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Wheat yield prediction using CERES-wheat V4.6 an operational approach for Uttar Pradesh, India

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Abstract
CERES-Wheat model embedded in DSSAT v4.6 was used to simulate the yield under irrigated condition for the eight locations representing different agroclimatic zones of Uttar Pradesh. The genetic coefficient required for running the CERES-Wheat v4.6 model was derived for commonly grown cultivars i.e. PBW-343 (22nd Nov, 29th Nov and 06th Dec) and Malviya-234 (13th Dec, 20th Dec and 27th Dec) at different agroclimatic zones. The simulated average yield is 3430 for F2 (pre flowering stage) and 3560 kg ha^{-1} for F3 (pre maturity stage) stage during 2014-15. The simulated yield production forecast during 2014-15 depicts increase grain yield by-9.3% more compare to year 2013-14. The maximum yield (F2=4824 & F3=4846 kg ha^{-1}) in Western agroclimatic zone (Modipuram) followed by lower yield (F2=2743 & F3=2893 kg ha^{-1}) in North eastern plain zone (Bahriach) in 2014-15. The validation of the simulated yield is highest correlation (R^2=0.98 and RMSE value 384, 372, 367, 355, 271, 269 and 196 kg ha^{-1} respectively) for Kanpur, Jhansi, Lucknow, Varanasi, Baharich, Modipuram and Faizabad, followed by Allahabad (R^2=0.93 and RMSE 110 kg ha^{-1}). The validation results indicate that the hind cast wheat yields for most of the districts are within the acceptable error limit (±10%) in all the years of validation; however, prediction was marginally higher in the year 2011-12 for Central Plain zone (Kanpur), 2012-13 for Buldelkhand Zone (Jhansi) and 2013-14 for Eastern Plain zone (Faizabad). The simulated yields are clearly able to indicate the yield variability due to rise of temperature encounter during booting or grain filling state in the wheat crop. The model validated for previous year grain yield showed deviation 9 to 10% which can be improved by further fine tuning the genetic coefficient and other input data at district level.

Keywords: wheat, yield forecast, crop simulation model

1. Introduction

Timely availability of reliable information on agricultural output and other related aspects is of great significance for planning and policy making particularly, in the management of concerns in areas such as food security, price stability, international trade etc. The information is extremely useful in identifying problem areas and the nature of required intervention in terms of spatial, temporal and qualitative inferences. However, the traditional approach, in spite of established procedures and wide coverage, has inherent limitations in the matter of providing an objective assessment of crops at the pre-harvesting stages with the desired spatial details by Agrawal, R and Mehta, S. C. 2007; Ghosh, *et al.* 2014 and Vashisth, *et al.* 2014.

CERES-Wheat crop simulation model has been widely tested and validated under diverse agro-climatic conditions in different states of India for various uses such as prediction of growth stages and crop duration, grain yield simulation, effect of planting dates on crop yield and water requirement, water scheduling, nitrogen management (Nain *et al*. 2004). Sharma and Kumar (2006) and Kiani *et al*. (2003) reported that the model predicted grain yield fairly well with difference between simulated and observed grain yield less than 10 %. Sharma and Kumar (2006) reported similar results while validating for grain productivity of all wheat varieties and the association between simulated and observed grain yield was significant (R^2= 0.8044). This shows that model was validated with a fair degree of accuracy under the given set of agronomic management, weather conditions and this can be used to work out management practices for yield maximization in north western Himalayan region. Sharma and Kumar (2006) and Heng *et al*. (2000) reported deviation of simulated yield over observed values ranging from -10.6 to 20.6 percent in different treatments.

In the present study Agromet Service Cell, IMD has made efforts to estimate the wheat yield on operational basis using DSSAT crop growth simulation model CERES-Wheat v4.6. Simulations were made under irrigated condition for the wheat-growing districts of Uttar Pradesh. As wheat cultivation is mostly irrigated and recommended NPK is applied, productivity of a given cultivar is primarily governed by the weather, particularly temperature and radiation. The methodology is already in use for generation of operational yield forecast for wheat and all the major crops in different states in the country.

2. Material and Methods

2.1 Yield Forecasting using DSSAT v 4.6

DSSAT v4.6 model were run using actual weather data during the cropping season for the districts of different Agroclimatic zones of Uttar Pradesh. CERES-wheat is useful tool to describe continuous crop growth and to estimate crop yield during the crop growing season and indicates crop stage and state. In addition following data are collected from AMFUs under FASAL project (2011-2014) for developing single/multiple regression models:

Statistical Model (Correction Factor)

As simulated yield is higher than actual district yield, suitable correction factor has been computed for each state using results from recent past years. A correction factor is mathematical adjustment made to calculate to account for deviations in observed yield. This is mainly to reduce the difference between simulated and observed yield. Average of previous year yield difference (simulated minus actual) considered as correction factor for yield forecast.

In spite of the improvements in data acquisition, many significant challenges still exist with observed data based functional models. Firstly, effective integration of different observed datasets into one modeling platform remains a challenging task. Secondly, most of the existing yield forecasting models are limited to a few crops or certain geographic reasons. Thirdly, the forecast models limitation and uncertainty need to be quantified by crop type, forecasting lead time, different geographic regions and other factors (e. g. climate, soil and management practices etc.). Fourthly, the scaling up/down of yield forecast may be complicated by the data availability at scales involved and the choice of a suitable technique.

Steps Followed:

(i) A trend was observed for the observed district yield data and then correction factor was calculated for those years where the trend was observed. In case where no trend line observed in yield data average of two to three years was taken.

(ii) According to sowing window means how much % area is covered by the particular variety on that selected sowing date, the weighted simulated yield calculated according *Singh et al* 2010.

Formula: Simulated Yield * Percentage Area Covered

Then, year wise accumulated simulated yield taken for the calculation of correction factor by summing up the weighted simulated yield. Observed yield data plotted with time series data as line graph. A common feature of time series data is trend; therefore, a trend line was plotted. The values from the above trend line equation (Y= a+bx) were subtracted from the average of the total accumulated simulated weighted yield. Again, input the above produced data and time data to produce the line graph of the data, then fit a linear trend line to the data. Finally, use the slope value of trend line to determine an appropriate correction factor.

As simulated yield is higher than actual district yield, suitable correction factor has been computed for each district using results from recent past years 2013-2014. Average of previous year yield difference (simulated minus actual) considered as correction factor for yield forecast.

Input data

Database Preparation

For final database as input to the simulation model (DSSAT v4.6) a long term data of weather and soil was scrutinized and processed. The input files for the model beside weather and soil require crop data needed in management practices such as plant population time of planting, irrigation and fertilizers scheduling etc. were collected. The data set is used for the purpose of giving forecast at F2 (Pre-flowering) and F3 (Pre-harvesting) Stages.

a) Weather data

Weather data plays important role for yield estimation in crop simulation model because the model responds to variability in weather parameters. To simulate the crop growth and development weather parameters needed are daily values of maximum and minimum temperature, bright sunshine hours (BSSH) or solar radiation, since light and temperature are one of the key parameters driving variables of plant processes. The complete weather data sets without any discrepancies are needed for crop simulation models to calculate dry matter accumulation and to determine the physiological development of the crop. District wise weather data (2010-2015) are obtained from Meteorological Centre, Lucknow and AMFUs of Uttar Pradesh representing different agroclimatic zones. District wise available weather data has been interpolated for nearest districts of Uttar Pradesh.

For the final (F3) predication 2014-15, observed data at all the locations is taken up to 31 March. After 31 March, one-week (7 days) medium range weather Forecast (MRFs) was incorporated and thereafter (45 days) daily extended range weather forecast (ERFs) data was taken to complete the crop cycle.

b) Soil data

District wise soil parameters such as organic carbon, clay contents, silt contents, soil pH is collected from Agromet field units (AMFUs) in DSSAT format for different layer. Missing soil parameters are also collected from NBSS & LUP, Nagpur and layer wise field capacity, wilting point and saturated hydraulic conductivity calculated as methodology developed by *Adhikari et al*. (2008).

c) Crop data/cultivar file

Dominant crop cultivar viz; PBW 343 and Malviya 234 considered for the forecast. Water and nitrogen management parameters considered in the model were as per agronomical recommendation widely accepted/practice in these agroclimatic zones and field experiments conducted by AMFUs under FASAL scheme of India Meteorological Department.

Genetic coefficient

Crop datasets include the genetic coefficients with genetic parameters that characterize the physiological and morphological processes determining crop growth, development and yield. Changes of genetic coefficient; changes the overall characteristic of the plant development (Singh *et al*. 2010) in table-1.

3. Results and Discussion

The CERES-Wheat v4.6 crop growth simulation model was calibrated and evaluated for the different agroclimatic conditions of wheat growing area of Uttar Pradesh. In the present study efforts are made to estimate the wheat yield for the year 2014-15 using CERES-Wheat crop growth simulation model embedded in DSSAT v4.6 software. Simulations were made under irrigated condition for the districts wise wheat-growing locations representing different agroclimatic zones of Uttar Pradesh. Daily weather data on maximum and minimum temperatures, rainfall and radiation were used for district wise of Uttar Pradesh for the current winter seasons 2014-2015. Solar radiation required by the crop model was calculated from bright sunshine hour. Genetic coefficient required for running the CERES-Wheat v4.6 model was derived for commonly grown cultivars i. e. PBW-343 (22^{nd} Nov-10 percent, 29^{th} Nov-15 percent and 06^{th} Dec-40 percent) and Malviya-234 (13^{th} Dec-20 percent, 20^{th} Dec-10 percent and 27^{th} Dec-5 percent area covered) at different locations. The simulated/forecasted grain yield, for the various districts are given for F2 (pre flowering) and F3 (pre maturity) stage for wheat crop for *rabi* season 2014-15 in fig-1. Yield percentage deviation for various stations representing different agroclimatic zones of Uttar Pradesh for the year 2011-12, 2012-13 and 2013-14 is sown in table-2. The simulated average yield is 3430 and 3560 kg/ha for F2 and F3 stage respectively during 2014-15. Wheat yield production forecast during 2014-15 depicts increase grain yield by -9.3% more compare to year 2013-14.

Validation of agroclimatic level forecast for wheat

The simulated yield of wheat crop for various districts of Uttar Pradesh representing different agroclimatic zones (Allahabad, Bahraich, Faizabad, Jhansi, Kanpur, Lucknow, Modipuram and Varanasi) have been prepared using CERES-Wheat model from 15 November to end of the March. The maximum yield (F2=4824 & F3=4846 kg/ha) in Western agroclimatic zone (Modipuram) followed by lower yield (F2=2743 & F3=2893 kg/ha) in North eastern plain zone (Bahriach) in 2014-15 in fig 1.

District observed yield collected from DAC&FW and compared with forecast yield shows that in the year 2011-12 Faizabad & Modipuram simulated yield underestimated and also in the year 2012-13 in Faizabad (Table 2). Yield forecast validation is highest correlation (R^2=0.98 and RMSE value 384, 372, 367, 355, 271, 269 and 196 kg ha^{-1} respectively) for Kanpur, Jhansi, Lucknow, Varanasi, Baharich, Modipuram and Faizabad, followed by Allahabad (R^2=0.93 and RMSE 110 kg ha^{-1}). The simulated wheat yield predication along with observed yield in 2011-12, 2012-13 and 2013-14 for various districts representing different agroclimatic zones in fig-2. The validation results indicate that the hindcast wheat yields for most of the districts are within the acceptable error limit (±10%) in all the years of validation; however, prediction was marginally higher in the year 2011-12 for Kanpur, 2012-13 for Jhansi and 2013-14 for Faizabad in fig-2. The moisture stress created by restricting the irrigation decreased the leaf water potential, canopy temperature depression, transpiration rate, stomatal conduction and photosynthesis. Moisture stresses decreased the yield and yield attributes with maximum reduction in number of tillers per plant followed plant height and ear length.

4. Conclusion

The simulated wheat yield predication along with observed yield in 2011-12, 2012-13 and 2013-14 for various stations representing different agroclimatic zones. The validation results indicate that the hindcast wheat yields for most of the districts are within the acceptable error limit (±10%) in all the years of validation; however, prediction was marginally higher in the year 2011-12 for Central Plain zone (Kanpur), 2012-13 for Buldelkhand zone (Jhansi) and 2013-14 for Eastern Plain zone (Faizabad). Yield forecast validation is highest correlation (R^2=0.98 and RMSE value 384, 372, 367, 355, 271, 269 and 196 kg ha^{-1} respectively) for Kanpur, Jhansi, Lucknow, Varanasi, Baharich, Modipuram and Faizabad, followed by Allahabad (R^2=0.93 and RMSE 110 kg ha^{-1}).

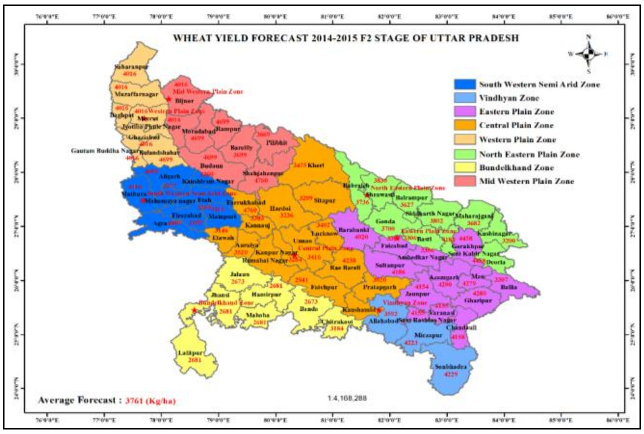

Fig1: District level simulated wheat yield (F2) Predication for Uttar Pradesh, India.

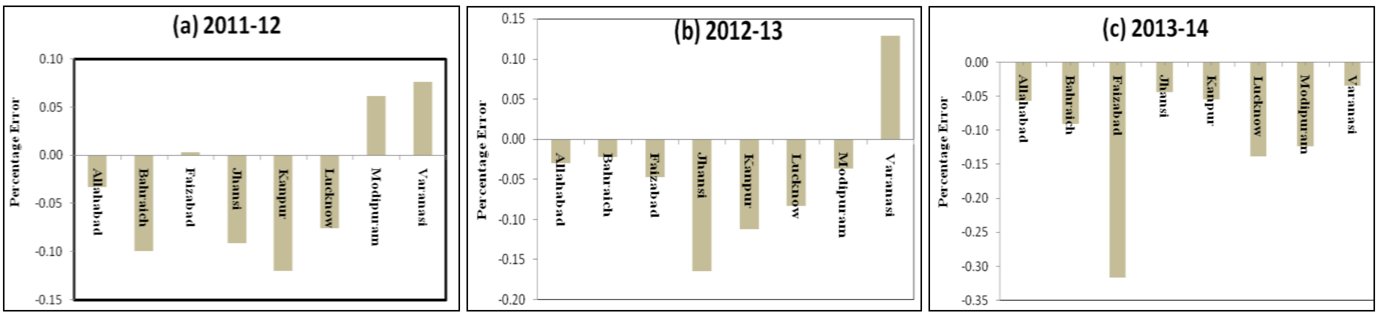

Fig 2: Validation of simulation models predication for wheat in different stations of Uttar Pradesh during 2011-12, 2012-13 and 2013-14.

Table 1: Genetic coefficient of wheat cultivars

VARIETY	P1V	P1D	P5	G1	G2	G3	PHINT
PBW 343	30	42	800	20	45	1.5	95
Malviya 234	20	90	770	23	34	1.3	95

Source: *Singh et al.* (2010)

Table 2: Observed and forecasts (kg ha^{-1}) Wheat yield in 2011-12, 2012-13 and 2013-14 for various stations representing different agroclimatic zones of Uttar Pradesh.

Sl. No.	Stations	2010-11	2011-12		2012-13		2013-14		R^2	RMSE
		Observed	Observed	Forecast	Observed	Forecast	Observed	Forecast		
1	Allahabad	2449	2628	2717	2435	2509	2531	2683	0.93	110.3
2	Bahraich	2901	3070	3407	2841	2904	3231	3554	0.98	271.9
3	Faizabad	2814	2956	2967	2663	2895	2470	2718	0.94	196.1
4	Jhansi	2750	3130	3444	2792	3342	2691	2814	0.78	372.4
5	Kanpur	3129	3311	3760	3555	4003	3480	3678	0.55	383.6
6	Lucknow	2830	2717	3038	2713	3158	2630	2951	0.79	367.0
7	Modipuram	4073	4278	4530	4129	4284	4065	4635	0.82	269.8
8	Varanasi	2743	2933	3425	3014	3370	2720	2817	0.94	355.0

Table 3: Districts wise weather data available from 2010-2015

Sl. No.	District
1.	Aligarh
2.	Agra
3.	Allahabad
4.	Barabanki
5.	Faizabad
6.	Sultanpur
7.	Varanasi
8.	Gorakhpur
9.	Kheri
10.	Etawah
11.	Hardoi
12.	Kanpur
13.	Lucknow
14.	Raebareli
15.	Meerut
16.	Modipuram
17.	Muzaffarnagar
18.	Bahraich
19.	Jhansi
20.	Hamirpur
21.	Moradabad
22.	Bareilly
23.	Shahjahanpur

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