Journal of Agrometeorology 16 (1) : 1-8 (June 2014)

Invited paper

Development of crop yield forecast models under FASAL- a case study of *kharif* rice in West Bengal

K. GHOSH, R. BALASUBRAMANIAN, S. BANDOPADHYAY[2], N. CHATTOPADHYAY, K.K. SINGH[1] and L.S. RATHORE[1]

Agricultural Meteorology Division, India Meteorological Department, Pune

[1]India Meteorological Department, Mausam Bhavan, New Delhi

[2]Regional Meteorological Centre, IMD, Kolkata

E-mail: kripanghosh@yahoo.co.in

ABSTRACT

Crop yield forecasts are prepared at District, State and National level under the ongoing project "Forecasting Agricultural output using Space, Agrometeorology and Land based observations (FASAL)", operational at Ministry of Agriculture, Govt. of India in collaboration with Space Application Centre (SAC), Institute of Economic Growth (IEG) and India Meteorological Department (IMD). As per the mandate of the project, crop yield forecasts are being generated for 13 major crops. Different models are used by these organizations for generation of crop yield forecasts. Under FASAL project, IMD in collaboration with 46 Agromet Field units (AMFU) located at different State Agricultural Universities (SAUs), ICAR institutes, IITs, develops intra-seasonal operational yield forecast for the major crops during *kharif* and *rabi* seasons using statistical model. Within IMD, in addition to the Agricultural Meteorology Division, all the Regional Meteorological Centres (RMCs) and Meteorological Centres (MCs), located in different states are also working in this project. Long period crop yield data as well as weekly weather data as per meteorological standard week have been used for development of the district level yield forecast models. For developing the yield forecast, models using composite weather variables have been studied. Simple and weighted weather indices have been prepared for individual weather variables as well as for interaction of two at a time considering throughout the crop growing season. Minimum data set required to develop the statistical model have also been mentioned in this paper. In order to demonstrate the data requirement, methodology for crop yield forecast through regression technique along with the interpretations, the relevant data of West Bengal have been taken up. National level crop yield forecast is prepared by the Mahalanabis National Crop Forecasting Centre (MNCFC) based on the state level forecast generated in IMD.

Key words: Kharif rice, yield forecast, weather indices, West Bengal, FASAL

Crop acreage estimation and crop yield forecasting are the two components which are crucial for the sound planning and policy making in the agricultural sector of the country. The traditional approach of crop production estimation in India involves a complete enumeration for estimating crop acreage and sample surveys based on crop cutting experiments (CCE) for forecasting crop yields. The crop acreage and corresponding yield estimate data are used to obtain production estimates. These yield surveys being extensive, as plot yield data are being collected under scientifically designed complex sampling design that is based on a stratified multistage random sampling, the production estimates are obtained much after the crop season is over. However, the Government requires advance estimates of production of major crops in the country for taking various policy decisions relating to pricing, marketing, export/import distribution etc. These emphasise the need to develop the methodology for in-season estimation of crop production.

There were inherent limitations in the system of agricultural statistics, in spite of established procedures and wide coverage, in providing an objective assessment of crops at the pre-harvest stages with the desired spatial details, which are essential to identify problem areas. There was, therefore, need to enhance the capabilities of the system of crop forecasts and crop estimation with the help of technological advancements and the adoption of emerging methodologies. To fulfill this goal, in recent past, Department of Agriculture and Cooperation (DAC), Ministry of Agriculture (MoA), Govt. of India has launched a comprehensive scheme "Forecasting Agricultural output using Space, Agrometeorology and Land based observations (FASAL)" for in-season crop acreage estimation and crop yield forecast through adoption of emerging methodologies. A number of organizations like Institute of Economic Growth (IEG), India Meteorological Department (IMD), Space Applications Centre (SAC), National Sample Survey Organisation (NSSO) etc. are involved in the scheme for forecasting crop yield at various stages of crop growth during the growing season.

The mandate of IMD is to issue yield forecast for various major crops at vegetative (F1), mid-season (F2) and pre-harvest (F3) stages for different States where these crops share larger area. However, to overcome the variations in crop and environmental conditions existing within the State, the operational models have been developed at finer scale, i.e. at District level. State level production is finally estimated using the area weighted District level yield predictions.

In the present paper, in order to demonstrate the methodology for crop yield forecast through regression technique along with the interpretations, the relevant data of kharif rice of West Bengal, being the predominant crop in the State, have been used. The methodology is already in use for generation of operational yield forecast for all the major crops in different States in the country.

MATERIALS AND METHODS

As magnitude of the variables in successive weeks are composed to generate weather indices to explain the variation in productivity of crops during the crop growing season, yield forecast models have been developed here based on modified Hendricks and Scholl model (Agrawal *et al*. 1986) using composite weather indices for generation of operational yield forecast. Detailed information and equation of the model along with genesis have been discussed below.

Models using composite weather variables

Models suggested by Fisher (1924) and Hendrick and Scholl (1943) used small number of estimated parameters for taking care of distribution pattern of weather over the crop season. Fisher utilised weekly weather data assuming that the effect of change in weather variable would not be abrupt or erratic in successive weeks but an orderly one following some mathematical law. It was assumed that these effects as well as magnitude of the variable in successive weeks are composed of the terms of a polynomial function of time.

Hendrick and Scholl (1943) modified the Fisher's technique assuming that a second degree polynomial in week number would sufficiently express the effects in successive weeks. Based on this, Hendricks and Scholl suggested,

$$Y = A_0 + a_0 \sum_{w=1}^{n} X_w + a_1 \sum_{w=1}^{n} wX_w + a_2 \sum_{w=1}^{n} w^2 X_w + e$$

where, X_w denotes value of weather variable under study in w-th week, n is the number of weeks in the crop season and A_o, a_o, a_1 and a_2 are the model parameters. This model was extended to study combined effects of weather variables and an additional variate T representing the year for time trend.

Hendrick and Scholl model has been further modified at Indian Agricultural Statistics Research Institute (IASRI), where, the effects of changes in weather variables on yield in the w-th week were expressed as second degree polynomial in respective correlation coefficients between yield and weather variables (Agrawal *et al*. 1980, 1983; Agrawal and Jain. 1982; and Jain *et al*. 1980). The relationship was, thus, explained in a better way as weather in different weeks receives appropriate weightage.

Agrawal *et al*. (1986) further modified this model considering that the impact exerted by changes in weather variables in w-th week on yield is a linear function of respective correlation coefficients between yield and weather variables. The significant effect of trend on yield was also removed while calculating correlation coefficients of yield with weather variables to be used as weights. The studies on effects of second degree terms of weather variables showed that (i) the models using correlation coefficients based on yield adjusted for trend effect were better than the ones using simple correlations and (ii) inclusion of quadratic terms of weather variables and also the second power of correlation coefficients did not improve the model.

Partial crop season data considering different weather variables simultaneously have been used to develop the forecast model in following finally recommended

Table 1: Weather indices used in models using composite weather variables

	Simple weather indices					Weighted weather indices				
	Tmax	Tmin	Rf	RH I	RH II	Tmax	Tmin	Rf	RH I	RH II
Tmax	Z10					Z11				
Tmin	Z120	Z20				Z121	Z21			
Rf	Z130	Z230	Z30			Z131	Z231	Z31		
RH I	Z140	Z240	Z340	Z40		Z141	Z241	Z341	Z41	
RH II	Z150	Z250	Z350	Z450	Z50	Z151	Z251	Z351	Z451	Z51

form

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

where,

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

Where, X_{iw}/ $X_{ii'w}$ is the value of i^{th}/i'^{th} weather variable under study in w-th week, r_{iw}/$r_{ii'w}$ is correlation coefficient of yield (adjusted for trend effect, if present) with i^{th} weather variable/ product of i^{th} and i'^{th} weather variables in w^{th} week, m is week of forecast and p is number of weather variables used. Two weather indices were developed for each weather variable, i.e. simple as well as weighted accumulation of weekly weather variable, weights being correlation coefficients of weather variable in respective weeks with yield (adjusted for trend effect, if present). Similarly, indices were also generated for interaction of weather variables, using weekly products of weather variables taking two at a time. Combination of weather variables for Weather indices, thus, generated are presented in Table 1. Weather variables used for this model are maximum temperature (Tmax), minimum temperature (Tmin), rainfall (Rf), morning relative humidity (RH I) and evening relative humidity (RH II). Stepwise regression technique was used to select the important weather indices.

Data requirement

For development of district level yield forecast models, weather indices are generated using weekly cumulative value for rainfall and weekly average value for other parameters like maximum and minimum temperature, rainfall, morning, evening relative humidity etc. Long period data series of these parameters are mostly collected from National Data Centre, IMD, Pune. Long period crop yield data for the major crops of different States are collected from the respective State Department of Agriculture and also from the website of Directorate of Economics and Statistics, Department of Agricultural and Cooperation, Ministry of Agriculture, Govt. of India (http://eands.dacnet.nic.in/).

While developing the District level yield forecast models, long period weekly data for all the weather variables from the date of sowing of crops upto the date of forecasting along with long period crop yield data are used.

Crops and periodicity for generation of yield forecast

District level yield forecasts are generated for all the major crops at vegetative (F1), mid-season (F2) and pre-harvest (F3) stages, in both the *kharif* and *rabi* seasons, for different States of the country by 46 Agromet Field units (AMFU) located at different State Agricultural Universities (SAUs), Indian Council of Agricultural Research (ICAR) institutes, Indian Institute of Technology (IITs) etc., with subsequent preparation of State level forecasts by State Agromet Centres (SAMC) of IMD of respective States. The forecasts are then validated against the observed data. To verify the performance of the yield forecasts at different levels, the acceptable limit of error has been considered as ±10% at District level and ±5% at State level. The list of 13 major crops (rice (*kharif* and *rabi*), jowar (*kharif* and *rabi*), maize, bajra, jute, ragi, cotton, sugarcane, groundnut (*kharif* and *rabi*), rapeseed, mustard, wheat and potato), which have been selected for generation of yield forecasts by the AMFUs in various States of the country are presented in Table 2.

National level crop yield forecast is prepared by the Mahalanabis National Crop Forecasting Centre (MNCFC) based on the state level forecast generated in IMD. The yield forecasts at F1, F2 and F3 stages are generated on different dates for different crops, mutually agreed between IMD and MNCFC.

To demonstrate the methodology for crop yield forecast through regression technique along with the interpretations, in the present paper, *kharif* rice for West

Table 2: List of crops selected for yield forecast at different Agromet Field Units (AMFUs)

Sr.No.	State	AMFU stations	Crops
1	Andhra Pradesh	Hyderabad	Rice (K, R)
		Tirupathi	Groundnut (K)
2	Arunachal Pradesh	Basar	Rice and maize
3	Assam	Jorhat	Rice, rapeseed-mustard and jute (K)
4	Bihar	Pusa	Wheat, maize, rice, sugarcane, jute and potato
5	Chatiisgarh	Raipur	Rice and wheat
6	Gujarat	Anand	Maize, groundnut, wheat and rice
		Navsari	Sugarcane and rice
		Junagadh	Groundnut, wheat, bajra and cotton
7	Haryana	Hissar	Wheat and cotton
8	Himachal Pradesh	Palampur	Wheat and maize
		Solan	Maize and wheat
9	Jammu and Kashmir	Jammu	Wheat and maize
		Srinagar	Rice, mustard and maize
10	Jharkhand	Ranchi	Rice, ragi and wheat
11	Karnataka	Dharwad	Jowar (R) and groundnut (K)
		Bangalore	Ragi (K), groundnut (K) and rice (K, R)
12	Kerala	Trissur	Rice (K, R)
13	Meghalaya	Umiam	Maize and rice
14	Maharashtra	Pune	Groundnut (K) and sugarcane
		Parbhani	Jowar (R) and Cotton
		Akola	Cotton, wheat and rice
		Dapoli	Rice (K, R)
15	Madhya Pradesh	Morena	Bajra and mustard
		Indore	Maize and wheat
		Jabalpur	Rice and wheat
16	Orissa	Bhubaneshwar	Rice(K, R) and Groundnut (R)
17	Punjab	Ludhiana	Wheat, mustard, cotton and potato
18	Rajasthan	Udaipur	Maize and wheat
		Jodhpur	Bajra, rapeseed-mustard, cotton, sorghum, and wheat
		Bikaner	Bajra and rapeseed-mustard
19	Tamilnadu	Adhuturai	Rice (K and R)
		Coimbatore	Rice (K and R) and maize (K and R)
		Kanniwadi	Rice (K and R) and maize
20	Uttar Pradesh	Faizabad	Rice, wheat, maize (K) and potato
		Modipuram	Wheat, sugarcane and potato
		Kanpur	Rice, wheat, mustard and potato
		Allahabad	Wheat, rice, mustard and Potato
		Varanasi	Rice, maize, wheat ,mustard and potato
21	Uttarakhand	Pantnagar	Rice, wheat and sugarcane
		Roorkee	Rice, wheat and sugarcane
22	West Bengal	Kharagpur	Maize, groundnut and potato
		Kalyani	Rice (K, R), jute, and potato
		Pundibari	Jute, rapeseed-mustard, rice (K, R) and potato
		Port Blair	Rice (K), maize and groundnut
23	New Delhi	New Delhi	Wheat, mustard and maize

kharif = K and *Rabi* = R

Table 3: Production of *kharif* rice (average production during 2007 to 2011) in different districts of West Bengal.

Sl. No.	Districts	Production (in Tonnes)	Contribution in State production (%)	Cumulative contribution in State production (%)
1	Midnapur (West)	1230726	12.65	12.65
2	Burdwan	1227850	12.62	25.27
3	Birbhum	909944	9.35	34.62
4	Bankura	868118	8.92	43.54
5	Purulia	669146	6.88	50.42
6	24 Parganas (South)	662921	6.81	57.23
7	Murshidabad	588081	6.04	63.27
8	Hooghly	529901	5.45	68.72
9	Midnapur (East)	462459	4.75	73.47
10	Dinajur (North)	388415	3.99	77.46
11	24 Parganas (North)	384691	3.95	81.42
12	Cooch-Behar	382698	3.93	85.35
13	Dinajpur (South)	359930	3.70	89.05
14	Malda	328045	3.37	92.42
15	Jalpaiguri	299480	3.07	95.49
16	Nadia	258888	2.66	98.15
17	Howrah	126895	1.31	99.46
18	Darjeeling	52243	0.54	100

Table 4: The yield forecast models for different districts of West Bengal developed using composite weather variables

Sl. No.	Districts	Equation	R^2	RMSE ($kgha^{-1}$)
1	Bankura	Y=383.580 +(44.418*Time) +(0.149*Z451)	0.90	143.57
2	Birbhum	Y=-6917.698+(55.952*Time)+(26.634*Z20)+ (-1.380*Z251)+(0.053*Z131)	0.83	193.25
3	Burdwan	Y=5398.074+(40.69*Time)+(20.18*Z41)+(0.078*Z231)	0.83	173.99
4	Cooch Behar	Y=2616.359+(38.351*Time)+(0.005*Z351)+(0.148*Z51)	0.91	84.65
5	Dinajpur (N)	Y=1881.845+(111.19*Time)+(14.030*Z51) + (0.035*Z251)+(2.517*Z50)	0.96	69.17
6	Dinajpur (S)	Y=554.947+(55.520*Time)+(23.561*Z41) +(0.162*Z151)	0.94	97.93
7	Hoogly	Y= -749.5+(57.022*Time)+(125.575*Z41)+ (2.665*Z141) +(2.536*Z151)	0.87	114.11
8	Midnapur (E)	Y = -122.679903 + (292.930485*Z21)	0.56	271.58
9	Midnapur (W)	Y=1486.960+(43.372*Time)+(-0.013*Z341)	0.85	163.04
10	Murshidabad	Y= -14486+(29.498*Time)+(44.657*Z20)	0.88	153.10
11	Purulia	Y = 4139.890705 + (Time * 35.769441) + (Z11 * 126.938263) + (Z141 * 0.325143) +(Z251 * 0.773085)	0.92	123.70
12	24 Parganas(N)	Y=742.485+(46.044*Time)+(1.674*Z121) +(0.860*Z151)	0.93	85.72
13	24 Parganas (S)	Y = 3878.093 + (247.968 * Time)+(2.469 * Z121) +(0.496 * Z241)	0.93	102.19

Table 5: Observed and forecasts (kgha^{-1}) *kharif* rice yield in 2010 and 2011 for various districts of West Bengal

Sl.	Districts	2010		2011	
No.		Observed yield	Forecasted yield	Observed yield	Forecasted yield
1	Bankura	2482	2985	3050	3221
2	Birbhum	2885	3232	2882	3112
3	Burdwan	2893	3125	3006	2994
4	Coochbehar	2276	2071	2057	1866
5	Dinajpur (N)	2631	2449	2577	2537
6	Dinajpur (S)	2954	2663	2502	2681
7	Hoogly	3043	3139	2838	3298
8	Midnapur (E)	2285	1948	2107	1857
9	Midnapur (W)	2484	2580	2580	2690
10	Murshidabad	2574	2653	2464	2632
11	Purulia	1712	2569	2708	2378
12	24 Parganas(N)	2375	2551	2460	2887
13	24 Parganas (S)	2110	2020	2136	2046

Bengal has been considered. Long term rice yield data for the major rice growing districts of West Bengal have been collected from the State Department of Agriculture, Govt. of West Bengal and long term data series for different Weather parameters have been collected from National Data Centre, IMD, Pune.

State level crop yield forecast

For generation of State level crop yield forecast, the districts contributing towards 92% production of the State are identified for development of yield forecast models of respective districts. Subsequently, State level crop yield forecast is obtained based on the area weighted District level yield forecasts. The general equation used for generation of crop yield forecast at state level is as follows.

$$Y = \sum_{i=1}^{n} \frac{A_i X_i}{A_i}$$

Where

A_i and X_i are the area and predicted yield of crop for ith district.

RESULTS AND DISCUSSION

As discussed above, to demonstrate the methodology of yield forecast at District and State level, identification of the districts for developing district level yield forecast models to forecast yield of *kharif* rice in the State of West Bengal as well as the ability of the models to predict rice yield in respective districts with respect to the observation are analysed and the findings are elaborated in the forthcoming section.

Selection of districts

Selection of districts for generating State level yield forecast in West Bengal has been made based on the average production of *kharif* rice during recent five years (2007 to 2011). The Districts have been arranged in descending order with respect to *kharif* rice production and subsequently, contribution (%) of each district towards State production is calculated and presented in Table 3. The results show that 92% of the State production is achieved due to contribution from 14 districts with highest contribution from Midnapur (West) (12.65%) and lowest contribution from Malda (3.37%). The models for yield forecast of *kharif* rice for all these Districts have been developed based on modified Hendrick and Scholl model (Agrawal *et al*. 1986) using composite weather indices and their performance is studied.

Performance of district level forecast models for kharif rice

Yield forecast models of *kharif* rice for different districts of West Bengal have been prepared using long term crop yield data as well as long period data of weekly values of weather variables from 27th to 41st standard meteorological week for respective districts. As per the average of recent five years, Birbhum district shows highest productivity (2966 kg ha^{-1}) followed by Burdwan

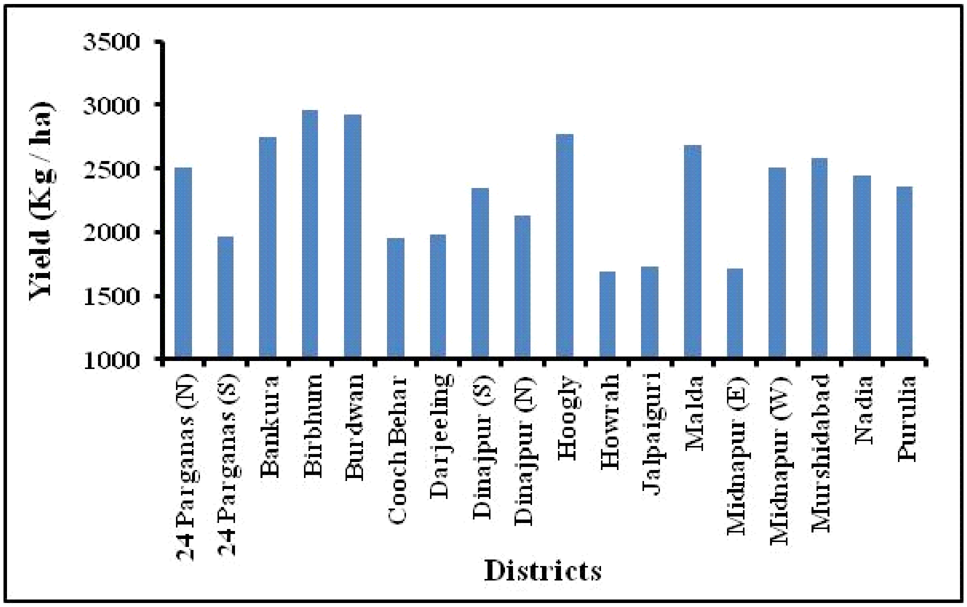

Fig. 1: Average productivity of *kharif* rice in different districts of West Bengal during recent five years (2007 to 2011)

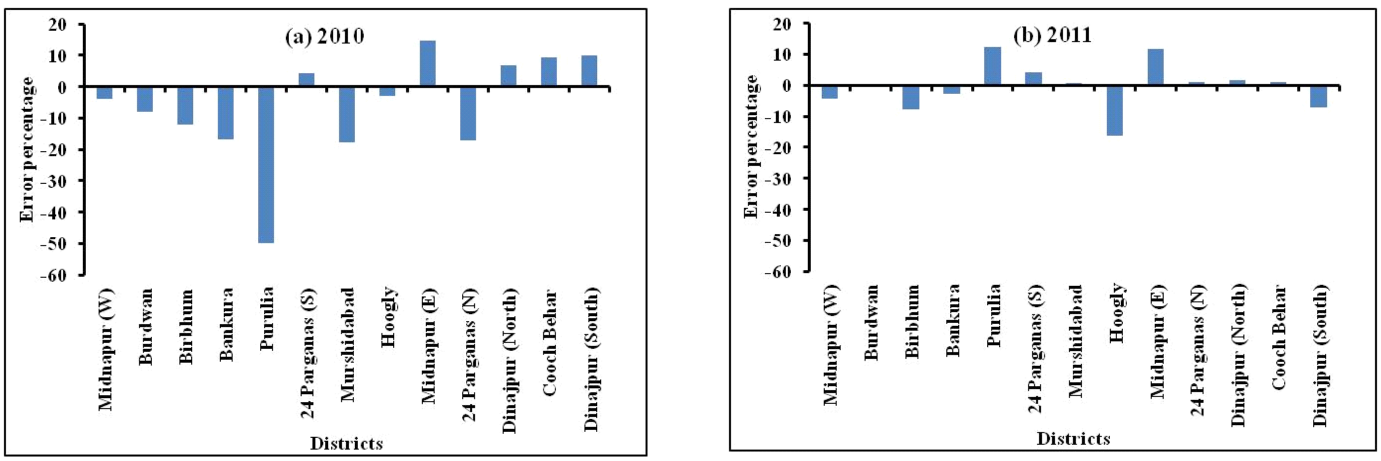

Fig. 2: Validation of forecast models for *kharif* rice in different districts of West Bengal during 2010 and 2011.

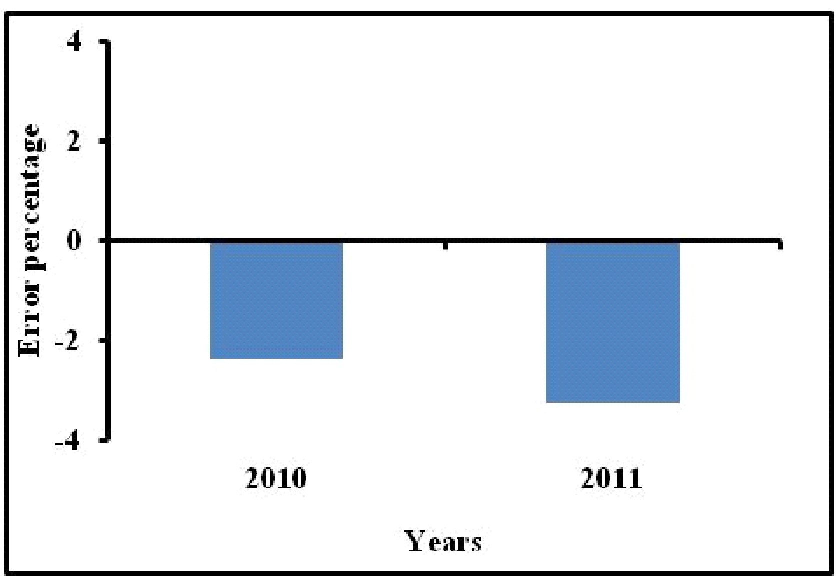

Fig. 3: Validation of State level forecast of *kharif* rice for West Bengal during 2010 and 2011.

(2924 kg ha^{-1}) (Fig. 1). Yield forecast models for the major *kharif* rice producing districts have been developed and their performance has been validated against the observed yield in 2010 and 2011.

The models developed using composite weather variables consider simple and weighted weather indices prepared using individual weather variables as well as interaction of two at a time throughout the crop growing season. Most of the models also include technology as an independent variable. Prediction is best for the districts of Dinajpur (North) with highest Correlation (cc=0.98) and least RMSE value (69.17 kg ha^{-1}) followed by Dinajpur (South) (cc=0.97 and RMSE=97.93 kg ha^{-1}). The yield forecast models developed using Composite weather variables are significant at 5% level of significance and presented in Table 4.

Rice yield forecasts along with observed yield in 2010 and 2011 for various districts of West Bengal are presented in Table 5 and results of validation of forecasts for these years are presented in Fig. 2. The validation results indicate that prediction of yield forecast is better for most of the Districts in 2011 as compared to 2010. The predicted *kharif* rice yields for most of the Districts are within acceptable error limit (±10%) in both the years of validation; however, prediction was marginally higher only for a few districts.

Performance of state level forecast for* kharif *rice

State level yield forecast has been generated using area weighted district level yield forecasts and validated for the year 2010 and 2011. The validation results presented in Fig. 3 show that both the years, the state level yield forecasts (-2.4% and -3.3% in 2010 and 2011, respectively) generated from district level yield forecasts using composite weather variables performed well and remain under acceptable limit (±5%).

CONCLUSION

For establishment of methodology of crop yield forecast under FASAL project, modified Hendrick and Scholl model (Agrawal *et al.* 1986) using composite weather indices has been used for developing the District level yield forecast models and their performance is studied. During the process of development of the models, simple and weighted weather indices are prepared for individual weather variables as well as for interaction of two at a time considering throughout the crop growing season. The performance of the model in predicting yields at district level for various major crops in different States of the country is quite satisfactory. The studies carried out for *kharif* rice of West Bengal in the paper also reflect the similar result. The prediction of State level *kharif* rice yield for West Bengal is also near accurate for both the years.

ACKNOWLEDGEMENT

The authors are grateful to Dr. Ranjana Agarwal, Former Principal Scientist and Head (Division of Forecasting Techniques), Indian Agricultural Statistical Research Institute (IASRI), New Delhi for her valuable guidance and constant support for carrying out the studies to develop the models. The authors are also thankful to the staff of Crop Yield Forecasting Section of Agrimet Division, IMD, Pune for rendering help in developing the yield forecast models and analyzing the results.

REFERENCES

Agrawal, Ranjana, Jain, R. C. and Singh, D. (1980). Forecasting of rice yield using climatic variables. *Ind.* J. *Agri. Sci.,* 50(9):680-684.

Agrawal, Ranjana and Jain, R.C. (1982). Composite model for forecasting rice yield. *Ind.* J. *Agri. Sci.,*52(3):189-194.

Agrawal, Ranjana, Jain, R. C. and Jha, M.P. (1983). Joint effects of weather variables on rice yields. *Mausam,* 34(2): 177-181.

Agrawal, Ranjana, Jain, R.C. and Jha, M.P. (1986). Models for studying rice crop-weather relationship. *Mausam,* 37(1): 67-70.

Fisher, RA. (1924). The influence of rainfall on the yield of London wheat at Rothamsted. *Phil. Trans. Roy. Soc.,* B213:89-142.

Hendrick,W.A. and Scholl. J.C. (1943).Technique in measuring joint relationship the joint effects of temperature and precipitation on crop yield. *North Carolina Agric. Exp. Sta. Tech. Bull.,* 74.

Jain, R.C., Agrawal, Ranjana and Jha, M.P. (1980). Effect of climatic variables on rice yield and its forecast. *Mausam,* 31(4): 591-596.

Website of Directorate of Economics and Statistics, Department of Agricultural and Cooperation, Ministry of Agriculture, Govt. of India (http://eands.dacnet.nic.in/).

Received : April 2014 ; Accepted : May 2014