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Pre harvest forecasting of Ragi (Hill Millet) using weather and biometrical characters in Dang district

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Abstract
This research paper presents a comprehensive investigation into the pre-harvest forecasting of Ragi (Hill Millet) yield within the Dang district, employing a novel approach that integrates weather parameters and biometrical characters. The study acknowledges the significance of accurate yield prediction in modern agricultural practices, aiding farmers, policymakers, and the agricultural industry in optimizing resource allocation and management. The research objectives encompass the formulation of a pre harvest model that synergistically incorporates weather data and biometrical traits to proactively estimate Ragi yield. Through the application of multiple regression model, Discriminant function analysis and Composite forecast, correlations between weather parameters, biometrical characters, and yield are discerned and harnessed to construct the pre harvest model. The study revealed that discriminant function gave better result in the 42nd and 43rd SMW with minimum forecast error % even though low R^2 values as compared MLR models. The combined forecast obtained by forecast values based on biometrical character and weather data found good by using Model 2_42 and Model 2_43 (discriminant function).

Keywords: Multiple linear regression, discriminant function, composite forecast

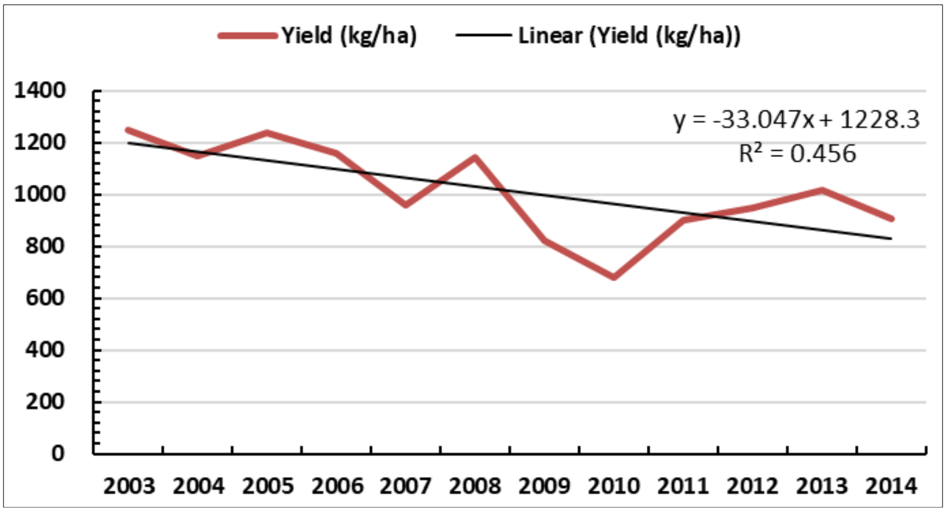
Introduction
Ragi, also known as finger millet or Hill Millet, is a traditional crop that has been cultivated in India for centuries. It is grown mainly in dryland areas, hilly regions, and tribal areas across various states. Ragi is known for its nutritional value, resilience to adverse conditions, and suitability for rainfed farming systems. These plant species, referred to as underutilized, share certain traits: a) they are plentiful within developing countries yet rare on a global scale; b) there exists limited scientific knowledge about them; and c) their current utilization falls short of their economic potential (Gruere *et al.*, 2006) [15]. The pre-harvest forecasting of Ragi (Hill Millet) in the Dang district using weather parameters and biometrical characters is a study aimed at predicting the yield of Ragi crops before they are harvested. Ragi, also known as finger millet or Hill Millet, is an important cereal crop cultivated in various regions, including the Dang district. Accurate forecasting of Ragi yield before harvest can be immensely beneficial for farmers, policymakers, and the agricultural industry as a whole. The relationship between crops and weather has been explored by Fisher (1924) [9] and Hendricks and Scholl (1943) [16]. They formulated models that required the estimation of a small number of parameters, taking into account the distribution pattern of weather during the crop's growing season. Agrawal *et al.* (1986) [3] and Jain *et al.* (1980) [17] modified this model by representing the impacts of weather parameter changes on yield. Subsequent research by Chauhan *et al.* (2009) [6], Garde *et al.* (2012) [12], Mahdi *et al.* (2013) [18], Garde *et al.* (2021) [10], Singh *et al.* (2014) [19], Garde *et al.* (2020) [13] and Banakara *et al.* (2023) [5] investigated the correlations between weather parameters and rice crop yield in various regions worldwide. Likewise, Agrawal *et al.* (2012) [1], Sisodia *et al.* (2014) [20], and Garde *et al.* (2023) [14] devised predictive models for different crops in diverse Indian regions.

Data and Methodology

Weather data: previous 12 years of weekly weather data were collected from Hill Millet Research Station, Waghai, Dang. In study, weekly weather data related to Kharif crop season starting from a fortnight before sowing up to last of reproductive stage were utilized for the development of statistical models. Therefore, the weather data for Ragi crop, from May-June (23rd standard meteorological week, SMW) to September (39th and 40th standard meteorological week, SMW) in each year were utilized.In the present study, following weather parameters were considered.

- Maximum Temperature,
- Minimum Temperature
- Average Relative Humidity
- Rainfall

Yield data: It was collected from Directorate of Economics and Statistics (www.eands.dacnet.nic.in) and report of Directorate of Agriculture, Gujarat State, Gandhinagar (http://agri.gujarat.gov.in).



Biometrical data

The biometrical data of Ragi crop were collected from different experimental trials which were conducted on research farm located at Rajendrapur and Rambhas. The following observation collected at maturity stage of crop *viz.* Plant height (cm) (G1), No. of tillers/ Plant (G2), Main ear length (cm) (G3), No. of fingers / ear (G4), Days to 50% flower (G5).

Statistical data analysis

Multiple regression model (MLR) techniques using weather indices

In this method, weekly data on weather variables have been utilized for constructing weather indices (weighted & un-weighted along with their interactions). The weighted indices are weighted accumulations of the weather variables over weeks, where weight being correlation coefficient between de-trended yearly crop yields and weather parameters with respective weeks (Agrawal *et al*. 2001, Garde *et al*. 2015) [2, 11]. The forms of indices are given as below:

$Z_{i,j} = \sum_{w=1}^{m} r_{iw}^{j} X_{iw}$ and $Z_{i,i',j} = \sum_{w=1}^{m} r_{ii'w}^{j} X_{i'w}$

Where,

j = 0, 1 (where, '0' represents un-weighted indices and '1' represents weighted indices)

m = Week up to forecast

w = week number (1, 2...., m)

r_{iw} = Correlation coefficient between adjusted crop yield and i^{th} weather variable in w^{th}week

$r_{ii'w}$ = Correlation coefficient between adjusted crop yield and the product of i and i'^{th} weather variable in w^{th} week

X_{iw} and $X_{i'w}$are the i and i'^{th} weather variable in w^{th} week respectively

The pre-harvest forecast models were obtained by applying the Multiple Linear Regression Techniques (MLR) by taking predictors as appropriate un-weighted and weighted weather indices. Stepwise regression analysis was used for selecting significant variables. The regression model was as follows:

Model 1

$$Y = A_0 + \sum_{i=1}^{p}\sum_{j=0}^{1} a_{i,j} Z_{i,j} + \sum_{i \neq i'=1}^{p}\sum_{j=0}^{1} a_{i.i'.j} Z_{i,i',j} + cT + e$$

Where,

$Z_{i,j}$ and $Z_{i,i',j}$ are the weather indices

i,i' = 1, 2, …p

p = Number of weather variables under study

Y = District total crop yield (q/ha)

T = Year number

A_0 is the intercept

Aij, aii' j, c are the regression coefficient

e is error term normally distributed with mean zero and constant variance

Discriminant function analysisusing weather indices

In this method, weighted indices along with their interactions were considered for development of discriminant score. Two discriminant score have been obtained from these indices. For quantitative forecast, regression models were fitted by taking the discriminant scores and trend variable as the regressors and crop yield as the regressand (Agrawal *et al*. 2012, Garde *et al*. 2020). The form of the developed model is as follows:

Model 2

$$Y = A_0 + \beta_1 ds_1 + \beta_2 ds_2 + \beta_3 T + e$$

Where,

A_0= intercept of model
β_i's (i=1, 2, 3) = the regression coefficients
ds_1 and ds_2 are the two discriminant scores
T = trend variable
e is error term normally distributed with mean zero and constant variance

Multiple regression model (MLR) techniques using biometrical character

The forecast **Model 3** was obtained by applying the Multiple Linear Regression Techniques (MLR) by taking regressors as original quantitative biometrical characters which was collected from different experimental plots of the research farm and the regress and as plot crop yield. The following model was developed for the year 2014.

Model 3

$$Y = A_0 + \sum_{i=1}^{p} a_i G_i + e$$

Where,
Y = Wheat crop yield per plot (kg/ha)
Gi = Value of the i^{th} character (i= 1, 2, ….p), p = no. of biometrical characters
e = Error term normally distributed with mean zero and constant variance
A_0 is the intercept and$a_i$is the coefficient of regression

Composite forecast

The composite forecast y_c obtained by a linear combination of 'n' forecasts y_i;i=1,2,….n; can be written as follows,

$$y_c = \sum_{i=1}^{n} w_i y_i = w_1 y_1 + w_2 y_2 + \ldots\ldots + w_n y_n, \sum_{i=1}^{n} w_i = 1$$

where y_i = The forecast computed from i^{th} approach with errors e_i distributed as N (0, σ_{ii}) and w_i = The weight assigned to the i^{th} forecast.
The simplest strategy of combining forecasts from different models could be to get a composite forecast as simple average of the component forecasts. The composite forecast were given by

$$y_{cs1} = \frac{1}{n}\sum_{i=1}^{n} y_i = \frac{1}{n}(y_1 + y_2 + \ldots\ldots + y_n)$$

Results and Discussion

Multiple regression model (MLR) techniques using weather indices

The model development was carried out for 38th SMW and 43th SMW by using models as discussed in above section. The best fit models were selected based on highest value of Adjusted R^2. From the Table 1, it was observed that value of Adj. R^2 varies from 0.69 per cent to 0.75 per cent. The Model 1 at the 40th SMW and 41st SMW showed highest Adj. R^2. Further validation of week wise best fit models was done for the year 2015 (Table 2). The comparisons of the different developed models were carried out with Forecast error (FE %).

Table 1: MLR regression model 1 equations

Model 1	Forecast model equation	Adjusted R^2
38	$Y = 436.279 + 4.619Z_{4,1} + 0.265Z_{1,2,1}$	0.69
39	$Y = 1868.481 + 0.499Z_{1,2,1} + 0.035Z_{2,4,0}$	0.73
40	$Y = 1950.211 + 0.499Z_{1,2,1} + 0.030Z_{2,4,0}$	0.75
41	$Y = 2105.208 + 0.419Z_{1,2,1} + 0.024Z_{2,4,0}$	0.75
42	$Y = 2740.332 + 0.344Z_{1,2,1}$	0.71
43	$Y = -2087.680 + 9.319Z_{4,1}$	0.71

Table 2: Forecast yield obtained using weather indices in MLR model

Model 1	SMW	Observed Yield	Forecast Yield	Forecast error %	Adj R^2
2015	38	908	1269	-39.75	0.69
	39		1256	-38.32	0.73
	40		1288	-41.88	0.75
	41		1373	-51.16	0.75
	42		1657	-82.44	0.71
	43		813	10.46	0.71

Discriminant function analysis using weather indices

Similarly, the model development was carried out for 38th SMW and 43th SMW by using Discriminant function analysis. The best fit models were selected based on highest value of Adjusted R^2. From the Table 3, it was observed that value of Adj. R^2 varies from 0.40 per cent to 0.72 per cent. The Model 3 at the 43rd SMW showed highest Adj. R^2. Further validation of week wise best fit models was done for the year 2015 (Table 4). The comparisons of the different developed models were carried out with Forecast error (FE %).

Table 3: Discriminant function model 2 equations

Model 2	Forecast model equation	Adjusted R^2
38	$Y = 1230.059 - 42.569T - 113.071ds_1 - 89.467ds_2$	0.59
39	$Y = 1228.076 - 33.024T$	0.40
40	$Y = 1228.076 - 33.024T$	0.40
41	$Y = 1228.076 - 33.024T$	0.40
42	$Y = 1234.228 - 39.827T - 112.374ds_2$	0.62
43	$Y = 1224.776 - 41.317T - 135.4371ds_2 + 62.466ds_1$	0.72

Table 4: Forecast yield obtained using weather indices in discriminant function model

Model 2	SMW	Observed Yield	Forecast Yield	Forecast error %	Adj R^2
2015	38	908	625	31.19	0.59
	39		799	12.03	0.40
	40		799	12.03	0.40
	41		799	12.03	0.40
	42		932	-2.70	0.62
	43		883	2.75	0.72

Multiple regression model (MLR) techniques using biometrical character

The Multiple Linear Regression Techniques (MLR) used by taking regressors as original quantitative biometrical characters. The details of model of the model given the Table 5. Further validation of week wise best fit models was done for the year 2015 (Table 6).

Table 5: MLR regression model 3 equations using biometrical character

Model 3	Forecast model equation	Adjusted R^2
2014	$Y = -792.296 + 42.945G_5 + 299.254G_2 - 158.617G_3$	0.30

Table 6: Forecast yield obtained using biometrical character in MLR model

Model 3	Observed Plot Yield	Forecast Plot Yield	Forecast error %	RMSE	Adj R^2
	3603	2942	18.36	1068.363	0.30
	4298	2797	34.93		
	3665	2333	36.36		
	2168	2624	-21.03		
	3140	1477	52.98		
	4684	3026	35.40		
	2022	1862	7.90		
	3804	2916	23.34		
	3897	2151	44.80		
	1975	2817	-42.63		
	1597	3375	-111.28		
	2901	1699	41.45		
	3989	2884	27.71		
	3750	3003	19.93		
	3858	3210	16.79		
	2677	2576	3.79		
	1957	3195	-63.28		
	1500	3281	-118.73		
	2957	2464	16.65		
	3179	2747	13.58		
	3488	2491	28.58		
	3556	2616	26.41		
	3815	2975	22.00		
	3420	2180	36.25		
	3864	2827	26.83		
	3858	2839	26.40		
	3309	2847	13.95		
	3216	2599	19.19		
	2574	2660	-3.34		
	3475	2639	24.06		
Avg. Plot yield	3207	2668	16.78		

Composite forecast

In the present study composite forecast was obtained for the year 2015 using model which were developed using biometrical characters data of years 2014 and weather-data of year 2003-2014. Therefore, based on R^2 and forecast error % the best forecast yield models were selected from Model 1 i.e. 40^{th} and 41^{st} SMW model and from Model 2 i.e. 42^{nd} and 43^{rd} SMW model. The forecast obtained from these Model 1, 2 and Model 3 i.e. avg. forecast plot yield were utilized to get composite forecast. The details are shown in the Table 7 and Table 8.

Table 7: Composite forecast using Model 1, Model 2 and Model 3

Model	Forecast Yield (Model 1, 2)	Model	Forecast Yield (Model 3)	Composite forecast
Model 1_40	1288	Model 3	2668	1978
Model 1_41	1373			2021
Model 2_42	932			1800
Model 2_43	883			1776

Table 8: Composite forecast for the year 2015

Year	Observed Yield	Composite forecast	Forecast error %
2015	908	1978	-117.84
		2021	-122.52
		1800	-98.24
		1776	-95.54

Conclusion

The study revealed that discriminant function gave better result in the 42nd and 43rd SMW with minimum forecast error % even though low R^2 values as compared MLR models. The combined forecast obtained by forecast values based on biometrical character and weather data found good by using Model 2_42 and Model 2_43 (discriminant function). This strategy though simple is obviously not the most desired as it gives equal weights to all forecasts irrespective of their precision. It will required to use another different strategies like Weights proportional to inverse of the variances, Weights depend on variances and co-variances (Dickson, 1975) [7].

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