soaked in water for 3 hours and drained the superficial water. After that seeds were dried in tray drier at temperature of 60°C and kept for drying until they completely dried. Then they were ground in and the flour obtained was roasted and stored in airtight container. The prepared samples were evaluated for various nutritional characteristics.

Proximate analysis: Protein, fat, fiber, ash, and moisture were determined and computed on dry weight basis according to AOAC (2010). The moisture content of samples was determined by drying the samples at 100°C until a constant weight was obtained. Dried samples were analysed to determine the total nitrogen content using microkjeldahl method. A conversion factor of 6.25 was used to calculate protein content. The ash content was determined by burning 1 g of oven-dried sample in a crucible in a muffle furnace at 550°C for 24 h. The total lipids were isolated using the Soxhlet method. Crude fiber was measured by digestion with 1.25% sulphuric acid followed 1.25% of sodium hydroxide, while the carbohydrates content was determined by the difference of total solid (100) minus other solid components.

Minerals analysis: The dried samples were wet digested in 25 ml of diacid mixture (nitric acid and perchloric acid; 9:4) as per method given by (Ranganna 2007). The digested samples were analyzed for sodium, potassium and calcium by using Flame Photometer Model Mediflame 128 and for iron, zinc and copper atomic absorption spectrophotometer, AAS - 4129 was used. Phosphorus was determined by spectrophotometer. *In vitro* iron bio availability was also determined in samples (Rao and Prabhavati 1982). All the estimations were done in triplicate and reported on dry weight basis.

Development of food products: After trials of many recipes enrichment and prototype, development was taken up for the recipes with higher acceptability. Three iron enriched variants each of *ladoo, mathri*, *shakkarpare* and biscuits were prepared. The first recipe of each product was control i.e garden cress was not incorporated. Variant-1 was subjected to incorporation of un-processed garden cress seeds.Variant-2 was subjected to incorporation of processed garden cress seeds. After a series of trials using ingredients in various proportions and adopting different processing methods, the concept of the iron enriched products took shape (Table 1). Garden cress seeds were chosen for iron enrichment along with other ingredients viz. amaranth seeds and sesame seeds to prepare *ladoo, mathri, shakkarpare* and biscuits and to find out the best iron rich recipe among

Table 1. Recipes standardized ingredients used

Control	Variant-1	Variant-2
Ladoo		
Amaranth flour-25g Wheatflour-25g Jaggery-40g Fat-10g	Amaranth flour-25g Wheat flour-20g Jaggery-40g Fat- 10g Garden cress flour (UP)-10g	Amaranth flour-10g Wheat flour-10g Jaggery-40g Fat- 10g Garden cress flour(P)-10g Sesame seeds-15g Grated coconut-5g Raisin-5g
Mathri		
Refined flour-25g Amaranth flour-30g Fat-20g	Refined flour-40g Amaranth flour-30g Garden cress flour(UP)-10g Fat-20g	Refined flour-50g Amaranth flour-20g Gardencress flour(P)-10g Sesame-16g Fenugreek-1g Fat -20g Black pepper-2g
Shakkarpare		
Refined flour-60g Sugar-30g Amaranth flour-10g	Refined flour-40g Amaranth flour-10 Garden cress flour(UP)-10g Sugar-30g	Refined flour-30g Amaranth flour-20g Garden cress flour(P)-10g Sugar-30g Sesame seeds-10g
Biscuit		
Refined flour-50g Amaranth flour-10g Fat-30g Salt-1g Sugar-4g Omum2g Cumin-2g Baking powder-1pinch	Refined flour -45g Amaranth flour-5g Garden cress flour (UP)-10g Fat-30g Salt-1g Sugar-4g Omum-2g Cumin-2g Baking powder-1pinch	Refined flour -40g Amaranth flour-10g Garden cress flour (P)-10g Fat-30g Salt-1g Sugar-4g Omum-2g Cumin-2g Baking powder-1pinch

products viz. *ladoo, mathri, shakkarpare* and biscuits by nutritional quality.

Preparation method for recipes

Ladoo- Roasted wheat flour till light brown. Added all the measured ingredients in wheat flour and simultaneously prepared jaggery syrup of one thread consistency. Added syrup in prepared mixer and made small rounded *ladoos.*

Mathri- In refined wheat flour, added all the measured ingredients and rubbed with melted ghee (shorting). Kneaded stiff dough and prepared small flattened rounded *mathri*, deep fried till light brown in colour.

Shakkarpare- Added all measured ingredients in refined wheat

Table 2. Proximate composition (% dry weight basis) developed recipes

Recipes	Proximate parameters	Treatments			
		Control	Variant-1	Variant-2	Mean
Ladoo	Moisture	8.08	8.68	7.93	8.23
	Ash	1.33	1.93	2.1	1.79
	Crude fat	23.71	23.87	23.97	23.85
	Crude fiber	0.36	1.1	1.43	0.96
	Crude protein	7.9	8.83	9.55	8.76
	Total carbohydrate	58.73	55.59	55.02	56.55
	Mean	16.69	16.57	16.82	16.69
	Factors	Parameters (A)	Variant (B)	A×B	
	CD (p=0.05)	0.04	0.02	0.07	
Mathri	Moisture	6.2	6.52	6.03	6.25
	Ash	1.47	1.9	2.27	1.88
	Crude fat	36.21	36.21	36.24	36.22
	Crude fiber	0.25	0.87	0.95	0.69
	Crude protein	8.45	9.97	10.44	9.62
	Total carbohydrate	47.42	44.55	44.07	45.35
	Mean	16.67	16.67	16.67	16.67
	Factors	Parameters (A)	Variant (B)	A×B	
	CD (p=0.05)	0.06	BS	0.11	
Sakkarpare	Moisture	5.7	6	5.58	5.76
	Ash	0.52	0.73	0.95	0.73
	Crude fat	31.8	31.95	32.15	31.97
	Crude fiber	0.08	0.72	0.8	0.53
	Crude protein	3.99	4.83	5.16	4.66
	Total carbohydrate	57.91	55.76	55.36	56.34
	Mean	16.67	16.67	16.67	16.67
	Factors	Parameters (A)	Variant (B)	A×B	
	CD (p=0.05)	0.09	BS	0.16	
Biscuits	Moisture	7.47	7.83	7	7.43
	Ash	1.02	1.8	2.23	1.68
	Crude fat	26.81	26.95	27.02	26.93
	Crude fiber	1.33	1.43	1.84	1.54
	Crude protein	6.09	6.47	6.82	6.46
	Total carbohydrate	57.51	55.51	55.09	56.03
	Mean	16.7	16.67	16.67	16.68
	Factors	Parameters (A)	Variant (B)	A×B	
	CD (p=0.05)	0.08	BS	0.14	

flour. Kneaded stiff dough and rested the dough for 20 min covered with damp cloth. Rolled it and cut into diamond shaped s*hakkarpare*. Deep fried in medium flame till golden brown.

Biscuits- Mixed and stifted thrice all the measured ingredients. Creamed ghee and folded the flour into it. Prepared dough and rested for 20 minutes covered with damp cloth. Rolled and cut in squares with the help of cutter and baked at 175 ºC for 15 min.

RESULTS AND DISCUSSION

Proximate composition of developed recipe (% dry weight basis): In *ladoo* all the proximate parameters like ash

Table 3. Mineral composition (mg100g^{-1} DW basis) of developed recipes

Recipes	Minerals	Treatments			
		Control	Variant-1	Variant-2	Mean
Ladoo	Copper	5.54	6.19	7.08	6.27
	Zinc	3.45	4.06	6.77	4.76
	Calcium	38.01	42.02	51.32	43.78
	Sodium	8.00	11.21	17.00	12.07
	Phosphorus	125.30	139.70	146.21	137.07
	Potassium	441.61	633.11	692.12	588.95
	Mean	103.65	139.38	153.42	132.15
	Factors	Parameters (A)	Variant (B)	A×B	
	CD (p=0.05)	0.06	0.04	0.11	
Mathri	Copper	4.15	5.29	7.92	5.79
	Zinc	3.17	4.56	6.06	4.60
	Calcium	39.22	42.01	51.92	44.38
	Sodium	73.20	74.80	79.10	75.70
	Phosphorus	125.10	139.53	145.71	136.78
	Potassium	371.81	643.58	682.71	566.03
	Mean	102.78	151.63	162.24	138.88
	Factors	Parameters (A)	Variant (B)	A×B	
	CD (p=0.05)	0.35	0.25	0.062	
Shakkarpare	Copper	3.88	4.09	4.88	4.28
	Zinc	2.54	3.08	4.12	3.24
	Calcium	36.78	40.30	50.52	42.53
	Sodium	7.01	7.50	8.60	7.70
	Phosphorus	98.12	102.21	113.51	104.61
	Potassium	357.40	453.00	482.19	430.86
	Mean	84.29	101.70	110.64	98.87
	Factors	Parameters (A)	Variant (B)	A×B	
	CD (p=0.05)	0.33	0.23	0.58	
Biscuits	Copper	4.09	4.68	5.77	4.85
	Zinc	2.46	3.07	4.16	3.23
	Calcium	37.20	40.68	50.21	42.70
	Sodium	50.30	56.31	59.81	55.47
	Phosphorus	95.61	102.81	111.71	103.38
	Potassium	442.80	553.20	573.71	523.24
	Mean	105.41	126.79	134.23	122.14
	Factors	Parameters (A)	Variant (B)	A×B	
	CD (p=0.05)	0.09	0.06	0.15	

(2.10 %), crude fat (23.97 %), crude fibre (1.43 %), and crude protein (9.55 %) were significantly higher in variant-2 i.e. treated garden cress seeds incorporated *ladoo* except moisture (7.93 %) and carbohydrates (55.02 %). Similarly in *mathri*, variant-2 was analysed with high content of ash, crude fat, crude fiber (6.95 %) and crude protein. Similar trend was observed in variant -2 of *shakkarpare* and biscuits and having more amounts as compared to control and variant-1.

Mineral content: for proximate parameters, variant-2 of all the developed iron rich products was again assessed for its highest values of analysed minerals viz. copper, zinc, calcium, sodium and phosphorus when compared with variant-1 and control formulation. The mineral content of *ladoo* and *mathri* 7.08, 6.77, 51.32, 17.00, 146.21, 692.12 and 7.92, 6.06, 51.92, 79.10,145.71, 682.71 mg $100g^{-1}$ of copper, zinc, calcium, sodium, phosphorous and potassium were analysed on dry weight basis. Same trend was observed in shakkarpare and biscuits. The control provided 87.33 mg of calcium whereas the experimental samples provided more than 120 mg.

***In-vitro* iron content:** Total iron content ranged between 32.92-69.71, 35.69-65.64, 34.95-49.32 and 37.73 -59.27mg $100g^{-1}$ for *ladoo, mathri, Shakkarpare* and biscuits for different treatments. *In-vitro* iron content was significantly higher in variant-2 in all the recipes in which treated garden cress seed powder was used. It indicated that treated garden cress seed increased iron content in recipes. Four recipes, total iron content was reported highest in *mathri* 50.76 mg followed by *ladoo*5, biscuits mg and *shakkarpare* mg. *In-vitro*

Table 4. Total, ionisable, soluble iron content and bioavailability of iron content in whole and treated garden cress seeds

Recipes	Parameters	Treatments			
		Control	Variant-1	Variant-2	Mean
Ladoo	Total iron ($mg100g^{-1}$)	32.92	47.92	69.71	50.18
	Ionisable iron ($mg100^{-1}g$)	1.83	2.44	3.55	2.61
	Soluble iron($mg100g^{-1}$)	25.53	39.76	55.93	40.41
	Bioavailable iron (%)	2.88	2.92	3.07	2.96
	Mean	15.79	23.26	33.07	24.04
	Factors	Parameters (A)	Variant (B)	A×B	
	CD (p=0.05)	0.02	0.02	0.04	
Mathri	Total iron ($mg100g^{-1}$)	35.69	50.94	65.64	50.76
	Ionisable iron ($mg100g^{-1}$)	1.85	2.81	3.63	2.76
	Soluble iron($mg100g^{-1}$)	25.72	40.07	58.45	41.41
	Bioavailable iron (%)	2.17	2.93	3.06	2.72
	Mean	16.36	24.19	32.70	24.41
	Factors	Parameters (A)	Variant (B)	A×B	
	CD (p=0.05)	0.02	0.02	0.04	
Shakkarpare	Total iron ($mg100g^{-1}$)	34.95	36.22	49.32	40.16
	Ionisable iron ($mg100g^{-1}$)	0.85	1.15	1.53	1.18
	Soluble iron($mg100g^{-1}$)	26.12	30.05	38.80	31.66
	Bioavailable iron (%)	1.98	2.04	2.45	2.16
	Factors	Parameters (A)	Variant (B)	A×B	
	CD (p=0.05)	0.02	0.02	0.03	
	Mean	12.78	13.90	18.43	15.04
Biscuits	Total iron ($mg100g^{-1}$)	37.73	42.21	59.27	46.40
	Ionisable iron ($mg100g^{-1}$)	1.22	1.73	1.94	1.63
	Soluble iron($mg100g^{-1}$)	27.75	36.95	43.63	36.11
	Bioavailable iron (%)	1.64	1.90	1.99	1.84
	Mean	17.09	20.70	26.71	21.50
	Factors	Parameters (A)	Variant (B)	A×B	
	CD (p=0.05)	0.02	0.02	0.04	

iron content (ionisable iron, soluble iron and per cent bio availability iron) was highest in *ladoo* (3.55 mg, 55.93 mg and 3.07 %) and *mathri* (3.63 mg, 58.45 mg and 3.06 %). The treatment of soaking and drying of garden cress seeds had an appreciable influence on total iron, ionisable iron and soluble iron content as well as bioavailability of iron in variant-2 for all developed recipes when compared with variant-1 having incorporation of unprocessed garden cress seeds and control which contained no garden cress. Singh and Srivastava (2012) also observed same trend in iron rich *namakpare* mixes. Nathiya and Vigasini (2014) formulated and assessed the nutrient content of cookies (nutricookies) and observed that samples with 10g, 20g and 30g garden cress seeds provided 24.58, 34.58 and 44.58 mg of iron $100g^{-1}$.

Rana and Kaur (2016) prepared supplemented products viz. biscuits, *ladoo* and *namakpare* with garden cress seeds using proportions of 5, 10 and 15 per cent. The iron content of supplemented biscuit was 13.60 mg and hat of control was 5.20 mg. The Iron content of control *ladoo* was 6.49 mg which significantly increased in supplemented *ladoo* to13.37 mg. The iron content of control *namakpara* was 2.70 mg which increased to 7.61 mg in supplemented *namakpara.* Kaur et al (2018) reported that in vitro iron bioaccessibility of legumes based product reported maximum when fortified with ascorbic acid rich foods.

CONCLUSION

Present investigation reveals the effect of garden cress seeds on nutritional quality of *ladoo, mathri*, s*hakkarpare* and biscuits. Garden cress is rich source of iron. Processing i e soaking for 3 hrs, drying at 60°C and roasting of seeds had significant effect on proximate composition, minerals content, total iron, ionisable and soluble iron as well as per cent bioavailability of iron that enhanced after the treatment. These iron rich recipes can be recommended for supplementation in nutrition intervention program for combating iron deficiency.

Received 23 November, 2021; Accepted 21 January, 2022

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Indian Journal of Ecology (2022) 49(2): 629-635
DOI: https://doi.org/10.55362/IJE/2022/3571

Manuscript Number: 3571
NAAS Rating: 5.79

Energy Use Pattern and its Efficiency in Paddy Cultivation in Indian Punjab

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***Abstract*:** Efficient use of energy resources in agriculture is one of the pre-requisites for sustainable agricultural production. Energy intensive paddy cultivation is blamed for several ecological problems of the Indian Punjab. In this backdrop, the present study was carried out to measure the energy use pattern in paddy cultivation across different farm categories along with identification of wasteful uses and calculation of energy use efficiency (EUE) in Punjab during 2018-19. The total energy expended in paddy cultivation was 47014.69 MJ/ha and the average energy use showed an inverse relationship with the farm size. Among different energy sources, chemical fertilizers were the dominant ones (42%) followed by electricity consumption for irrigation (36.05%), machine energy (18%), diesel fuel (17%), human labour (1.36%) and FYM (1.11%).The use of chemical, mechanical and electrical energy varied positively with the farm size while it varied negatively for human and animal labour, seed and FYM. Net energy gain was estimated at 0.175 million MJ/ha. High EI of 6.77 MJ/Kg with a low energy productivity index of 0.148 kg/MJ indicated that there is room for improving energy productivity. The EUE for small farmers (4.98) was the highest. Very high use of NRE and commercial energy was observed which could be harmful to the environment and ecology in the long run.

***Keywords*:** Energy use efficiency, Farm category, Inputs, Paddy, Renewable

Energy is an integral part to overall human development process. It has turned out to be the most valuable input in agriculture in its various forms. Agriculture, basically an energy conversion industry, requires energy as an essential input to production, enhancing food security, adding value and contributing to rural economic development. Efficient use of energy resources in agriculture is one of the principal requirements for sustainable agricultural production as it not only provides financial savings and fossil resources preservation but also reduces air pollution. In India, agriculture has transformed into a commercial entity, largely due to technological innovations which call for large scale use of energy making it imperative to carry out analysis of energy use in crop production systems. Thus, right source and appropriate mix of energy input into crop production is very important from the economic as well as environment point of view. The steady decline in the energy-use efficiency in the present agriculture is also a matter of great concern and calls for optimal and proper utilization of energy inputs involved in various farm operations (Kumar et al 2020, Praveen et al 2021). For farms operating at lower levels of efficiency, sufficient potential exists for improving the productivity by proper management and allocation of the existing resources and technology (Samarpitha et al 2016). Therefore, there is need to access the energy trends in agriculture and to know how far can farms increase their output simply by efficiently utilizing the available resources.

In India, rice is the staple food crop for more than 70 per cent people and accounts for 40-45 per cent of the total area covered by cereal crops. Punjab state with 3.1 million hectares of land under rice contributes about 21 per cent of rice to the national pool. However, energy intensive paddy cultivation is blamed for several ecological problems of the state. Besides depleting the ground water, the consumption of energy in pumping underground water for paddy cultivation is increasing overtime. Electricity being free for agriculture sector, the financial burden on state exchequer has been increased enormously. Therefore, present study was carried out to measure the energy use pattern in paddy cultivation across different farm categories along with identification of wasteful uses and calculation of energy use efficiency (EUE) in Punjab.

MATERIAL AND METHODS

The present study was carried out in the Punjab state. The cross-section data pertaining to the agricultural year 2018-19 were taken from the data collected under centrally sponsored 'Comprehensive scheme to study the cost of cultivation of principal crops in Punjab' operating in the Department of Economics and Sociology, Punjab Agricultural University, Ludhiana for the present study. The data were collected from a sample of 300 farm households in 30 tehsils spread across the three agro-climatic zones of the Punjab state. From each zone, farmers were selected using three-stage stratified sampling technique, with tehsil as stage one, a village/cluster of villages as stage two and operational holdings within the clusters as stage three. From each village/cluster, a sample of ten operational holdings i.e. small (< 1 -2 ha), Medium (2-6 ha) and large (≥6 ha) were selected randomly. Requisite information relevant to various inputs used in paddy cultivation such seed, diesel fuel, fertilizers (N, P_2O5 and K_2O), chemicals, crop yield (economical yield), total working hours of labors as well as draught power used for different farm operations along with total working hours of agri-machinery and equipment etc. were recorded. Data on crop grain yield was used for the estimation of straw yield using crop to residue ratio method (Chauhan 2012).

Estimation of input energy expenditure: The data on inputs and output was converted to energy units using embodied energy equivalents for each input and output energy type, and expressed in Mega Joules (MJ) using specific energy coefficients (Table 1). The energy requirement of electricity consumed for lifting groundwater for irrigation purpose was calculated using capacity of the electric motor/submersible pump-set and duration of pump-set run as following:

Electricity consumption (KWh) =

Capacity of the electric motor/submersible pump-set (HP)×duration of pump-set run× 0.746

Table 1. Energy coefficients used in energy calculation for paddy cultivation

Energy source	Energy coefficient (MJ $unit^{-1}$)
Human labour (h)	
Adult man	1.96
Adult woman	1.57
Animal labour (h)	14.05
Fertilizer(kg)	
N	60.6
P_2O_5	11.1
K_2O	6.7
Farmyard manure (FYM)	0.3
Chemicals (kg)	
Granular chemicals (Kg)	120*
Liquid chemicals (l)	102**
Machinery (h)	62.7
Diesel (l)	56.31
Seed/Grain (kg)	14.57
Straw (kg)	12.5
Electricity (kWh)	11.93

Source: Singh and Singh, 2002; *Canakciet al2005, **Gopalanet al1978

Average annual fuel consumption for a specific make and model tractor was approximated as follows (Grisso et al 2004):

Average diesel fuel consumption (Litre/h) = 0.305 × Ppto

Where *Ppto* = maximum power take-off power, KW

The input energy used in engaging agri-machinery was computed from the total weight, useful life, energy coefficient and time of operation. The conversion coefficients used to compute energy values for different agri-machinery were 87.63 MJ/kg for combine harvester,93.61MJ/kg for tractor and 62.7 MJ/kg for other agri-machinery i.e. cultivator, disk harrow, planker (Canakciet al 2005). Economic life of agri-machinery stated in the American Society of Agricultural and Biological Engineers (ASABE) standards were used in the estimation of agri-machinery energy expenditures. Data regarding average weights of different agri-machinery was collected and used to compute energy inputs from agri-machinery as explained in the following equation:

$$ME = \frac{W}{L \times A} \times C \times T$$

where,

ME is agri-machinery energy (MJ/ ha),C is conversion factor for the machinery (MJ/Kg)

W is weight of machinery (kg), L is the useful life of the machinery (h),T is the working time (h) and A is the area under paddy (ha).

Further, each agricultural input was categorized as direct and indirect energy source. Direct energy sources (DE) are those which bring out the intended energy directly viz. diesel fuel, human labour, animal labour, electricity and irrigation, while the indirect energy sources (IDE) comprised energy sources i.e. seed, agri-machinery, fertilizers and chemicals used in paddy cultivation. Renewable energy (RE) includes seed, labour and irrigation, while NRE comprises diesel fuel, agri-machinery, electricity, chemicals and fertilizers.

Energy indices: Agriculture is not only a consumer of energy but also producer of energy in the form of energy output. To compare how efficiently paddy crop converts input energy into output energy following ratios were carried out.

Net energy (MJ/ha) = Output energy (MJ/ ha) - Input energy (MJ/ ha)

Specific energy or Energy Intensity (MJ/kg) = Input energy (MJ) /Crop yield (Kg)

Energy use efficiency (EUE) = Output energy (MJ / ha)/Input energy (MJ / ha)

Energy productivity (kg/MJ) = Economic output (Kg/ha) /Input energy (MJ/ha)

RESULTS AND DISCUSSION

Input energy use in paddy cultivation : The farmers were using energy from nine different sources for paddy cultivation i.e. human, draught animals, machines, diesel fuel, seeds, fertilizers, farm yard manure (FYM), chemicalsand electricity (Table 2, Fig. 1). The total energy expended for producing paddy was 47014.69 MJ/ha.

Among the different energy sources, chemical fertilizers were the dominant source of energy contributing 19907.92 MJ/ha which accounted for about 42 per cent of the total energy and among fertilizers, the share of nitrogenous fertiliser was highest (41.8 %). Two reasons can be attributed to explain this pattern, lack of knowledge among farmers about the recommended package of practices and nutrient based subsidies on chemical fertilizers especially nitrogen fertilizer. Further, electricity consumption for irrigation use also consumed a noteworthy share of 36.05 per cent in the total energy consumption. The pumping of irrigation water from deeper layers of underground water through submersible electric pumps and electric motors had led to the high electricity consumption in the state. Further, on account of free of cost supply of electric power to agricultural sector in Punjab state, farmers had no incentive in saving electricity. Different studies highlighted the indiscriminate use of nitrogen fertilizers and irrigation water in the transplanted paddy (Chaudhary et al 2017, Basavalingaiah et al 2020).

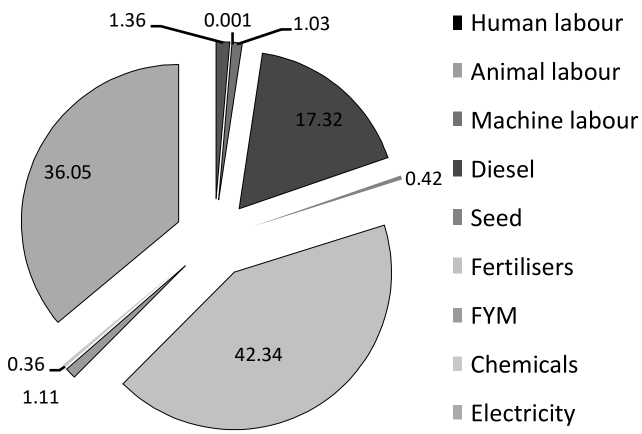

Fig. 1. Different inputs used in paddy cultivation (% share in input energy)

Further, diesel fuel used in prime movers and oil engines/generators for running pumps formed about 17 per cent of the total input energy. Another 485.71 MJ/ha of agri-machinery energy was used for various cultural operations of paddy cultivation. Thus, machine energy collectively accounted for about 18 per cent share while the draught (animal) power had negligible share in the input energy. Further, human labour accounted for another 1.36 per cent followed by FYM (1.11%) whereas all other inputs formed less than one per cent share in the input energy. Seed energy constituted only 0.42 per cent share and different chemicals used for plant protection consumed only 0.36 per cent share in total energy expended in paddy cultivation.

Energy use pattern in paddy cultivation by sources and farm sizes: The results regarding level of energy use for paddy cultivation across different farm size categories in the state showed a direct relationship with farm size (Table 3).

Large farmers used the highest input energy of 48193.01 MJ/ha while on medium and small farmers was

Table 2. Energy input-output pattern in paddy cultivation in Punjab

Input/output (unit)	Qty used unit area^{-1} (ha)	Total energy equivalent (MJ ha^{-1})	% share
Human labour (h)	325.37	637.72	1.36
Animal labour (h)	0.13	0.26	0.001
Machine labour (h)	13.79	485.71	1.03
Diesel (l)	20.13	8143.59	17.32
Seed (Kg)	13.47	198.45	0.42
Fertilisers (Kg)	349.82	19007.92	42.34
N (Kg)	324.29	19652.06	41.80
P (Kg)	19.27	213.89	0.45
K (Kg)	6.26	41.97	0.09
FYM (Kg)	1747.19	524.16	1.11
Chemicals (Kg)	1.40	167.17	0.36
Electricity (KWh)	198.04	16949.71	36.05
Total energy input (MJ ha^{-1})		47014.69	100.00
Energy output (MJ ha^{-1})			
Grain (Kg)	6939.5	102010.8	46.37
Straw (Kg)	9437.7	117971.7	53.63
Total energy output (MJ ha^{-1})	16377.25	219982.55	100.00

47267.32 and 44088.49 MJ/ha respectively. Similar results were obtained for paddy cultivation in Karnataka in an earlier study (Kumar et al 2019) though they were in contrast to that for Bihar (Kumar et al 2014). Source-wise analysis indicated that in all size groups of farmers, fertilizer was dominant source of energy consuming more than 41 per cent of the input energy and they were using excess fertilizer energy in the form of nitrogen, phosphorous and potash respectively, as compared to the recommendations of package of practices and this was mainly due to major share of nitrogenous fertilisers used by them which are comparatively cheaper than fertilisers having P and K contents. Farmers' reliance on energy derived from electricity used for irrigation also increased with farm size and varied from 15220.52 on small to 17783.56 MJ/ha for large farmers. The large farmers were also using relatively higher mechanical energy in total input energy i.e. 8728.95 MJ/ha accounting for 18.11 per cent of total energy input. These farmers were more reliant on agri-machinery as they derived 222.07 MJ/ha from machine use (0.46%) which consumed 8506.88 MJ/ha (17.65%) of diesel fuel. The use of human labour for carrying out different farm activities in paddy cultivation was the least for the large farmers i.e. 1.24 per cent in comparison to small ones with1.63 per cent. Further, the large farmers were deriving highest share of energy from chemicals for plant protection (0.41%) as compared to medium and small farmers (0.29% each). The small farmers appeared to be more inclined towards ecology and environment though use of this energy was guided by lack of economic power to buy costly inputs and farm machinery. The energy utilized from biological (renewable) sources was highest for small farmers which could be attributed to the use of family labor and farm based inputs in larger quantities rather than commercial sources of energy. The use of chemical, mechanical and electrical energy varied positively with the farm size, while the use of human labour, animal labour, seed and FYM showed a negative relationship with the farm size. This is mainly due to huge investment capacity of the large farmers and lack of knowledge among the farmers about the recommended practices.

Productivity, input-output energy and EUE in paddy across sources and farm size: Average grain and straw yield of paddy obtained by sample farmers was 6939.51 Kg/ha and 9437.73 Kg/ha respectively. The total energy output from both main- and by-product varied from 217631.19 MJ/ha on medium to222664.59 MJ/ha on large farm category (Table 4). Energy output for small farms was higher than medium due to higher grain and straw yield. The net energy gain of 0.173 million MJ/Ha indicated that paddy cultivation is energy efficient in the area. On account of paddy

Table 3. Farm-category wise energy input pattern in paddy cultivation

	Energy source/Farm category	Small	Medium	Large	Overall
A	Human Labour	720.06 (1.63)	654.01 (1.38)	599.49 (1.24)	637.72 (1.36)
B	Animal Labour	5.68 (0.01)	1.75 (0.004)	0.940 (0.002)	0.26 (0.001)
C	Machine labour	7220.99 (16.38)	8613.45 (18.22)	8728.95 (18.11)	8629.30 (18.35)
D	Machine use	25.12 (0.06)	106.70 (0.23)	222.07 (0.46)	485.71 (1.03)
E	Diesel	7195.87 (16.32)	8506.75 (18.00)	8506.88 (17.65)	8143.59 (17.32)
F	Seed	211.31 (0.48)	189.26 (0.40)	183.75 (0.38)	198.45 (0.42)
G	Fertilisers	19840.74 (45.00)	19512.25 (41.28)	20357.32 (42.24)	19907.92 (42.34)
	N	19500.63 (44.23)	19364.42 (40.97)	20035.46 (41.57)	19652.06 (41.80)
	P	309.21 (0.70)	119.99 (0.25)	264.03 (0.55)	213.89 (0.45)
	K	30.90 (0.07)	27.84 (0.06)	57.83 (0.12)	41.97 (0.09)
H	FYM	742.79 (1.68)	652.97 (1.38)	340.71 (0.71)	524.16 (1.11)
I	Chemicals	126.39 (0.29)	136.83 (0.29)	198.29 (0.41)	167.17 (0.36)
J	Electricity	15220.52 (34.52)	17506.80 (37.04)	17783.56 (36.90)	16949.71 (36.05)
	Total energy input (MJ ha^{-1})	44088.49	47267.32	48193.01	47014.69

Note: Figures in parenthesis are percentages to the respective total energy input yield differences, the energy gain was observed to be relatively low on medium farms as compared to that on the small and large farms.

With output energy of 219982.5 MJ/ha and input energy of 47014.69 MJ/ha, EUE of 4.68 was obtained in paddy cultivation. The EUE for small farmers (4.98) was higher than medium (4.60) and large farmers (4.62). In a study for South-Western Punjab, EUE of 5.0 was found for transplanted paddy cultivation (Singh et al 2019).In another study for Bihar, again the EUE was found to decline with farm size (Kumar et al 2014). Energy identity (in terms of EUE and energy productivity) and energy input were found to be directly related to farm size for paddy cultivation in Punjab except for small farmers. High energy intensity of 6.77 MJ/Kg was found with a low energy productivity index of 0.148 kg/MJ indicating that there is room for improving energy productivity of rice crop in transplanting cultivation methods. Since chemical fertilisers were easily available in the study area, farmers were overusing these especially small ones. However, over and indiscriminate usage of fertilizer results in significant reduction in crop yield over a period of time and increases the pollution problems. In a study for Karnataka, higher EUE under DSR compared to transplanted paddy was mainly attributed to the significant decrease in energy inputs and scope for saving energy by 6 per cent existed in transplanting method (Basavalingaiah et al 2020). Yuan and Peng (2017) reported that adoption of simplified and reduced input practices resulted in increased EUE and energy productivity by about 19 and 25 per cent, respectively than the farmers' practice in China. Thus, there is need to take suitable steps to increase EUE in paddy cultivation either by minimizing input use or by using them judiciously.

Direct and indirect energy use: Direct and indirect sources of energy use in paddy cultivation comprised about 55(25731.28 MJ/ha) and 45 per cent (21283.41 MJ/ha) of the total energy input respectively (Table 4 and Fig. 2). In all the farm categories, the share of direct energy in was more than 52 per cent and it was the highest for medium category farmers i.e. 56.42 per cent as they were having higher share of machine use as well as diesel fuel in input energy than other farm categories. Maximum energy in indirect form on small farms (47.51%)was on account of relatively higher share of indirect forms of energy like labour, FYM and seeds.

Electricity used for irrigation formed the major share i.e. 65.87 per cent and almost same pattern was observed for all the farm categories as more than 65 per cent of direct energy was obtained from electric power only (Fig. 3a). Diesel formed about 32 per cent share in the direct energy whereas human labour contributed only 2.48 per cent. Animal labour share in direct energy was negligible.

Among indirect sources of energy, major share of about 94 per cent was from fertilisers only with maximum (95.56%) being for large farmers Figure 3b. FYM had share of only 2.46 per cent with maximum being for small farmers i.e. 3.55 per cent. In terms of chemicals about 0.79 per cent indirect energy was used and maximum was in large farmers i.e. 0.93 per cent. Machine use indirectly contributed 2.46 per cent of IDE and large farmers were the leaders in this category with 2.28 per cent share of mechanical energy while for rest it was less than or equal to one per cent only. Thus, electricity as DE and fertilisers in form of IDE were major energy sinks for paddy cultivation in Punjab.

Table 4. Farm-category wise energy pattern in paddy cultivation

Item (Unit)/farm category	Small	Medium	Large	Overall
Total energy input (MJ ha^{-1})	44088.49	47267.32	48193.01	47014.69
Total energy output (MJ ha^{-1})	219457.80	217631.19	222664.59	219982.55
Grain	101767.50	100920.46	103254.56	102010.83
Straw	117690.30	116710.73	119410.03	117971.72
Net energy (Million MJ ha^{-1})	0.175	0.170	0.175	0.173
Energy Intensity (MJ Kg^{-1})	6.37	6.88	6.86	6.77
Energy use efficiency (EUE)	4.98	4.60	4.62	4.68
Energy Productivity (Kg MJ^{-1})	0.157	0.145	0.146	0.148
Direct energy (MJ ha^{-1})	23142.13 (52.49)	26669.30 (56.42)	26890.87 (55.80)	25731.28 (54.73)
Indirect energy (MJ ha^{-1})	20946.36 (47.51)	20598.02 (43.58)	21302.14 (44.20)	21283.41 (45.27)
Renewable energy (MJ ha^{-1})	1679.84 (3.81)	1497.99 (3.17)	1124.89 (2.33)	1360.59 (2.89)
Non-renewable energy (MJ ha^{-1})	42408.64 (96.19)	45769.33 (96.83)	47068.12 (97.67)	45654.10 (97.11)

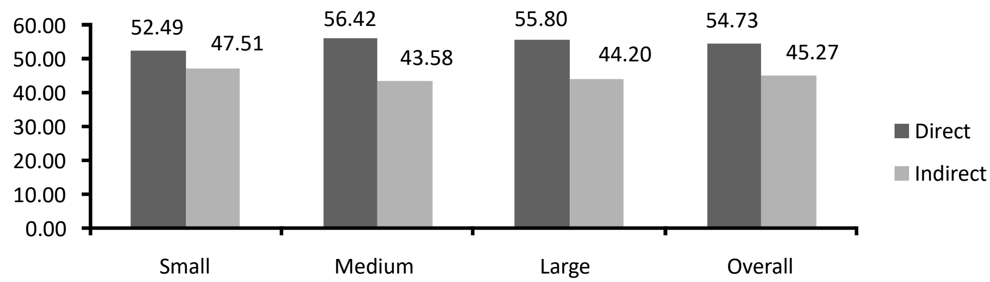

Fig. 2. Farm category wise sources of input energy- Direct and Indirect (% share in input energy)

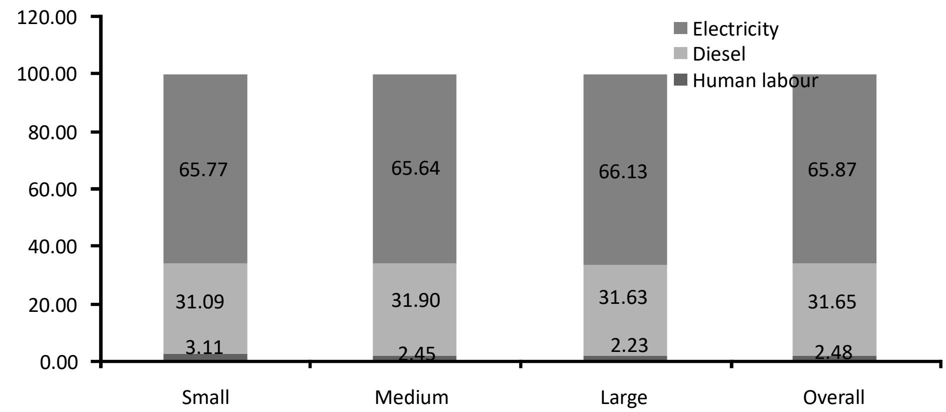

Fig. 3a. Farm category wise sources of direct energy (% share in direct energy)

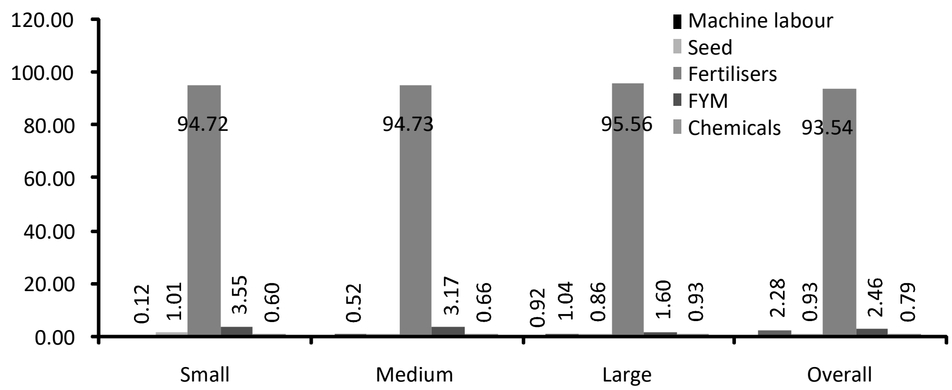

Fig. 3b. Farm category wise sources of indirect energy (% share in indirect energy)

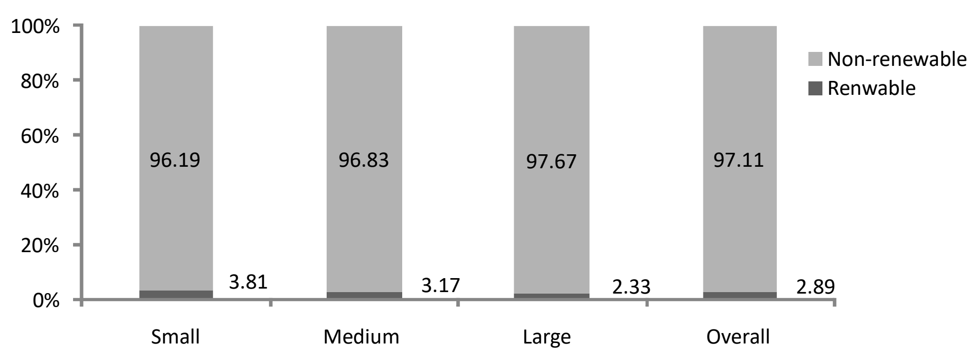

Fig. 4. Farm category wise sources of renewable and non-renewable energy (% share in input energy)

Renewable (RE) and non-renewable energy (NRE) use: Very high use of NRE i.e. 45654.1 MJ/ha (97.11 %) as compared to RE i.e. 1360.59 MJ/ha (2.89%) was observed (Table 4). Several researchers have found similar results that the share of NRE was much higher than that of renewable energy consumption indicating paddy production being mostly depending on fossil energy sources (Kazemi et al 2015, Nassir et al 2021). The selected farmers had used more of NRE sources due to subsidized price but this could be harmful to the environment and ecology in the long run. Therefore, paddy farmers need to switch over to renewable energy sources in paddy production. However, many external factors come in the way of adoption of environmentally benign energy sources in agriculture such as dwindling availability of FYM and increasing labour scarcity.

Energy utilized from biological (renewable) sources was highest among small farmers (3.81%) followed by medium than large farmers (Fig. 4). This could be attributed to the use of family labour and farm based inputs in relatively larger quantities by small and medium farmers as compared to that by the large farmers thus, indicating relatively better management of biological sources of energy by smaller farmers. Similar results were obtained in study for paddy in Karnataka (Kumar et al 2019). Non-commercial energy from labour and FYM constituted only 2.47 per cent share in the total energy with rest being sourced from commercial sources. In a similar study, per hectare use of both commercial and non-commercial energy was more in paddy crop in comparison to wheat crop (Kumar et al 2020).

CONCLUSIONS

With net energy gain, paddy cultivation is energy efficient in Punjab but over-whelming consumption of electric and chemical fertiliser energy underpin the opportunities for energy saving. Paddy cultivation is mostly dependent on commercial, non-renewable and indirect energy forms which do not augur well for sustainability of paddy production and soil ecology of agricultural lands in the state. Energy management at the farm level needs serious attention both for efficient and economical use of energy as well as for the safe guard of agro-ecosystem. Lack of knowledge of scientific recommendations, improper use of modern means of energy, subsidization of commercial energy and prevailing myth and mind-set of the farmers are the most likely obstacles in efficient energy utilization which need to be addressed. Strengthening of extension services can help in encouraging the judicious use of energy intensive inputs by replacing these with alternative organic sources as well by through adoption of recommended farming practices. Farm level adoption of environment friendly technology of paddy cultivation viz. direct seeded technology (DSR) may also help in energy saving without compromising the level of output.

Received 12 December, 2021; Accepted 02 April, 2022

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Indian Journal of Ecology (2022) 49(2): 636-642
DOI: https://doi.org/10.55362/IJE/2022/3572

Manuscript Number: 3572
NAAS Rating: 5.79

Sources of Income Inequality among Rural Farm Households in North Western Himalayas

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Abstract: Study assesses the inequality arising from variations of economic opportunities across different agro-climatic zones of Himachal Pradesh. The poor in the state tends to diversify their income portfolio towards wages and salaries. Income from wages and salaries is most equally distributed, yet it contributes maximum (43.63%) in total inequality. The high Gini correlation of wages and salaries with total income (R_k=0.597), showing that households which are above in the total income stratum derive more income from wages and salaries activities, also contributed its share (43.63%) in total inequality. Wages and salaries and livestock inequalities are increasing in its effect; other factors remaining constant. One per cent increase in income from wages and salaries and livestock, increased total inequality by 0.115 and 0.140 per cent. The income from agriculture and livestock tend to significantly reduce income inequality in the state. However, agriculture is the major income source across all Zones showed a wide disparity among the share of other sources in the total income. Income of households was more unevenly distributed in the Zone-II, and Gini index for the Zone-II (G_k =0.231) was higher than that of the Zone-IV, Zone-III and Zone-I of the state. The result of the Theil index emphasized within group inequality was the key contributor to overall disparity across agro-climatic zones. Therefore, Policy intervention at zonal level would be imperative for correcting spatial imbalances in income distribution among agricultural households of Himachal Pradesh, and would cover the way for their comprehensive and more unbiased development.

Keywords: Agro-climatic zones, Correlation, Income inequality, Theil index

With poor people making up less than a tenth of its population, Himachal Pradesh is one of more prosperous states in India. Since 1994, there has been a steady decline in poverty in the state, especially in the rural areas. As a result, the difference in poverty levels between the state's rural and urban areas has narrowed considerably. In spite of this, Himachal Pradesh's western and central districts record higher levels of poverty than its other regions. Growth in the state has been modest after 2005, driven mainly by the non-farm sectors of the economy. In urban areas, consumption inequality has increased. The economy of Himachal Pradesh is predominantly dependent upon agriculture and in the absence of strong industrial base, any fluctuations in the agricultural or horticultural production, effects the economic growth of the State. Most of Himachal Pradesh's people are engaged in farming. Non-farm jobs account for a lower share of employment than in most other states. Over two-thirds of Himachal Pradesh's workforce is self-employed, and very few of the rest have salaried jobs. Since 2005, jobs in the state have grown, albeit slowly. Many of the jobs created during this period were in construction. While female labor force participation in the state is high, it has been declining in recent times. During 2017-18 about 8.84 percent of state income has been contributed by agriculture sector alone (Economic survey of HP, 2018-19).

There has been much debate about economic growth and increasing inequality both across the countries and within the country. Researchers and policy makers have tried to explain this relationship both at micro and macro level but could not get any conclusion. Few decades ago, this debate has also been started in India and continues today without any common consciences (Pal and Ghose 2007). A number of studies from developing countries have suggested that diversification of rural economy towards non-farm activities has considerable potential to augment farmers' income and reduce rural poverty (Adams 2001, Barrett et al 2001, Janvry et al 2005). Diversification towards non-farm activities overcomes the land constraint to income growth, enables the farmers cope up with the shocks of crop failure and enhances their capacity to invest in productivity-enhancing agricultural inputs and technologies. Further, a growing rural non-farm sector can absorb surplus labour from agriculture, reduce rural urban migration, narrow down rural-urban disparities and promote farm-nonfarm linkages. The rural non-farm sector is quite heterogeneous in India, and its distributional consequences are likely to vary depending on whether an income source is accessible to the rich or the poor. Adams (2001) in Egypt have found inverse relationships between non-farm income and land ownership as well as household income. The studies from Rwanda (Dabalen et al 2004), Jordan (Adams 2001), on the other hand, have found that non-farm income has un-equalizing effect on income distribution.

Evidences from the existing literature suggested that most of the studies in the Indian context pertaining to income inequality of rural households and distributional consequences of income sources have been carried out for the country as a whole. However, effective poor growth policy prerequisites a clear understanding of regional composition of income earned by farm households and distributional impact of income sources. The present study is an attempt to show the actual picture of the extent of income inequality by sources of income between agricultural households prevailing in different zones of Himachal Pradesh.

MATERIAL AND METHODS

Data: Himachal Pradesh is a hilly and mountainous Indian Himalayan state. This state is the only state in India with nearly 90% of the population living in rural areas. It is located in the central chain (lesser Himalaya) of mountain ranges. Being a hilly State, the cropping pattern and the agricultural income of the farmers vary according to the altitude of the State. In the valley areas, the main agricultural products are food grains, i.e., wheat, maize, paddy, pulses, sugarcane, oilseeds etc., whereas due to suitable topography and climatic conditions, the hilly areas of the state are widely known for horticultural products, viz., apple, seed potato, apricot, grapes, ginger, dry fruits etc. To conduct this study, purposive sampling was adopted to select districts of agro-climatic zones of Himachal Pradesh. Una, Hamirpur, Solan and Kangra districts of Himachal Pradesh were selected purposively from Zone-I, Mandi and Sirmaur districts from Zone-II, Shimla and Kullu districts from Zone-III and Chamba and Kinnaur districts were selected from Zone-IV. The survey covered 120 rural farm households from each agro-climatic zones of Himachal Pradesh. Thus, a sample of 480 rural farm households was ultimately selected from four agro-climatic zone of Himachal Pradesh by adopting probability proportion method. The required information was collected from the sample households with the help of pre-tested survey schedule during 2020-21. The data pertaining to income of agricultural households in Himachal Pradesh from various sources viz., agriculture, livestock, wages and salaries and non-farm income were collected from selected households.

The four major income sources were crop farming, livestock, wages and salaries and non-farm business. Income from crop farming is from the cultivation of various seasonal and annual crops. Income from livestock is earned by a household from the sale of various products like milk, eggs and live animals. Wages and salaries are derived by various household members employed in labour outside their household – either in other's fields or in non-farm enterprises. Income from wholesale and retail trade, manufacturing, transportation and storage, accommodation and food service, construction and other services were covered under non-farm business. Some households reporting unusual and high negative income from crops and livestock farming were removed from the dataset to avoid their possible influence on the estimates of our substantive interest.

Analytical approach: Gini coefficient and Theil index have been used. Gini coefficient has been computed to explain the inequality across various zones of Himachal Pradesh. Following Kaditi and Nitsi (2011), vertical decomposition of inequality (Gini coefficient) was performed to measure the contribution of various income sources to total inequality. Apart from decomposing inequality by income source, horizontal decomposition of inequality into within and between zones was obtained by the Theil index, which provided information on how inequality arises from variation of economic opportunities across zones.

Gini coefficient and vertical decomposition of inequality:

Following Lerman and Yitzhaki (1985), the Gini coefficient for total income inequality, *G*, was computed as follows

$$G = \sum_{k=1}^{K} S_k G_k R_k \qquad (1)$$

Where S_k represents the share of source *k* in total income and reflects how important the income source is with respect to total income, G_k is the source Gini corresponding to the distribution of income from source *k* indicating equality/inequality of income distribution from a given income source, and R_ki s the Gini correlation of income from source *k* with the distribution of total income indicating how a given income source is correlated to the total income of a household.

In eq. (1),

$$G_k = 2Cov\,(Y_k, F_k) / \overline{Y}_k \qquad (2)$$

and

$$R_k = Cov\,(Y_k, F)/Cov\,(Y_k, F_k) \qquad (3)$$

Where $\overline{Y}_k$ is the mean income from income source k, Cov(Y_k, F_k) is the covariance between income component k and its cumulative distribution, Cov(Y_k, F) is the covariance between income component k and cumulative distribution of total income.

Further, using the Gini decomposition by income source, the effect of changes in a particular component on inequality can be estimated, holding income from all other sources constant. Assuming a change in each household's income from source equal to *e*, where *e* is close to 1, then the partial derivative of the Gini coefficient with respect to a percentage change e in source k will be

$$\frac{dG}{de_k} = S_k(R_k G_k - G) \qquad (4)$$

Then, the marginal effect of the income source relative to the overall Gini can be obtained by dividing eq. (4) by overall Gini coefficient as follows

$$\frac{dG\ /(de_k)}{G} = \frac{S_k R_k G_k}{G} - S_k \qquad (5)$$

Following Kimhi et al robustness of the marginal effect was observed using bootstrapping techniques.

Theil index and horizontal decomposition of inequality: The Theil index is one of the two most commonly applied inequality measures

The key advantage of Theil index is that unlike the Gini coefficient the total amount of inequality measured by it can be decomposed into two additive components of between group and within group inequality as

$$I = \sum_{m=1}^{m} [\frac{N_m}{N}] \left(\frac{\overline{Y}m}{\overline{Y}}\right) \ln\left(\frac{\overline{Y}m}{\overline{Y}}\right) + \sum_{m=1}^{m} \{\frac{N_m}{N}\frac{\overline{Y}m}{\overline{Y}}) \,\mathrm{Im} \qquad (6)$$

Where m equals the number of groups (zones in the present case), N and N_m the total number of households and the number of households in group m respectively, Y_m the monthly income of a household in group *m* and $\overline{Y}$ is the mean income of all households. The first and second term of eq. (6) represents between group and within group inequality respectively.

As a small number of households in the dataset was total or source as negative or zero and these numbers were not a significant proportion of the total sample, m negative and zero values were replaced with very small positive value (e) following Bellu and Liberati (2018).

In this study, e is taken as 10^{-10}.The analysis has been carried out using Stata/SE..

RESULTS AND DISCUSSION

Household income composition across income quintiles: Agriculture has been found to be the biggest source of income for farm households and it makes up 42.91 per cent of the total income on an average (Table 1), while wages and salaries activities, with a share of 32.01 per cent of the total income, comprise the second largest income source after agriculture. Non-farm income contributes only 13.52 per cent to the total household income. On an average animal production contributes only 11.52 per cent to the total household income. The difference in the contribution to income by various sources across income quintiles is pronounced. It is worthwhile to note that agriculture is the dominant source of income for the bottom quintile (20 per cent households), accounting for nearly 51 per cent of their total household income. Wages and salaries and livestock are the other major sources of income for these households. Share of livestock in total income decreases on moving from the bottom to top quintile, while on the contrary, share of crop cultivation tends to be higher in the higher income quintile.

The share of non-farm in total income is maximum (19.51%) for the top 20% of households. This pattern of income distribution indicates that the poor households depend mainly on the agriculture and wage labour and while the rich specialize towards non-farm activities. The declining share of agriculture and livestock income from the bottom to top income quintile, and rising share of wages and salaries, and non-farm income point towards the fact that income and employment opportunities in Himachal Pradesh is increasing. The large farmers may not prefer livestock as it is labour intensive. These trends also point towards the distress nature of wage work in the farm and non-farm sectors and other business activities in the non- farm sector.

Inequality Decomposition by Income Sources

Decomposing overall income inequality: It was observed that not all the households earn from all the activities, therefore, zero income value from the sources magnified the component's Gini (G_k) the Gini index of total income (Table 2). The Gini for non-farm income (G_k) is highest (0.732) followed by that for wages and salaries (0.449). The, income from wages and salaries is most equally distributed (yet it contributes maximum (43.63%) in total inequality as it is a

Table 1. Sources of income of farm households by income quintile

Quintile	Average income (INR/Household)	Agriculture income (%)	Livestock income (%)	Wages and salaries (%)	Non-farm income (%)
Bottom	402388.78	50.56	17.16	26.88	5.41
Second	552180.05	49.10	13.87	25.77	11.26
Third	646340.63	46.01	12.31	32.12	9.57
Fourth	760023.49	42.35	10.84	32.27	14.54
Top	1076842.38	35.41	8.20	36.88	19.51
Overall	687555.06	42.91	11.52	32.01	13.62

Source: Computed by the authors using data from farm households major source of income (S=0.321). The high correlation of wages and salaries with total income (R = 0.597), showing that households which are above in the total income strata derive more income from wages and salaries activities, also contributed its share in total inequality (Fig. 1).

The lowest value of Gini correlation in the case of livestock (R_k = 0.172) indicates the biasness of the income source towards lower income quintile. This source has the potential to reduce overall income inequality. Wages and salaries and livestock inequality increasing in its effect; other factors remaining constant, 1% increase in income from wages and salaries and livestock, increases total inequality by 0.115% and 0.140%. Income from agriculture and that from livestock tend to significantly reduce income inequality in the state. Pavithra and Vatta (2013) have also reported prevalence of high income inequality in Punjab with Gini coefficient of 0.52; however, they reported that income from non-farm activities decreases income inequality. Vatta and Sidhu (2007) reported that non-farm sources reduce the overall income inequality in the state. In light of this, it is important to mention that the unease in the findings reported here regarding the nature of impact of non-farm source on inequality among households is mainly attributed to the differences in the concept of a household and consideration of activities under non-farm sources in earlier studies.

Decomposition of overall income inequality by agro-climatic zones of Himachal Pradesh: Himachal Pradesh with an area of 55,673 sq. km has various agro-climatic situations. The state has been divided into four agro-climatic zones on the basis of homogeneity, altitude, rainfall pattern, cropping pattern, etc. as: sub-mountain low hills sub-tropical (Zone -I), Mid-hills sub-humid (Zone-II), High hills sub temperate wet (Zone-III), and High hills sub temperate dry (Zone-IV) (Fig. 2, Table 3). The present study further disentangles the income inequality by income sources across the various agro-climatic zones of Himachal Pradesh. Income of households is more unevenly distributed in the Zone-II, and Gini index for the Zone-II (G_k =0.231) is higher than that of the Zone-IV (G_k =0.212), Zone-III (G_k =0.174) and Zone-I (G_k =0.130) of the state (Table 4). Distribution of income among households is comparatively more equal in the sub-mountain low hills sub-tropical zone. However, agriculture is the major income source across all Zones; a wide disparity exists among the share of other sources in the total income. Wages and salaries is the second major source across all Zones and has significant share in the total income in the Zone-I (S_k =30.8%). Livestock has significant share in the total income in the Zone-I (S_k =11.9%), while in the Zone-IV it contributes only (S_k =8.1%) to the total income of the

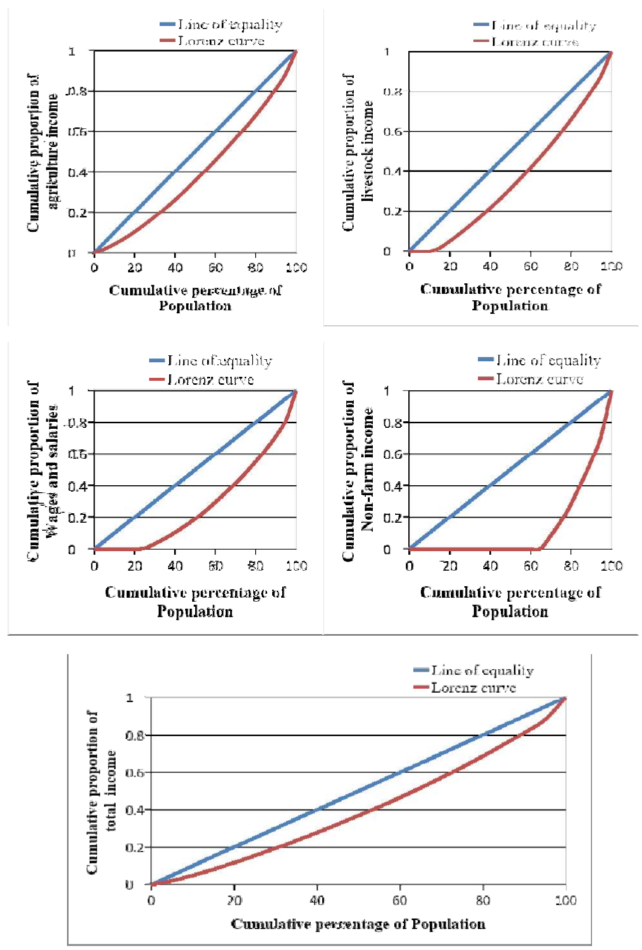

Fig. 1. Lorenz curve of income sources

Table 2. Decomposition of inequality by sources of income

Source of income	Income share (S_k)	Source Gini (G_k)	Gini correlation (R_k)	Share in total Gini	Marginal contribution to Gini/% change
Agriculture	0.428	0.215	0.554	0.258	-0.169(0.0347)*
Livestock	0.115	0.285	0.172	0.028	-0.086(0.0129)*
Wages and salaries	0.321	0.449	0.597	0.436	0.115(0.0456)*
Non-farm income	0.136	0.732	0.547	0.276	0.140(0.0336)*
Total income		0.197			

Source: Computed by the authors using data from farm households
Note: Figures in parentheses indicates bootstrapped standard error
*,@ and + statistical significance at 1,5 and 10 % levels

households. Non-farm activities is an important source of income after agriculture and livestock in the Zone-I. Further, earnings from agriculture, with an exception in Zone-III, contribute maximum to total income inequality and are significantly inequality increasing in their effect across all the zones. Wage and salaries has the highest share in Gini coefficient in the Zone-IV (64.5%),

1% increment in income from wages and salaries activities, ceteris paribus, would significantly increase inequality by 22.9% in the region. Therefore, any effort to bridge the inequality gap in the zone should not be wage and salary oriented. The non-farm income is the most unequally distributed in Zone-IV (G_k =0.754) followed Zone-II, Zone-III and Zone-I.

Decomposition of income inequality within and between agro-climatic zones: Theil index is more for 'within' the zone

Table 3. Agro-climatic zones of Himachal Pradesh, India

Agro-climatic zones	Districts covered	Major crops grown	Altitude (m)	Average rainfall (mm)	Cropping intensity (%)
Sub-mountain low hills sub-tropical (Zone -I)	Una, Bilaspur, Hamirpur, Solan and Kangra	Wheat, Maize, Paddy, Gram, Sugarcane, Mustard, Potato, Vegetables	Up to 650	1100	185
Mid-hills sub-humid (Zone-II)	Mandi and Sirmaur	Wheat, Maize, Barley, Black Gram, Beans, Paddy	651-1800	2200	187
High hills sub temperate wet (Zone-III)	Shimla and Kullu	Wheat, Barley, Lesser Millets, Pseudo-cereals (Buckwheat and Amaranthus), Maize and Potato	1801-2200	1000	179
High hills sub temperate dry (Zone-IV)	Chamba, Kinnaur and Lahul-Spiti	Wheat, Barley, Pseudo-cereals (Buck wheat and Amaranthus)	Above 2200	Snow fall	133

Source: Himachal Pradesh Department of Revenue

Table 4. Decomposition of inequality by sources across agro-climatic zones

Agro-climatic zones	Source of income	Income share (S_k)	Source Gini (G_k)	Gini correlation (R_k)	Share in total Gini	Marginal contribution to Gini/% change
Zone-I	Agriculture	0.445	0.088	0.575	0.173	-0.272(0.031)*
	Livestock	0.119	0.187	0.090	0.015	-0.104(0.018)*
	Wages and salaries	0.308	0.282	0.647	0.434	0.126(0.048)@
	Non-farm income	0.126	0.677	0.572	0.336	0.250(0.059)*
	Total income		0.130			
Zone-II	Agriculture	0.416	0.295	0.768	0.409	-0.007(0.070)*
	Livestock	0.118	0.272	0.233	0.032	-0.086(0.023)*
	Wages and salaries	0.339	0.328	0.569	0.275	-0.064(0.070)
	Non-farm income	0.129	0.739	0.701	0.283	0.157(0.078)@
	Total income		0.231			
Zone-III	Agriculture	0.488	0.199	0.495	0.277	-0.212(0.054)*
	Livestock	0.147	0.301	0.358	0.091	-0.056(0.045)
	Wages and salaries	0.204	0.576	0.458	0.309	0.105(0.077)
	Non-farm income	0.159	0.738	0.477	0.322	0.162(0.092)+
	Total income		0.174			
Zone-IV	Agriculture	0.371	0.206	0.344	0.123	-0.247(0.043)*
	Livestock	0.081	0.311	0.075	0.008	-0.072(0.017)*
	Wages and salaries	0.415	0.450	0.733	0.645	0.229(0.075)*
	Non-farm income	0.133	0.754	0.471	0.222	0.089(0.069)
	Total income		0.212			

Source: Computed by the authors using data from farm households
Note: Figures in parentheses indicates bootstrapped standard error
*,@ and + statistical significance at 1,5 and 10 % levels

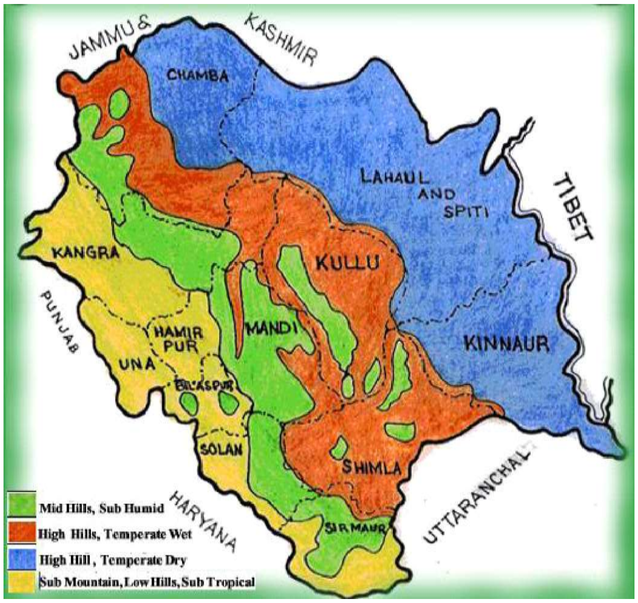

Fig. 2. Agro-climatic zones of Himachal Pradesh

Table 5. Theil index of inequality by agro-climatic zones

Source of income	Agro-climatic zones	
	Between	Within
Agriculture	0.0039	0.0895
Livestock	0.0139	0.2023
Wages and salaries	0.0465	0.4103
Non-farm income	0.0096	1.2237
Total income	0.0038	0.0794

Source: Computed by the authors using data from farm households

than the corresponding 'between' values for all the sources as well as total income (Table 5). Choudhary and Singh (2020) also observed that the value of Theil index is more for within the zone and district than the corresponding between values for all the sources as well as total income. This indicates that intra-zonal inequality is the main contributor in total inequality in the zones respectively. Therefore, policies aimed at the elimination of income differences between the various agro-climatic zones would not be more meaningful. Orientation of efforts within a geographically aggregated district represented by agro-climatic zones would be more imperative for smoothening the income inequality of agricultural households in Himachal Pradesh.

CONCLUSIONS

Improving the income of agricultural households and their even distribution among them is the basic goal of any policy intervention in agriculture. The present study estimated the inequality prevailing among agricultural households in Himachal Pradesh and examined the state's effect on income inequality from various sources of income that would be crucial from a policy perspective. In almost all quintiles, crop production is the major source of income. On the opposite wages and salaries are the potential source to bridge the inequality gap. Therefore, strategic measures to improve these sub-sectors and to enable households to diversify their sources of income will also have a stronger redistributive impact of farmers' income. Nevertheless, it is important to keep in mind that in the Zone-IV income from wages and salaries triggers inequality in the region. Therefore, contribution of income sources to zonal inequality should be kept in mind during policy formulation and functioning. Further, it is important to re-emphasize that non-farm sources have significant equalizing effect in the Zone-I, Zone-II and Zone-III of the state. Hence, their contribution to rural Himachal Pradesh sustainable growth cannot be completely ignored. Finally Theil index decomposition shows that within group inequality is the key contributor to overall disparity across agro-climatic zones. Therefore, policy intervention at zonal level would be imperative for correcting spatial imbalances in income distribution among agricultural households of Himachal Pradesh, and would cover the way for their comprehensive and more unbiased development.

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Received 10 January, 2022; Accepted 22 March, 2022

Indian Journal of Ecology (2022) 49(2): 643-646
DOI: https://doi.org/10.55362/IJE/2022/3573

Manuscript Number: 3573
NAAS Rating: 5.79

Comparison of First and Second Waves of COVID-19 in Metropolitan Chennai City

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Abstract: The study aims to perform a comparative analysis of new cases of COVID-19 reported during the peak time of two waves in Chennai city in 2019-2020.Eight zone-wise variables for 15 zones of Chennai City were studied. They were reduced to fewer factors using a dimension reduction technique called factor analysis, and a standardized index value for each zone and two waves was obtained. The region of hot spots was identified using the Kriging interpolation method using the standardized index value. During wave 1, the average daily number of deaths, new cases, and active cases was 37, 2071, and 21163, respectively, but it was 76, 6663, and 39385 in the second wave. The second wave has a two times higher number of deaths, 3.2 times higher number of new cases, and 1.8 times of active cases. The first wave had a higher percentage of infected people aged 40 years or older, whereas it was more people aged 10-39 years in the second wave. The Krigged estimates showed comparison showed the regions at a higher risk of COVID-19 transmission. Population demographics play a vital role. The zone with a more slum population (Sholiganallur) does not show much intensity of new cases.

Keywords: COVID-19, Two waves, Hot spots, Chennai city

COVID-19, a new virus from SARS-Cov-2 that arose in 2019 during a pneumonia outbreak in Wuhan, China, has sparked a global pandemic and caused significant health problems worldwide. The two waves have affected many countries. The first case of COVID-19 was reported in India on 30 January 2020, while the index case in Tamil Nadu was reported on 7 March 2020 from Chennai City, Tamil Nadu (Chennai Corporation 2020). One of the metropolitan cities, Chennai, has the highest daily number of Covid-19 cases and the fastest growth rate of new cases (Chennai Corporation 2020). In the last week of June 2020, new cases peaked. As a result, the Indian government has implemented a series of preventative measures, including four phases of lockdowns (24 March 2020 to 14 April 2020; 15 April 2020 to 3 May 2020; 4-17 May 2020 and 18-31 May 2020) (Directorate of public health 2021), followed by a gradual return to normalcy in social interaction, workforce, and commercial activity. Except for the necessary wearing of face masks, maintaining social distance, and hand washing routines, life in the city has returned to normal as of July 2020. Unfortunately, the number of new Covid-19 cases has begun to rise, reaching a peak in the second week of May 2021(Directorate of public health 2021). The State Government was forced to reintroduce the Janata curfew, which meant a strict regional lockdown (Greater Chennai Corporation 2021), in which people were asked to stay at home, avoid national and international travel, industrial lockdown, educational institution closures, avoid mass community gatherings, close bars, and restaurants, wear masks, and maintain social distance. The government's priority is to keep the workload on the healthcare system to a minimum, limit population infection, and provide better health care to sick people (Indian Institute of Technology 2020). This study aims to compare new Covid-19 cases reported in Chennai city during the peak of two waves in 2019-2020. A dimension reduction technique, factor analysis was used for each zone and two waves, and a standardized index value was obtained. Further hot spots were obtained using the standardized index values and the Kriging method.

MATERIAL AND METHODS

Chennai city profile: Chennai is the fourth largest metropolitan city in India, with a population of 8 million (Indian Institute of Technology 2020). It is located in the north-eastern part of Tamil Nadu and lies between latitude 12°50'4" and 13°17'24" and longitude 79°58'53" and 80°20'12". It is the capital of Tamil Nadu, one among the 38 districts, and comprises an area of 626.435sq Km. It is divided into 200 wards and 15 zones, namely Thiruvottiyur, Manali, Madhavaram, Tondiarpet, Royapuram, Thiruvikanagar, Anna Nagar, Teynampet, Kodambakkam, Valasaravakkam, Alandur, Perungudi, and Shollinganaluur(India Today 2021, Jain VK 2021).

Data collection: The study used secondary data that has been collected from various sources(Jain 2021, Manly BFJ 1986, Rukmini 2021, Sekhar 1991). During wave_1 (w1), the number of new cases peaked in the last week of June 2020 and during the wave_2 (w2) in the second week of May 2021. The zone-wise average number of deaths, new cases, and active cases per day during the peak week has been considered for the analysis. Five zone-wise variables considered for the analysis are the area in sq km, the number of households (HH), total population, male population, and slum population (Jain VK 2021). A dimension reduction technique of factor analysis(State planning commission 2017, Times of India 2021, The Economic Times 2021, Vasna J 2012) has been used to reduce the above eight variables into fewer factors highly inter-correlated variables are the necessary measure for factor analysis. The suitability of the data set for the study has been assessed using Bartlett's test of sphericity, Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy.

The steps involve examining the correlation matrix and then extracting factors that can be improved using varimax rotation. It helps to maximize the variance of each factor. The eigenvalues show the variance explained by each factor. The factor analysis technique extracts common variance from all variables given as input and assigns fewer factor scores. A standardized index value for each zone(factor score of each zone minus minimum score / Maximum score minus minimum score) was obtained using the factor scores, and the percentage of variation was explained as weights. The index value was obtained for each wave then individually integrated into ArcGIS 10 software (ESRI, Redlands, CA, USA). The centroid point of the zone has been considered as a location parameter (latitude and longitude). The spatial interpolation method of kriging has been applied for points not measured. Finally, a map with kriged estimates of Covid transmission using eight variables for the Chennai Metropolitan City was obtained.

RESULTS AND DISCUSSION

The total number of new cases during the peak week of w1 (starting from 28 June 2020 and ending 4 July 2020) had 14497 new cases and 264 deaths. The total number of new cases during the peak week of w2 (9 May 2021 and ending 15 May 2021) had 46642 new cases and 529 deaths. The per-day average number of deaths, new cases, and active cases during w1 was 37, 2071, and 21163, whereas, in w2, was 76, 6663, and 39385, respectively. Comparing deaths per day in w1 was higher in Tondiarpet and Teynampet and in w2, it was Thiru-vi-ka Nagar. When it comes to new and active cases, Anna Nagar was in both waves (Table 1). All the eight variables included have been standardized to eliminate different scales of measurement. The correlation coefficient was>0.3 in absolute value. Bartlett's test is highly significant, and KMO's test value was 0.7, an acceptable value for factor analysis. The reduction technique extracted two factors from the eight variables studied. The male population, slum population, number of HH were identified as the priority factor. The second factor consists of the zonal area. Both the waves have shown similar results except for the percent of variation explained. Using w1data, the percentage of variation explained by the two factors were 62.7 and 19.7%, respectively; and in w2, was 63 and 16.6%, respectively. Comparing two waves independently as per the index value,

Table 1. Demographic details and COVID-19 case details of Metropolitan chennai City

Zone No	Zone name	Lat	Long	Area in sq Km	No. of Households	Population	Male population	Slum population	Wave_1 (28.6.2020 to 3.7.2020) Average Deaths per day	Average New cases per day	Average Active cases per day	Wave_2 (9.5.2021 to 15.5.2021) Average Deaths per day	Average New cases per day	Average Active cases per day
1	Thiruvottriyur	13.1643	80.3001	28.51	70300	322600	162107	23325	2	98	1080	2	229	1368
2	Manali	13.1779	80.2701	42.33	19161	131868	69007	0	0	53	456	1	131	619
3	Madhavaram	13.1488	80.2306	40.55	49007	196027	99954	0	1	84	889	3	322	1583
4	Tondiarpet	13.1261	80.2880	23.83	161927	647694	324430	39098	6	172	1879	4	449	2342
5	Royapuram	13.1137	80.2954	42.33	158687	634742	322703	11045	4	200	2241	3	350	2033
6	Thiru-vi-ka nagar	13.1199	80.2342	42.33	178923	751695	368105	38440	3	168	1712	12	561	3128
7	Ambattur	13.1143	80.1548	43.07	127519	509460	256411	636	1	134	1059	6	647	3880
8	Anna ngar	13.0850	80.2101	25	160968	643895	321690	26984	3	243	2739	11	686	4155
9	Teynampet	13.0405	80.2503	25.19	125401	754670	380957	68032	6	227	2142	7	560	3521
10	Kodambakkam	13.0521	80.2255	22.4	167630	670504	338001	39098	4	234	2339	10	628	3903
11	Valasaravakkam	13.0403	80.1723	28.51	88120	345961	174641	6410	2	115	1104	4	500	3141
12	Alandur	12.9975	80.2006	41.5	66133	265297	133153	0	1	60	789	3	332	2092
13	Adayar	13.0012	80.2565	136.32	128724	1157053	588940	45540	3	136	1551	6	656	3879
14	Perungudi	12.9654	80.2461	42.33	85607	343518	173751	0	1	106	674	3	391	2266
15	Sozhanganallur	12.9010	80.2279	42.23	49102	172094	87458	124000	0	41	509	1	221	1475
Total				626.43	1637209	7547078	3801308	422608	37	2071	21163	76	6663	39385

six zones were at higher risk of transmission of COVID-19 infection, whereas nine zones were in w2. The index value greater than 50 (average value) in w1 (Table 2) zones are Kodambakkam, Anna Nagar, Teynampet, Tondiarpet, Royapuram, and Thiru-vi-ka-Nagar was at greater risk of Covid_19 transmission of infection. In contrast, zones Madhavaram, Alandur, Sholiganallur, and Manali have shown less risk of transmission. In w2, Anna Nagar, Kodambakkam, Thiru-vi-ka-Nagar, Teynampet, Ambattur,Adayar, Tondiarpet, Valasaravakkam and Royapuram have shown a greater risk of Covid-19 transmission of infection. In contrast, zones Madhavaram, Thiruvottriyurr, Sholiganallur, and Manali showed less risk of transmission. During the peak week of w1 and w2, the infected persons of ≥40 years were higher in w1 than w2. The infected persons of less than 10 yrs and ≥80 years were almost similar in both the waves. In contrast, the percentage of infected persons aged 10-39 years was higher during w2 than w1.The percentage of males has been significantly higher than the females (Fig. 2). The central region was at higher risk compared to the North and South regions (Fig. 3A and 3B). The map showed in w1 the hot spot zones were mainly Royapuram, partly Tondiarpet, Thiru-vi-ka-Nagar, Anna Nagar, and Kodambakkam. The map of w2 shows the cold spots diminished, and high concentration has moved up to Ambattur.

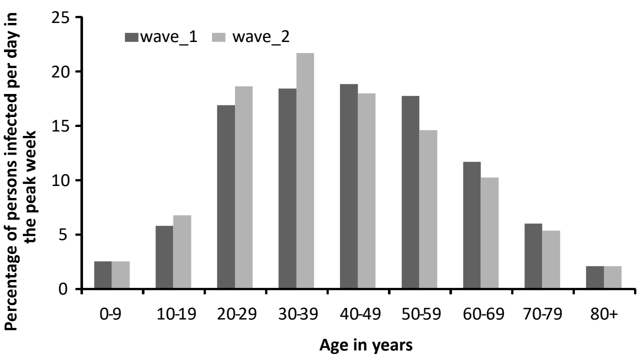

Fig. 1. The age distribution of COVID-19 infected persons in wave_1 and wave_2 during the peak week

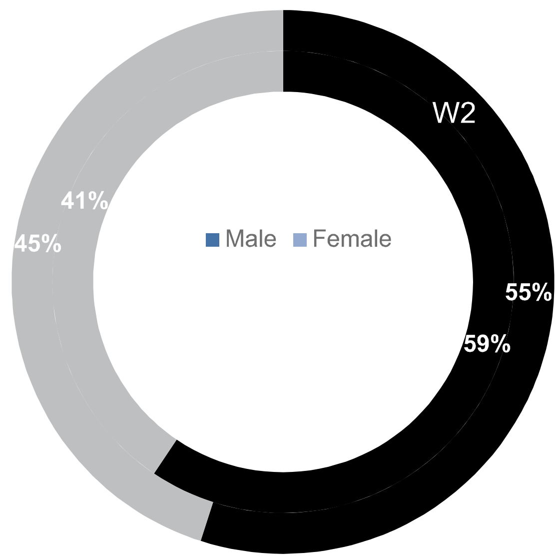

Fig. 2. Percentage distribution of COVID-19 infected persons in wave_1 and wave_2 during the peak week

Table 2. Standardized score for wave_1 and wave_2 of Metropolitan Chennai city

Zone	Name	wave_1 standardized index value	wave_2 standardized index value	Difference in the value
z10	Kodambakkam	100.00	95.40	4.60
z8	Annanagar	99.80	100.00	-0.20
z9	Teynampet	99.00	77.4	21.60
z4	Tondiarpet	92.50	63.3	29.20
z5	Royapuram	86.50	52.4	34.10
z6	Thiru-vi-ka nagar	75.90	91.90	-16.00
z7	Ambattur	44.00	75.50	-31.50
z11	Valasaravakkam	42.20	53.90	-11.70
z13	Adayar	40.20	70.40	-30.20
z1	Thiruvottriyur	36.40	23.70	12.70
z14	Perungudi	27.00	39.10	-12.10
z3	Madhavaram	19.50	24.00	-4.50
z12	Alandur	18.30	31.30	-13.00
z15	Sholinganallur	2.60	7.90	-5.30
z2	Manali	0.00	0.00	0.00

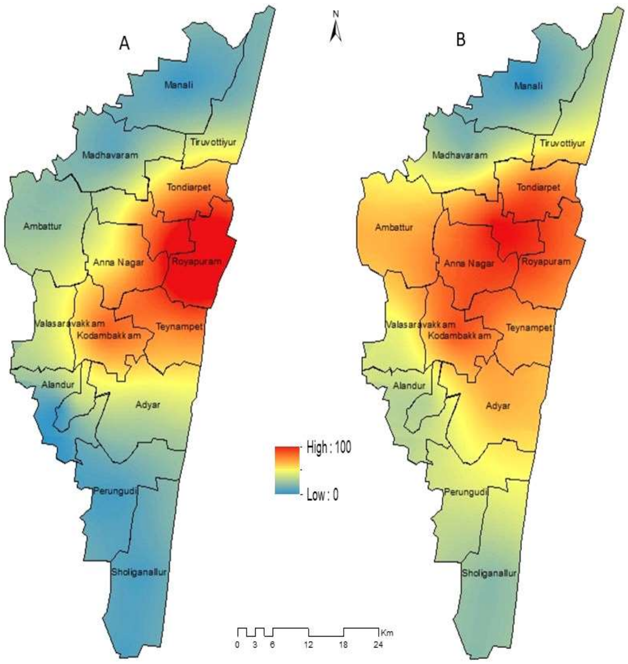

Fig. 3. Zonal variation of the kriged estimates of COVID-19 disease during wave_1 and wave_2

CONCLUSION

The Metropolitan Chennai city was considered a hot spot area covering nearly 63 and 50% of the cases during the first and second waves of Tamil Nadu (Vasna Joshua 2021, Wikipedia 2021). The second wave has a two times higher number of deaths, 3.2 times higher number of new cases, and 1.8 times of active cases. Population demographics play a vital role, whereas the zone with a more slum population (Sholiganallur) does not show much intensity of new cases. The study has used zone as a unit of analysis. If finer grid points like wards have been used more precisely, it would be possible to pinpoint the hot and cold spots. The data used have been reported from different sources that are openly available. The demographic data have been to refer to the year 2017. The analysis has used the average number of new cases in a peak week rather than the peak day since the rise in many COVID-19 cases on any particular day may not be exact. Since there may be a delay in reporting the test results and also due to more testing done in the second wave (Wikipedia 2021). Due to limited information, the trend pattern could not be assessed.

Received 12 September, 2021; Accepted 02 April, 2022

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Indian Journal of Ecology (2022) 49(2): 647-650
DOI: https://doi.org/10.55362/IJE/2022/3574

Manuscript Number: 3574
NAAS Rating: 5.79

Assessment of DNA Damage in Blood of Iraqi Museum Workers

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Abstract: This study was done to evaluate the risk of natural alpha emitter's concentrations in blood of museum employees and any potential DNA damage that may be linked to it. The current research was conducted on employees in State board of antiquities and heritage, Abd al-karim qasim museum and Iraqi museum. Blood samples were collected from 30 participants in employees group and 30 participants in controls group that was collected from general population. Alkaline comet assay has been used to assess DNA damage in lymphocytes of participants. The results showed higher DNA damage and high comet L/W value in employees (1.56) compared with control group (1.1).The smokers have increased average L/W value compared to participants who never smoked in employee group. From this study concluded based on these results, exposure of museum employees and archaeologists to natural ionizing radiation may have increased risk to DNA damage and cancer compared to non-occupational employees.

Keywords: Comet assay, DNA damage, Lymphocytes, Museum, Radon gas

Radiation is known for causing DNA damage (Yusuf et al 2020, Surniyantoro et al 2020). It is also a known carcinogen Some studies has also suggested that DNA damage can also be caused by chronic low level natural radiation (Sinitsky and Druzhinin, 2014, Walczak et al 2020). In addition to that, a study has found adoptive response in people who live in chronic low dose natural radiation (Kumar et al 2015, Mohammadi et al 2006). High radon concentrations has been measured previously in old heritage buildings (Nastro et al 2018, Mansor and Rashid 2020), the state board of antiquities and heritage and the Iraqi museum. The radon levels were measured and an average of 702 Bq/m^3 has been obtained very similar to the study mentioned above. Likewise, the study was carried in Abd al-karim qasim antique museum building employees. In the current study, the risk of high natural alpha emitter's concentration was assessed by the help of comet assay to detect any genotoxic effects of high alpha radiation compared to the controls of general population. Comet assay is selected based on many researches that suggested it to be suitable for DNA damage and genotoxic effects caused by ionizing radiation and more importantly due to the effects of ionization that form ions when interacting with the target materials and these ions is attracted by applying voltage to reveal the comet tail that are composed of damaged DNA fragments (Ostling and Johanson 1984) and even used to detect environmental radiation damage of low doses (Azqueta et al 2009, Druzhinin et al 2015). Alkaline comet assay was used to detect more DNA damage types than the neutral comet (Singh et al 1988). The aim of this study is to find a link between the type of occupation and DNA damage.

MATERIAL AND METHODS

The current research was approved by the institutional review board (IRB) in Al-Nahrain school of medicine. Experiment was in accordance with Helsinki Declaration of 1975. Written Informed consents were signed from each participant to be enrolled in the research. This research enrolled 60 participants in total divided into two groups: 30 people were in the first group collected from general populations. 30 participants were in the second group from the sites. All participants answered detailed questionnaire involving general personal information and also included years of work, smoking habits, if diagnosed or treated from cancer, recent radiation exposure, current infections, family history or genetic diseases and chronic diseases. This study was carried out as mentioned previously in State board of antiquities and heritage, Iraqi Museum and Abd al-karim qasim museum all located in Baghdad, Iraq.

The protocol that is used in this study is similar to a previous protocol (Dhawan et al 2021). In short, after preparation of solutions as described in the previous reference, comet assay slides were prepared by dipping them in methanol and slides wiped clean and left to completely dry. To cover slides, normal melting agarose (NMA) used to cover the slides. The slides were kept overnight to adhere and solidify. Using disposable syringe and needle, 3 ml of vein blood were drawn and placed immediately into a 3 ml EDTA tubes. The blood was saved in cold container and transported to refrigerator to preserve it. Next, either lymphocytes are isolated, or can use whole blood both with good results (Singh et al 1988). After the first layer was solidified, low melting agarose (LMA) and blood mixture were added in second layer and LMA for the third layer and allow the agarose to solidify between layers and coverslips were replaced and now the slides are prepared. Afterwards, lysing solution were used to dip slides in it and kept it for 2 hours in refrigerator at 4°C. When time is done, slides were placed on the box arranging them together with no spaces between them. Allow them for 20 minutes in electrophoresis solution before performing electrophoresis at24 volts, 300 mill amperes for 30 minutes. After the electrophoresis is performed, the slides were placed in neutral solution to end the reactions for 5 minutes and repeated for 3 times. Lastly, stained the slides with ethidium bromide stain and kept the slides in the stain for 5 minutes then the slides were immersed in distilled water and coverslip was placed then observed under fluorescent microscope. The images were taken and calculations are made on these images using Image J program.

RESULTS AND DISCUSSION

Results were calculated based on the circular shape of cells. L/W value represent L for length of the circular cell and divided that number by width represent the width of circle with 90° angle to each other representing a + sigh. Considering these facts, the L/W value of 1 is the normal preferable value. When this value increases, there is more DNA damage and a comet tail was formed.Average L/W values of comet assay were observed in the blood of employees equal to (1.56) compared to control group (1.1). Employees on average have more DNA damage therefore longer comet tails and L/W value > 1. The L/W that is represented here is also representing the average of multiple random cells selected in the slide for each participant. Table 1 represents each participant and information about them and their resulted L/W e in employee group and Table 2 for control group. Numbering for participant is done according to the time of blood donation.

Refer to Figures 1 and 2; represent the L/W value for each participant. Figure 1 represent employees group and Figure 2 represent controls group. The employees group has more DNA damage than the control group. There was no value that is less than 1. There was an association between smoking and increased DNA damage observed in employees group.The smokers have increased average L/W value compared to never smokers in employee group (Fig. 3).

High alpha emitters concentrations like indoor radon gas, together with high radionuclides and other chemicals d in cigarettes increase the DNA damage that a person is exposed to and increases the chance of developing lung cancer by folds for smoking personnel (Who Handbook bn Indoor Radon A Public Health Perspective 2009). Workers in museums are constantly in contact with dusty old antiques or investigate ancient buildings. These antiques are usually made of natural earthy materials that contain natural

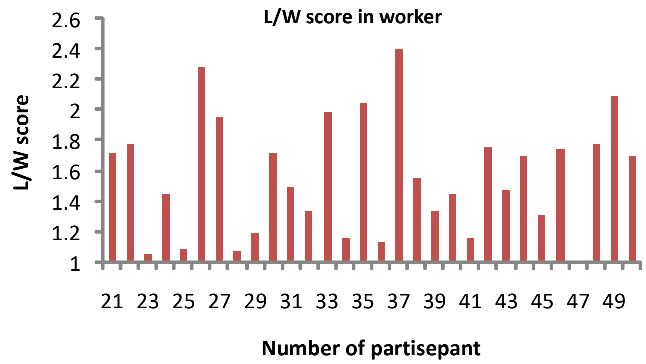

Fig. 1. L/W value for each employee

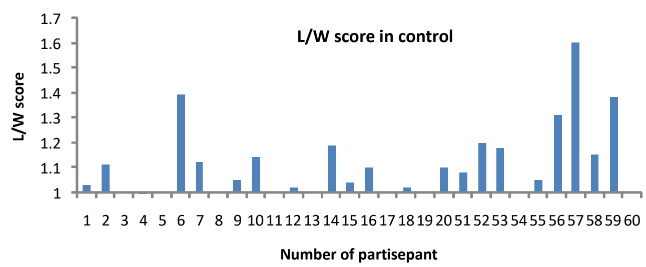

Fig. 2. L/W value for control

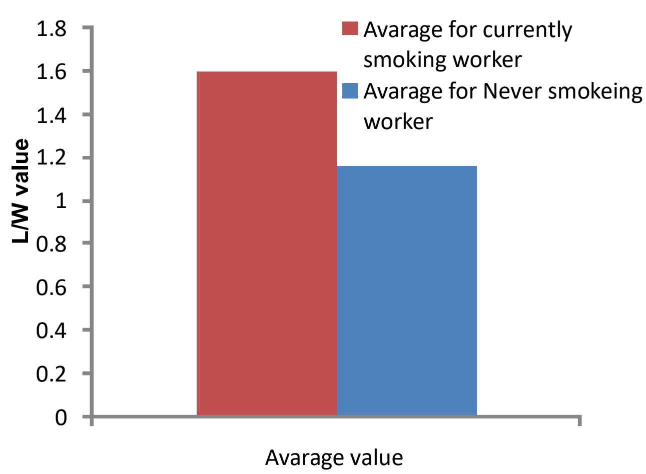

Fig. 3. Average L/W value for smokers compared to average value for non-smokers in employees group

Table 1. Number of participants and their age, duration of employment and L/W for each participant in employee group

No. of participant	Age (years)	Duration of employment (Years)	L/W	No. of participant	Age (years)	Duration of employment (Years)	L/W
21	32	1	1.72	36	29	1	1.14
22	30	1	1.78	37	26	1	2.4
23	32	1	1.05	38	30	1	1.56
24	29	1	1.45	39	28	5	1.33
25	53	28	1.09	40	41	7	1.45
26	50	1	2.28	41	29	1	1.16
27	24	1	1.96	42	55	25	1.76
28	30	1	1.08	43	55	34	1.48
29	45	20	1.19	44	31	9	1.7
30	34	6	1.72	45	49	20	1.31
31	47	13	1.5	46	34	1	1.75
32	59	28	1.34	47	38	8	1
33	59	18	1.99	48	56	2	1.78
34	27	1	1.16	49	34	7	2.1
35	26	1	2.05	50	22	1	1.7
Average	-	-	-	-	37.8	8.16	1.56

Table 2. Number of participant age and L/W value for control group

No. of sample	Age (years)	L/W	No. of sample	Age (years)	L/W
1	32	1.03	16	36	1.1
2	43	1.11	17	35	1
3	31	1	18	17	1.02
4	49	0.94	19	21	1
5	48	1	20	17	1.1
6	52	1.39	51	62	1.08
7	57	1.12	52	65	1.2
8	44	1	53	34	1.18
9	25	1.05	54	38	1
10	65	1.14	55	45	1.05
11	40	1	56	34	1.31
12	23	1.02	57	41	1.6
13	20	1	58	40	1.15
14	52	1.19	59	45	1.38
15	23	1.04	60	47	1
Average	-	-	-	39.36	1.1

radioactivity and may have dangerous materials that was unknown in old times to be of damage to human). The ignorance of safety and regulation laws and environmental contaminations often may increase contaminant in air that may damage health and cause the detected DNA damage and may become an opportunity for developing cancer. In general, soldiery lifestyle that are common in middle eastern countries, with a non-balanced diet and common health misconceptions can also be a significant factors for increased DNA damage observed (Ames 2001, Badran and Laher 2011, Mohammad 2021).

CONCLUSION

The outcome of this study demonstrated that DNA damage in employees working in museums has more DNA damage than other occupations. These participants have no signs or symptoms due to current disease, and have no genetic diseases that causes impaired DNA repair, not diagnosed or treated from cancer and no recent radiation exposure. The exposure to high natural radioactivity and type of occupation may contribute to the increased DNA damage indicated in this current research.

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Received 21 October, 2021; Accepted 02 January, 2022

Indian Journal of Ecology (2022) 49(2): 651-654
DOI: https://doi.org/10.55362/IJE/2022/3575

Manuscript Number: 3575
NAAS Rating: 5.79

Monitoring Influence of PGF2α, Estrogen and Oxytocin on Postpartum Uterine Involution by Ultrasonography in Ewes

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Abstract: The goal of this study was designed to investigate the effect of estrogen, oxytocin and PGFα on uterine involution post-partum (p.p). In addition, the times for ewes to go through involution by ultrasonographical rectal examination lead to assess the best time for insemination that ensure the highest fertilization rate to avoid endometrit is post-partum. This study carried out at sheep and goat's improvement station, state board of agricultural research in Agargof, during November 15,2020 to April 15, 2021. This study involved 30 ewes of 2-4 years old and 50-65kg body weight. Blood was collected to estimate progesterone concentration and the role of ovarian activity. Results showed a gradual decrease in uterine lumen and uterine diameter. The uterine horn diameter, at different weeks of post-partum in groups treated PGF2α was 40.63 mm at first week and decrease14.22 mm. The uterine involution in ewes treated with PGF2α on post-partum, facilitate uterine involution process in ewes and lead to remove uterine fluid (lochia) and decrease uterine size, and uterine lumen. The study proves progesterone concentration as indicator to detect Ewes' post-partum ovarian activity. The current study reveals that the ultra-sonographic approach is a viable option for uterine involution management.

Keywords: Sheep, Uterine involution, Post-partum, PGF2α, Oxytocin, Ultrasonography

Involution of the uterus includes uterine shrinkage, tissue loss, and tissue healing. (Zdunczyk et al 2004). The planectomies deteriorate within the first week following delivery, and lochia, a viscous brown fluid generated by endometrial erythrocyte autolysis, fills the uterine canal. During the second week of caruncle involution, necrotic plaques are discharged, and the lochia becomes less dense and more translucent. (Rubianes et al 1996). The caruncles re-epithelialize throughout the third and fourth weeks, and the uterine tissue mass diminishes, as seen by the considerable drop in uterine weight (Hauser and Bostedt 2002). The diameter of the uterine lumen and caruncle in German Lend ewes were measured during the first 30 days after birth, and it was discovered that in most ewes, uterine regression occurs around day 17 postpartum. However, the process was delayed in ewes that had obstetric interventions, cesarean section, or retained fetal membranes. For macroscopic uterine involution and takes around 17 to 35 days. (Fernande et al 2013). At 22 to 24 days after delivery, uterine involution is visible, and by 30 days after delivery is complete. (Ababneh and Degefa 2005). Silent ovulations can occur in ewes and are caused by inadequate steroid synthesis by the ovarian follicles. (Degefa et al 2006). The hypothalamus appears to become resistant to E2 as a result of the high levels of E2, resulting in the absence of behavioral estrus before the first postpartum ovulation. The hypothalamus becomes less resistant to E2 after being exposed to P4 released during the first luteal phase postpartum, and responds to E2 exposure in subsequent cycles. (Godfrey et al 1998). The P4 concentration seldom reaches 1 ng/mL during these short cycles, which last 3–4 days. (Hayder and Ali, 2008). P4 receptors are downregulated and oxytocin receptors are upregulated when the uterus is not exposed to P4 and estrogen before the first postpartum ovulation. From the third to the tenth day following delivery, the uterus decreases significantly, accompanied by a decrease in the frequency and length of uterine contractions. (Noakes et al 2001). Lochia, which are in a variety of hues and sizes, but are present in the uterus during normal involution. (Tzora et al 2002). The objectives of this study was to employ a Trans rectal Ultrasonography technique to directly image the reproductive system (ultrasonography is often used for pregnancy detection) and to quantify hormone levels to investigate ovarian activity in sheep.

MATERIAL AND METHODS

This research was conducted at Ruminant Researches Station – Ministry of Agriculture 25 Km North West of Baghdad (Agurgof). A total of thirty post-partum local breed ewes aged (2-4 years) with an average body weight of (50-60 kg) with a history of one lambing at least were used in the experiment. They were housed in semi opened shade regarding the nutritional regime. Careful clinical examination was done to determine that animals are healthy and free from diseases. Before starting the experiment, all ewes were submitted to trans-rectal and trans-abdominal ultrasonography to be sure that the 30 local ewes were in advance pregnancy. All ewes were signed by different numbers and colors then the females. Animals preparation for ultrasonic examination experimental animals was prepared prior examination by fasting of feed for 12 hrs. to improve the accuracy of trans rectal and transabdominal scanning. The hair on the ventral abdomen was gently trimmed and shaven (Super-Max, Green, Feltham). Prior to scanning, enough gel was given to the probe to ensure good contact and remove air between the probe and the animal's skin, and the gel was also placed on the right side of the ewe The diameter of the uterine horn and uterine lumen were measured on all ewes once a week from day one to day 42 post-partum. The liner-array prostate probe (7.5 MHz) was used to do a trans-rectal examination. After the rectum had been cleared of feces, the transducer was gently inserted into the rectum after a suitable amount of ultrasonic gel had been applied. The transducer was moved medially and laterally to provide the best view of the uterus and the greatest diameter of the uterine horn was measured and recorded on the ultrasound screen (Godfrey et al 2004, Hayder and Ali 2008). Ultrasound testing were performed using a real-time B-mode scanner with a multi-frequency (3.5 and 5 MHz), linear, and sector array transducer that produced rectangular and conical pictures. Beginning one week after delivery, uterine involution was examined weekly with a trans-rectal ultrasound examination and continuing until the commencement of ovarian activity using B-mode ultrasonography. The blood was collected from the jugular vein by vacationer's gel tubes, every 1 week after parturition to 6 weeks in post-partum. For determination of progesterone level blood samples was centrifuged at 3600 rpm for 10 minutes. Sera were collected by micropipette in small plastic tubes and kept in -20C until assay for progesterone. The skin on the jugular vein was cleaned by 70% alcohol. The needle was inserted in jugular vein in a single drive by the right hand, cotton being kept in the left hand, the tube was pressed toward the needle and held tightly until the desired amount of blood was collected about 5ml. The jugular vein is then drained of 5 ml of blood into vacuum tubes (Gel and Clot Activator). ELISA Test System was used to test P4 concentration. The kit was provided by Monobind Inc. Certified Company, Lake Forest, USA. When the uterine diameter did not decrease any more for three consecutive tests, the involution was considered complete. (Ali et al 2001).

Statistical analysis: The Statistical Analysis System-SAS (2012) application was used to detect the effect of different components on research parameters.

RESULTS AND DISCUSSION

The progesterone concentrations appear to be high (Table 1). At the beginning of the postpartum period, the number of women in groups 1 and 2 stays low (0.33, 0.30 and 0.30 respectively) and is in agreement with Kaulfuss et al (1996) where progesterone concentration during the first week of parturition varied from 0.1 to 0.2 ng /ml. Progesterone levels were e significant on the third to six weeks (In ewes, the progesterone profile is regraded during the postpartum phase also is shown in Figure 1. The low progesterone levels were observed in the second weeks of parturition, which is consistent with Hussain et al. (2016), who reported that progesterone concentration remained at basal levels in post-partum, and that the results show differences in from the first to the sixth weeks. The changes could be attributed to the

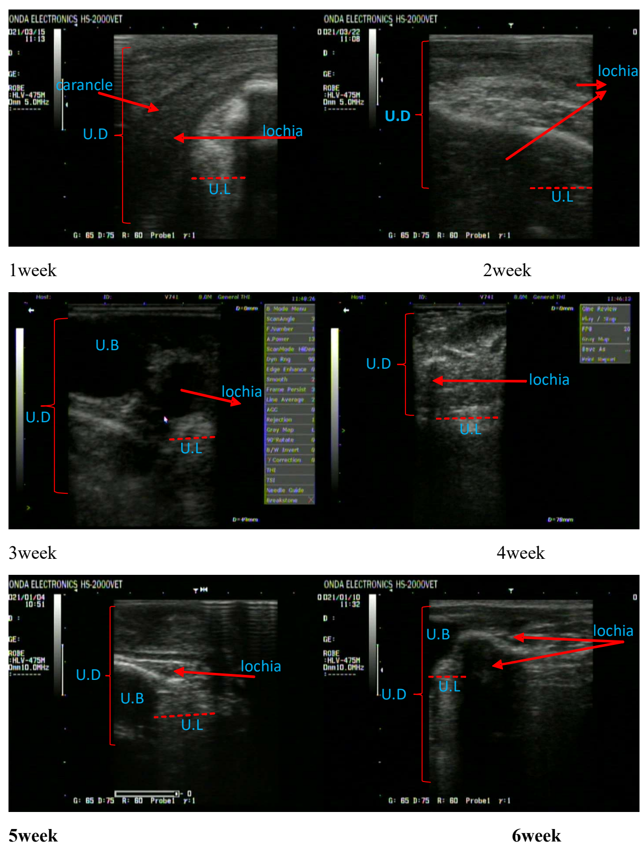

Fig. 1. Ultrasonography image of uterine involution in untreated control sheep at various postpartum periods (First to 6 week). The uterine wall and uterine lumen were easily separated by diverse ultrasonographyecho textures in the ultrasonography image of the postpartum uterus

Table 1. Progesterone concentration during post period in ewe progesterone (ng/ ml) (Mean ±SE)

Mean group	1 week	2 week	3 week	4 week	5 week	6 week	LSD value
Group 1	0.33±0.02Ac	1.93±0.64Ab	0.51±0.11A	2.02±0.70Ab	2.94±1.07Aa	0.34±0.03Bc	0.375 *
Group 2	0.30±0.00Aa	0.35±0.02Ba	0.31±0.01Ba	0.34±0.02Ba	0.34±0.02Ba	0.40±0.03Ba	NS
Group 3	0.30±0.00Ac	0.37±0.07Bc	0.35±0.05ABc	0.30±0.00Bc	3.00±0.70Ab	3.82±0.94Aa	0.381 *
LSD value	0.104 NS	0.287 *	0.194 *	0.295 *	0.402 *	0.391 *	---

Means with different capital letters in the same column and small letters in the same row are significantly differenti. * (P≤0.05).

Table 2. Uterine diameter at different period post-partum(mm)(Mean ±SE)

Week of examination	Group 1 treated PGF2α	Group 2 treated estrogen +oxytocin	Group 3 control	LSD value
1 week	40.63±1.49Ab	45.45±1.20Aa	43.30±1.02Aab	4.395*
2 week	31.20±1.63Ab	39.95±1.32Ba	41.95±0.80Aa	4.982*
3 week	22.76±0.62Bb	26.08±0.75Cb	34.04±1.21Ba	4.772*
4 week	17.22±0.67Cc	22.55±0.53Cb	29.56±1.07BCa	4.251*
5week	14.22±0.55Cb	16.26±0.46Db	28.13±0.97Ca	3.988*
6week	13.1±0.53Db	15.53±0.44Db	27.62±1.47Ca	4.846*
LSD value	4.027 *	5.179 *	4.522 *	----

See Table 1 for details

period of parturition, which could be in season or out of season as well as breed distinctions. The hypothalamic-pituitary-adrenal axis was activated, resulting in the development of estrogen synthesis and a decrease in progesterone levels, as well as a decrease in progesterone levels. The three groups' values differed significantly recorded utilizing before the typical luteal phase, small peaks of progesterone have been identified in postpartum ewes. They peak was at 0.5 ng/ml and then fade out after two weeks. From the moment of delivery to four weeks after delivery, the uterine diameter decreases rapidly (Table 2). There is no information about uterine involution after childbirth. The postpartum uterine diameter assessed by trans-rectal ultrasonography in the three groups is shown in Table 1. In groups 1 and 2, uterine involution occurred 35 days after delivery, while in group 3 it occurred 28 days after delivery. The third group completed uterine involution in a shorter amount of time than the first and second groups. The diameter of the uterine horn decreased considerably in all groups within the first four weeks after parturition. The purpose of the study is to provide information that can be used to improve reproductive efficiency through the use of ultrasonography. The percent decline in uterine diameter (mm) was 40.63, 31.20, 22.76, and 17.22 respectively during 4 weeks (Table 2). At the early days pp. of this inquiry, the uterine contents were present and exhibited a hypo echogenic feature, confirming Hauser and Bostedt's findings (2002). The current study is critical and provides information that will aid in enhancing reproductive efficiency. Understanding postpartum changes in the uterus and ovaries is critical to achieving maximal reproductive efficiency in ewes. Furthermore, the findings of this study demonstrated that real-time B-mode ultrasonography is a viable approach for evaluating uterine involution in post-partum ewes with uterine regression. It's also necessary to diagnose ovarian activity. The findings demonstrate that progesterone concentration is a strong predictor of luteal function throughout the postpartum period

CONCLUSION

The current study concluded that the ultrasonography approach is a viable option for uterine involution management and that uterine involution was completed more quickly in groups treated with PGF2, as measured by uterine diameter and lumen, as well as a decrease in lochia, than in other groups.

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Received 21 October, 2021; Accepted 02 January, 2022

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Date of Publication 15.04.2022