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Real time wheat yield assessment using technology trend and crop simulation model with minimal data set

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The issue of real time assessment of the direction and quantum of variability in wheat yields is addressed. A simple technology trend model in conjunction with crop simulation model (CERES-Wheat in DSSAT environment) was used for early wheat yield prediction at six locations representing the six major wheat-growing states, which contribute about 93% of national wheat production. A three-step approach, viz. (a) prediction of technological trend-based yields, (b) quantification of weather-induced yield variability using Crop Simulation Model (CSM), and (c) final yield prediction combining the previous two steps (a) and (b), was applied. A simulation model when run on a common set of soil properties, genetic coefficients and agronomic practices, is supposed to capture inter-annual yield variability due to year-to-year varying weather conditions. Deviation in observed wheat yield from its technology trend and deviation in simulated wheat yield from its trend/average showed positive relationship ($r = 0.57$, $P > 0.05$). An overall RMSE of 0.158 t ha^{-1} (5.619%) with R^2 0.97 was found against mean wheat yield of 2.815 t ha^{-1}. Real time weather data up to February and normal onward were used, for early wheat yield assessment at six locations. The study has significance in issuing an early 'national wheat' production forecast using in-season weather data up to February and normal weather data for the rest of the period.

FOODGRAIN production in India crossed 200 Mt mark in year 1999–2000, in comparison to 50.82 Mt in 1950–51. In spite of technological advancement in agriculture, large year-to-year variations in production continue, which is related to fluctuations in monsoon at a gross level[1]. Wheat, the second most important foodgrain crop, contributes about 37% to the total foodgrain production in India. Punjab, Haryana, Uttar Pradesh, Madhya Pradesh and Bihar contribute about 93% of wheat production in India. Wheat production fluctuated between a high of 75.6 Mt in 1999–2000 and 62 Mt in 1995–96 in India, while state-level fluctuations in wheat production ranged from 12.52 to 14.5 Mt (1995–96, 1998–99), 6.56 to 8.46 Mt (1995–96, 1999–00), 5.25 to 6.88 Mt (1995-96, 1998–99), 21.63 to 24.05 Mt (1995–

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96, 1996–97), 7.31 to 9.64 Mt (1995–96, 1999–2000) and 3.82 to 4.85 Mt (1995–96, 1997–98) in Punjab, Madhya Pradesh, Rajasthan, Uttar Pradesh, Haryana and Bihar, respectively, in last five years[2]. Under such a situation, the importance of early prediction of crop production can hardly be overemphasized. This would require pre-harvest estimates of crop acreage and yield. Acreage estimation of major crops, including wheat[3,4] has been demonstrated using remote sensing data in India, while yield prediction as based on weather has generally been done using empirical statistical approaches[5–7].

A substantial progress in crop simulation models has made them a serious contender for yield prediction at various spatial scales; district[8], state to national[9] level. Regional yield prediction using CSM requires large volume of inputs as well as regional level of weather data in combination with GIS and remote sensing[10]. Recent studies with groundnut model (PNUTGRO) indicate that the use of heuristic model in combination with the simulation model is able to mimic crop growth and yield[11]. Early prediction of crop yield has an additional requirement of deciding future weather data, which could be normal, predicted[12] or analogous year.

Although originally designed to quantify and formalize an understanding of the interaction of crop process with environment in determining growth and yield, DSSAT (Decision Support System for Agrotechnology Transfer) has become a popular tool among model users due to standardized input format, large validation studies, and coverage of crops through a common shell that allows the user to organize and manipulate crop, soil and weather data and to run crop models in different ways and analyse their outputs. The CERES (Crop Estimation through Resource and Environment Synthesis)-Wheat[13] part of DSSAT[14–16] has been validated and calibrated with experimental data in India[17,18] and recently its use for district-level wheat yield prediction has been demonstrated by Nain *et al.*[8] in Nainital District.

Here we address the issue of combining the technology trend model[19] and crop simulation model[8,9,20], with minimal set of data (temperature and rainfall) for six locations of major wheat-growing region in India, for early assessment of direction and quantum of weather-induced year-to-year variability in wheat yield. Amritsar, Faridabad, Jaipur, Bhopal, Lucknow and Patna have been selected for the study. Except Faridabad real time weather data (maximum and minimum temperature, rainfall) for all stations are available in the All India Weather Summary (AIWS) published by India Meteorological Department (IMD), Pune. Weather data of Delhi were used for Faridabad. The solar radiation was estimated using Bristow and Campbell[21] relationship. CERES-Wheat model in DSSAT 3.5 with genetic coefficient given by Hundal and Kaur[17] was used on a common set of soil properties and fertilizer input. The model was run on potential productivity situation (optimum sowing time and auto irrigation). The procedure for yield prediction involved (a) prediction of technology trend yield (OBS) (technology trend [19,22] can be estimated by regressing observed yield with time, which accounts for variation in yield due to advancement in technology – fertilizers, irrigation, improved agronomic practices, improved genetic potential, chemical application – of crop raising); (b) identification of weather-induced year-to-year variability (YDSIM) in wheat yield using simulation model, and (c) incorporation of weather-induced variability in trend yield. The following equations were used for yield prediction:

$$\mathrm{OBS} = a_1 + b_1 \times \mathrm{year}, \quad (1)$$

$$\mathrm{YDSIM}(\%) = ((\mathrm{YSIM} - \mathrm{SIM})/\mathrm{SIM}) \times 100, \quad (2)$$

$$= \mathrm{OBS} + (\mathrm{YDSIM}(\%) \times \mathrm{OBS})/100, \quad (3)$$

where OBS is the trend predicted yield; YSIM is the simulated yield; SIM is the simulated trend/average yield for total study period; YDSIM is the deviation in trend yield due to weather; is the pr edicted/estimated yield; a_1 and b_1 are the constant and slope obtained by regressing observed yields with year.

Analysis of wheat yields from 1991–92 to 1996–97 for the six study districts indicated a positive trend, varying between 33.5 kg ha^{-1} yr^{-1} in Lucknow to 60 kg ha^{-1} yr^{-1} in Bhopal, while yields in Jaipur decreased at the rate of 55.9 kg ha^{-1} yr^{-1} (Table 1). The technology trend explained 4.8% (Jaipur) to 77.8% (Bhopal) of variability in yield series.

Potential yields were simulated from 1995–96 to 2000–01 for the six stations using common inputs, except weather to capture year-to-year variability in wheat yield. Simulated potential yields ranged from 5.296 (1998–99) to 6.136 (1996–97) t ha^{-1} in Amritsar;

Table 1. Technology change and ratio of observed to potential yield

Station	Mean yield* (t ha^{-1})	Technological slope (kg ha^{-1} yr^{-1})	Avg. ratio of obs. to pot. yield[a]	Avg. ratio of pot. yield[a] to pot. yield[b]
Amritsar	4.240	51.3	0.74	0.97
Bhopal	1.740	60.0	0.36	0.99
Jaipur	2.211	– 55.9	0.44	1.02
Lucknow	2.289	33.5	0.47	1.02
Faridabad	3.809	66.0	0.76	1.01
Patna	2.744	42.1	0.53	1.00
Average	2.790	30.3	0.55	1.00

[a]Full season data have been used; [b]Real time data up to February and normal thereafter, have been used; Obs, Observed yield; Pot, Potential simulated yield. *Wheat season 1995–96 to 1999–00.

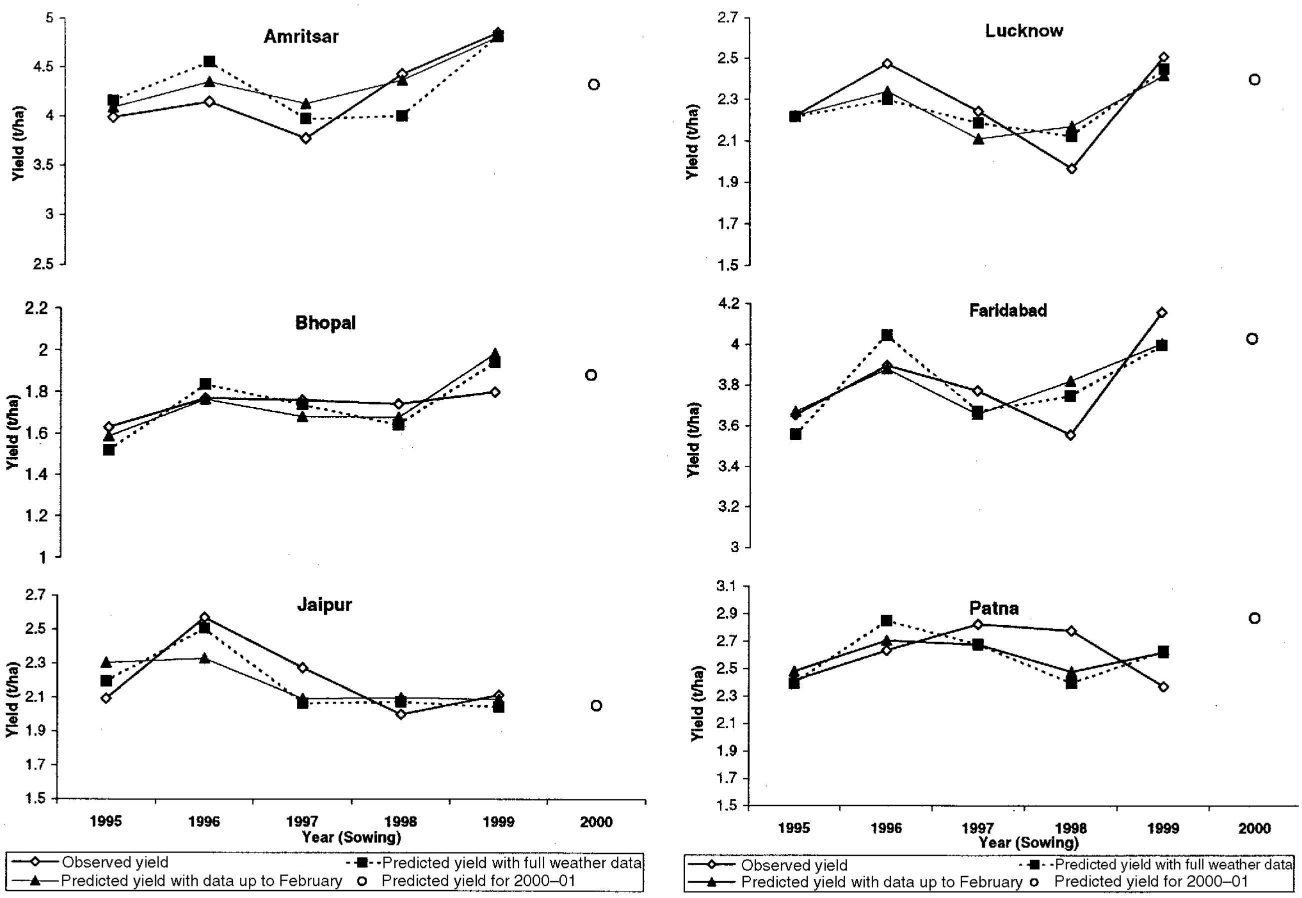

Figure 1. Comparison between observed and predicted wheat yields of Amritsar, Bhopal, Jaipur, Lucknow, Faridabad and Patna. Yields were predicted using full season weather data and weather data up to February.

4.379 (1998–99) to 5.321 (1996–97) t ha^{-1} in Bhopal; 4.789 (1997–98) to 5.718 (1996–97) t ha^{-1} in Jaipur; 4.531 (1998–99) to 5.149 (1996–97) t ha^{-1} in Lucknow; 4.837 (1998–99) to 5.573 (1996–97) t ha^{-1} in Faridabad; and 4.423 (1998–99) to 5.488 (1996–97) t ha^{-1} in Patna. CERES-Wheat model under-estimated the yields in 1998–99. The main cause may have been rainfall in the early season and high temperature in the later part, which affected the sowing and maturity, respectively.

Deviation in observed yield from its technological trend and deviation in simulated yield from its trend/average yield showed a positive correlation coefficient of 0.57, which increased up to 0.67, when two deviations of Amritsar and Patna for the wheat season of 1998–99 are omitted from the analysis. Results of prediction are shown in Figure 1. RMSE for the period 1995–99 for all stations has been calculated. It ranged from 0.1 t ha^{-1} (Bhopal) to 0.287 t ha^{-1} (Amritsar). Overall RMSE was 0.158 t ha^{-1} against the mean yield of 2.815 t ha^{-1} (5.619%). The R^2, when calculated between observed yield and predicted yield was found to be 0.964. When two predictions, Amritsar and Patna, for the wheat season of 1998–99 are omitted, RMSE improved to 0.1387 t ha^{-1} (5.136%), which shows high degree of agreement between observed and predicted yields. Individual RMSEs for each station were 0.29, 0.1, 0.12, 0.11, 0.14 and 0.24 t ha^{-1} against the mean observed yields of 4.24, 1.74, 2.21, 2.29, 3.81 and 2.60 t ha^{-1} for Amritsar, Bhopal, Jaipur, Lucknow, Faridabad and Patna, respectively.

Early assessment of crop yield provides sufficient time for policy-makers to meet the requirement of food and/or to provide storage, transportation and marketing facilities for growers. The issue of pre-harvest wheat yield prediction was studied using real time weather data up to February end and normal onwards. The regression coefficient was 0.984, when the predicted yield using full season real time weather data were compared with predicted yields using real time data up to February. The overall RMSE between observed and predicted yields was found to be 0.158 t ha^{-1} against the average yield of 2.815 t ha^{-1} (5.61%). Although the post-harvest revised estimates by Director of Economics and Statistics are issued much after harvest of crop, assessment of wheat yields for all six stations for the 2000–01 using the above approach was also carried

Table 2. Year-wise RMSE between observed and predicted yields and GDD deviation from normal during March

Year of of sowing	RMSE with full weather data set (t ha^{-1})	RMSE with weather data up to February (t ha^{-1})	Avg. GDD deviation from normal during March (heat unit)
1995–96	0.101	0.115	4
1996–97	0.213	0.144	1
1997–98	0.140	0.190	– 48
1998–99	0.258	0.191	26
1999–00	0.144	0.148	– 27

out. The predicted yields are 4.32, 1.878, 2.051, 2.403, 4.029 and 2.869 t ha^{-1} for Amritsar, Bhopal, Jaipur, Faridabad, Lucknow and Patna, respectively.

This study suggests that CERES-Wheat model incorporated in DSSAT environment captures the variability in wheat yield arising due to inter-annual varying weather conditions. The simple technology trend model to account for technology variation across the years in a district, in conjunction with the crop simulation model can be used for early assessment of wheat yields. Real time weather data up to February and normal in the later part of the wheat season show good agreement with observed yield. During the crop season 1998–99, prediction using normal data set after February, gave better RMSE. This could be due to the untimely rainfall during the early wheat season and high temperature in the later part, which the model showed as adverse for wheat yield; but inclusion of normal data after February having less GDD (Growing Degree Days) in March (Table 2), neutralizes the adverse effect of weather. The actual data on agronomic practices, genotypes (dominant cultivars of the region and their coefficient) and actual spatial soil data may significantly increase the accuracy of the procedure. While in the current study, analysis was restricted to only six districts for which weather data were available, a national-level wheat yield prediction would require a large number of weather data sets. This issue could be addressed either by having access to a large data set, spatially interpolated daily weather data[10] or by relating point weather data to large homogenous regions. In a related study, Dadhwal *et al.*[23] have classified the geographical area of Uttar Pradesh into seven major coherent wheat yield variability zones on the basis of weather-induced variability in wheat yield for the regional wheat yield prediction.

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