Vol. 14, No. 2, pp. 189-193 (2014)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Development of Multi Stage District Level Wheat Yield Forecast Models

AMIT K. SINGH[1], ANANTA VASHISTH[1,*], V.K. SEHGAL[1], A. GOYAL[1], H. PATHAK[2] AND S.S. PARIHAR[3]

[1]Division of Agricultural Physics, [2]Centre for Environment Science and Climate Resilient Agriculture, [3]Water Technology Centre
Indian Agricultural Research Institute, New Delhi-110 012

ABSTRACT

Multistage crop yield forecasts were done by developing district level statistical yield models at mid-season (45 days before harvest, DBF) and pre-harvest stage (25 DBF). Crop yield forecasts were generated for wheat crop in *rabi* season in Amritsar, Bhatinda and Ludhiana districts of Punjab. Long period crop yield data as well as weekly weather data as per meteorological standard weeks have been used for development of the district level statistical yield forecast models. For developing the statistical yield forecast models, composite weather variables have been used. These models developed at mid-season (F2) and pre-harvest (F3) stage of crop growing period. Simple and weighted weather indices were prepared for individual weather variables as well as for interaction of two variables at a time throughout the season. Validation of these models revealed RMSE of 558, 587 and 599 kg ha^{-1} for Amritsar, Bhatinda and Ludhiana districts, respectively in the mid-season, while 286, 419 and 404 kg ha^{-1} for Amritsar, Bhatinda and Ludhiana, respectively.

Key words: Wheat, Statistical models, Weather indices, Punjab

Introduction

More than 50% of population in India depends on agriculture for livelihood. The vagaries of weather leave the farming community in a uncertain and tough condition every year. Weather is the dynamic component of our physical surroundings. Crop yield is the resultant of complex interaction among factors of soil, atmosphere, plant genotype and management practices. The complex interactions of crop with various factors and among the factors make the crop yield forecasting an arduous task. Crop yield relies on weather to a larger proportion than any other single factor. Crop acreage estimation and crop yield forecasting are the two components which are crucial for the policy making and execution of planning for the agricultural sector of the country.

In India, traditional approach of crop yield estimation by complete enumeration method through crop cutting experiments has been time and labour intensive. For export /import decisions and contingency planning to small and marginal farmers, Government needs advance estimates of crop yield. In-season crop yield estimation is also necessary in the context of frequently changing weather scenario. Hodges *et al.* (1987) demonstrated the use of CERES-Maize model for yield forecasting in US Corn Belt. A real time

*Corresponding author,
Email: ananta.iari@gmail.com

forecasting system for the rice development stage by using SIMRIW model was developed as early by Horie *et al*. (1989). An operational wheat yield forecasting methodology for western Canadian prairie region was developed by combining simulation and regression modelling approaches (Walker, 1989). Several such examples include validation of wheat model AFRCWHEAT2 that incorporated responses to water and nitrogen supply (Porter, 1993), preliminary verification of water, nitrogen and crop growth components of CropSyst (Stockle *et al.*, 1994), GAPS Maize model to estimate maize potential yield in Illinois using historical weather data, soil series, crop varieties and planting dates information (Moen *et al.*, 1994), and estimation of potential yields of wheat in the Yaqui valley of Mexico using CERES model (Bell and Fischer, 1994). InfoCrop, a generic dynamic crop model, has been developed at Indian Agricultural Research Institute, New Delhi, and is being used widely for crop simulation studies. It provides integrated assessment of the effect of weather, variety, pests, soil and management practices on crop growth and yield (Aggarwal *et al*., 2005). In the present paper, a methodology for mid-season and pre-harvest forecast of wheat crop at district level has been discussed for Amritsar, Bhatinda and Ludhiana districts of Punjab.

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 growing season, operational yield forecast models in this study were developed based on the modified Hendrick and Scholl model (1943) using composite weather indices (Agrawal *et al.*, 1986).

Models using composite weather variables

This paper uses methodology suggested by Agrawal *et al*. (1986) where they adjusted Hendrick and Scholl model considering that the effect of change in weather in a specific week on the yield is a direct linear function of individual correlation coefficients between the yield and the weather variables. The large impact of trend on yield was additionally removed while computing correlation coefficients of yield with weather variables to be utilized as weights.

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

where,

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

X_w denotes 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, $X_{iw}/X_{ii'w}$ is the value of i^{th}/ii'^{th} weather variable under study in w^{th} week, $r_{iw}/r_{ii'w}$ is correlation coefficient of yield (adjusted for the trend effect, if present) with i^{th} weather variable/ product of i^{th} and ii'^{th} weather variables in w^{th} week; m is forecast week, and p is number of weather variables used. Two weather indices were developed for each weather variable, *i.e.,* simple and weighted accumulation of weekly weather variable, weights being correlation coefficients of weather variable with yield (adjusted for trend) in respective weeks. Similarly, indices were also generated for interaction of weather variables, using weekly products of two variables at a time. Weather variables were 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.

Partial crop season data considering different weather variables have been used simultaneously to develop the forecast model. Weather indices used in models using composite weather variables are shown in Table 1.

Data requirement

Long-period data of weather parameters (Tmax, Tmin, Rf, RH-I and RH-II) were collected from India Meteorological Department (IMD), Pune. Long-period yield data of wheat were collected from State Department of Agriculture, Govt. of Punjab and Directorate of Economics

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

and Statistics, Department of Agriculture, Cooperation, Ministry of Agriculture, Govt. of India.

Generation of yield forecast

District and state level yield forecasts were generated by the Agromet Field Unit (AMFU) and State Agromet Centers at vegetative (Fl), mid-season (F2) and pre-harvest (F3) stages, in both the *kharif and rabi* seasons, and validated against observed yield data. The weather variables pertained to 46th to 11th standard meteorological week.

In the present study, Amritsar, Bhatinda and Ludhiana districts of Punjab were considered because these districts come under the highly productive wheat belt of India. Long-term wheat yield data for Amritsar, Bhatinda and Ludhiana have been collected from the State Department of Agriculture, Govt. of Punjab.

Statistical analysis

Statistical test was used to calculate the percentage of difference between measured and predicted values for wheat in each growing season as follows: evaluated with the help of independent datasets observed from the year 2012–13 and 2013-14. Statistical indicators were used namely; coefficient of determination (R^2), root mean square error (RMSE) and normalized mean square error (nRMSE).

Results and Discussion

Model development and evaluation

Wheat yield forecast models are listed in Table 2. The coefficient of determination (R^2) values was 0.88, 0.61 and 0.86 at mid-season (45 days before harvest, DBF) for Amritsar, Bhatinda and Ludhiana, respectively. At pre-harvest stage (25 DBF), R^2 were 0.90, 0.63 and 0.89 for these districts.

Yield forecast through statistical models are listed in Table 3. The forecasted yield for Amritsar at mid-season stage (F2) was 5289.6 and 5437.5 kg ha^{-1} in the year 2012-13 and 2013-14 which were in good agreement with the observed yields of 4654 and 4969 kg ha^{-1} in the respective years. The percentage deviation of the yield

Table 2. Model development for mid-season and pre-harvest stages

District	Equation	R^2	RMSE
	Mid-season yield forecast models		
Amritsar	Yield = 729.025+ 60.909* Time + 14.952* Z231+ 46.277* Z11+ 2.963* Z121	0.88	206.25
Bhatinda	Yield = 4279.524+ 71.368* time	0.61	185.64
Ludhiana	Yield= 3406.375+ 56.280* Time -0.628* Z 241 -46.959*Z 31	0.86	170.62
	Pre-harvest yield forecast models		
Amritsar	Yield = 1669.851 + 68.015* Time + 0.795* Z241+ 0.584* Z141	0.90	187.29
Bhatinda	Yield = 3979.524+ 79.368* time	0.63	176.98
Ludhiana	Yield= = 3606.375 + 54.280* Time - 0 .628* Z 241 -46.959*Z 31	0.89	164.43

Table 3. Model evaluation/validation for year 2013 and 2014

District	Yield (kg/ha)	2013	2014	RMSE	nRMSE
		Mid-season			
Amritsar	Observed	4654	4969	558	11.6
	Predicted	5289.6	5437.5		
	% deviation	13.7	9.4		
Bhatinda	Observed	4787	4958	586.7	12.0
	Predicted	5421.4	5492.8		
	% deviation	13.3	10.8		
Ludhiana	Observed	4654	4969	599.3	12.5
	Predicted	4116.5	4313.7		
	% deviation	11.5	13.2		
		Pre-harvest			
Amritsar	Observed	4654	4969	286	6.0
	Predicted	4952.4	5243.0		
	% deviation	6.4	5.5		
Bhatinda	Observed	4787	4958	419.1	8.6
	Predicted	5249.4	5328.8		
	% deviation	9.7	7.5		
Ludhiana	Observed	4654	4969	404.0	8.4
	Predicted	4298.1	4522.1		
	% deviation	7.6	9.0		

forecast over observed yield was 13.7 and 9.4 for 2012-13 and 2013-14, respectively. The RMSE and nRMSE were 558 kg ha^{-1} and 11.6%, respectively, indicating satisfactory forecasting. The pre-harvest stage yield forecasts were 4952.4 and 5243.0 kg ha^{-1}. These pre-harvest stage yield forecast were also in good agreement with observed yields of 4654 and 4969 kg ha^{-1} in 2012-13 and 2013-14, respectively. The RMSE and nRMSE for pre-harvest stage forecast were 286 kg ha^{-1} and 5.9% and the percentage deviation was 6.4 and 5.5 for 2012-13 and 2013-14, respectively. Results are in conformity with Vashisth *et al*. (2014), who also reported satisfactory performance of the statistical model for estimating wheat yields at different growth stage under semi-arid region.

For Bhatinda district, forecast model for mid-season and pre-harvest stage shows that forecasting is strongly dependent on time of forecast. Forecasted yield for mid-season stage were worked out as 5421.4 and 5492.8 kg ha^{-1} in 2012-13 and 2013-14. Observed yield in 2012-13 and 2013-14 were 4787 and 4958 kg ha^{-1}. The RMSE and nRMSE was of 586.7 kg ha^{-1} and 12.04%, respectively indicating agreeable model performance. The percentage deviation of the forecasted yield over observed data was 13.3 and 10.8 for 2012-13 and 2013-14, respectively. For pre-harvest stage forecast, yields of 5249.4 and 5328.8 kg ha^{-1} for 2012-13 and 2013-14 were obtained with RMSE of 419.10 kg ha^{-1} and nRMSE of 8.60%. Results indicate that the models work good in mid-season and excellent in pre-harvest stage. The percentage deviation over observed yield data was 9.7 and 7.5 for 2012-13 and 2013-14, respectively.

In case of Ludhiana also, time of forecasting is most important, composite weather variables Z241, Z150 and Z41 in mid-season, and Z241 and Z31 in pre-harvest stage, indicating that Z241 is most influential factor in Ludhiana. The observed yields in 2012-13 and 2013-14 were 4654 and 4969 kg ha^{-1}, while forecasted yields at mid-season stage were 4116.5 and 4313.7 kg ha^{-1} which shows RMSE of 599.3 kg ha^{-1} and nRMSE of 12.45%. The percentage deviation over observed yield was 11.5 and 13.2 for 2012-13 and 2013-14, respectively. Forecasted yields at pre-harvest stage were 4298.1 and 4522.1 kg ha^{-1} (RMSE 403.97 kg ha^{-1} and nRMSE 8.39%). The percentage deviations over observed yield were 7.6 and 9.0 for 2012-13 and 2013-14, respectively. Better performance of the pre-harvest stage forecast can be attributed to further weather data inputs till harvest stage. Ghosh *et al.* (2014) reported that the performance of the district-level yield forecast model developed by using composite weather indices has been quiet satisfactory in predicting yields of major crops in different states of the country.

Conclusion

Statistical models based on weather indices can successfully simulate multi-stage yield forecast of wheat. The nRMSE values were 11.6, 12.0 and 12.5 for Amritsar, Bhatinda and Ludhiana respectively in mid-season forecast, while for pre-harvest forecast, values were 6.0, 8.6 and 8.4, respectively for Amritsar, Bhatinda and Ludhiana districts. This model is simple, does not require any sophisticated statistical tools, and can be used satisfactorily for district, agro-climatic zone and state level forecasting.

References

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

Aggarwal, P.K., Banerjee, B., Daryaei, M.G., Bhatia, A., Bala, A., Rani, S., Chander, S., Pathak, H. and Kalra, N. 2005. InfoCrop: A dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystems in tropical environments. II. Performance of the model. *Agric. Sys.* **89**: 47-67.

Bell, N.A. and Fischer, R.A. 1994. Using yield prediction models to assess yield gains: a case study for wheat. *Field Crops Res.* **36**: 161-166.

Ghosh, K., Balasubramanian, R., Bandopadhyay, S., Chattopadhyay, N., Singh K.K. and Rathore, L.S. 2014. Development of crop yield forecast models under FASAL – a case study of *kharif* rice in West Bengal. *J. Agrometeorol.* **16**: 1-8.

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.

Hodges, T., Botner,D., Sakamoto, C. and HaysHaug, J. 1987. Using the CERES-Maize model to estimate production for the U.S. Cornbelt, *Agric. For. Meteorol.* **40**: 293-303.

Horie,T., Nakagawa, H. and Nakano, J. 1989. Modelling and prediction of developmental process in rice, VII: A newly developed system for predicting rice developmental process, Japanese. *J. Crop Sci.* **58**: 29-30.

Moen, T.N., Kaiser, H.M. and Riha, S.J. 1994. Regional yield estimation using a crop simulation model: concepts, methods, and validation. *Agric. Sys.* **46**: 79-92.

Porter, J.R. 1993. AFRCWHEAT2: A model for the growth and development of wheat incorporating responses to water and nitrogen. *Eur. J. Agron*. **2**: 69-82.

Stockle, C.O., Martin, S.A. and Campbell, G.S. 1994. CropSyst, a cropping systems simulation model:Water/Nitrogen budgets and crop yields. *Agric. Sys.* **46**: 335-359.

Vashisth, A., Singh R. and Choudary, Manu 2014. Crop yield forecast at different growth stage of wheat crop using statistical model under semi-arid region. *J. Agroecol. Nat. Resour. Manage.* **1**: 1-3.

Walker, G.K. 1989. Model for operational forecasting of western Canada wheat yield. *Agric. For. Meteorol.* **44**: 339-351.

Received: 16 October 2014; Accepted: 20 December 2014