

# Simulation of Influence on Date of Sowing and Irrigation Levels on Grain Yield of Wheat using DSSAT-Model in Different Agroclimatic Zones of Uttar Pradesh, India

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## Abstract

The CERES Wheat (V4.6) Simulation Model was calibrated and validated using experimental field data collected on phenology, yield and yield attributes of ruling cultivars of wheat under FASAL (Forecasting Agricultural output using Space, Agro meteorology and Land base observation) scheme during the winter (*rabi*) seasons of 2012-13 to 2015-16 at Faizabad, Modipuram, Kanpur, Allahabad and Varanasi AMFUs (Agrometeorological Field Units) of Uttar Pradesh under irrigated condition with the objective to study the growth and yield of wheat at different sowing dates and irrigation levels and to simulate trends of wheat production. The genetic coefficient derived from the calibration of the CERES-Wheat Model for both varieties PBW-343 and Malviya-234 were reasonably very close to observed yield. Therefore, the model as used for evaluation of sowing date and irrigation level in wheat crop. The model was run for six sowing dates on seven days interval i.e. 30 October, 06, 13, 22 & 27 November and 5 December and increasing level of (five) irrigations. Simulation studies depicts that the model performance was good under three ( $I_3$ ) and four ( $I_4$ ) irrigation level, after five ( $I_5$ ) irrigation yields are same as  $I_4$  in most of the districts of different agro climatic zone while poor performance was observed under two ( $I_2$ ) and one ( $I_1$ ) irrigation level. Wheat yield was also simulated at different sowing dates, results shows that 22 November is the optimum sowing date for Bundelkhand, Central Plain, Eastern Plain, NE Plain and Vindhyan zone and 13 November for Mid western Plain, SW Plain, Bhabhara & Tarai and Western plain zone while less yield was observed in early and late sowing.

**Keywords:** Weather data, Soil data, Genetic coefficient and Irrigation.

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## INTRODUCTION

Wheat (*Triticum aestivum L.*) is one of the important staple foods in India and is grown under diverse sets of agro-climatic conditions. In the country, it is grown in the region within latitudes  $15^{\circ}$  to  $32^{\circ}$  N and longitudes  $72^{\circ}$  to  $92^{\circ}$  E under irrigated conditions. Punjab, Haryana, Uttar Pradesh, Uttarakhand, Madhya Pradesh, Rajasthan and Bihar are the leading states of India contributing more than 90 percent of the wheat for the country. In India, wheat is next to paddy in area and production, grown over an area of 27.75 million hectares with an annual production of 80.68 million

tones. India rank second after China in wheat growing countries. It is considered to be the backbone of the food security in India. Wheat is sown during November to December and harvest during March to April. The wheat-marketing season in India is assumed to begin from April every year.

Weather variables are one of the key components, which influence on growth, development and yield of the wheat crop over which man has very little control. Increased climatic variabilities and aberrant variations in meteorological parameters like hailstorm, frost, high wind and extreme temperature and

foggy condition during wheat growing (*Rabi*) season leads to natural disasters affecting wheat productivity, over the past few years, per hectare yield of wheat in India has fallen due the temperature rising steadily in January, February and March, a time most crucial for the wheat crop [1-3]. During January and February of 2006 temperatures kept rising steadily due to prolonged absence of rain. Since wheat is sensitive to moisture stress, it needs frequent irrigation for good growth and yield [4]. The average day and night temperatures have been 4-6°C higher than the normal, most striking during February, in wheat sowing region of the country, with the raised temperatures, crop matures early. The response to temperature varies with the stage of development, mainly booting (late ear development), anthesis (pollination and fertilization) and grain growth (a week after anthesis to maturity) [5]. Wheat productivity can be increased substantially by adjusting sowing date to optimum atmosphere temperature which encounters critical phenological stages of wheat. 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 predicting growth stage and crop duration, grain yield simulation, effect of planting dates on crop and water requirement, irrigation scheduling, nitrogen management [6]. Now several crop simulation models available which enable to assess the impact of different meteorological parameters on crop growth and yield [7-9]. The present study is aimed at the evaluation of CERES (Crop Environment Resource Synthesis) - Wheat model for optimum sowing date and irrigation scheduling on wheat crop.

## DATA AND METHODOLOGY

The field experiment was conducted during the winter (*rabi*) seasons of 2012-13 to 2015-16 under FASAL (Forecasting Agricultural output using Space, Agrometeorology and Land base observation) scheme at the experimental farm of (i) Narendra Deva University of Agriculture & Technology, Faizabad, (ii) Sardar Vallabhbhai Patel University of Agriculture, Modipuram, Merrut (iii) Chandra Shekhar Azad University of Agriculture & Technology, Kanpur (iv) Sam Higginbottom University of Agriculture, Technology & Sciences, Allahabad and (v) Institute of Agricultural Sciences, BHU, Varanasi. The data were collected on phenology, yield and yield attributes of ruling cultivars of wheat for calibration and validation. In this study two ruling cultivars PBW-343 and Malviya -234 were used under irrigated conditions for all districts of different agroclimatic zones of Uttar Pradesh, with the objective to study the growth and yield of wheat at different sowing dates and irrigation levels and to simulate trends of wheat production.

### Study Site

The study primarily focused on the districts falls under different agroclimatic zones of Uttar Pradesh where wheat is extensively cultivated, about nine

agroclimatic wheat growing zones viz; Vindhyan Zone, North Eastern Plain Zone, Bundelkhand Zone, Central Plain Zone, Western Plain Zone, South Western Semi Arid Zone, Eastern Plain zone, Bhabhra and Tarai Zone and Mid Western Plain Zone taken for study (Table-1).

### Data Collection

District wise wheat yield data for past ten years collected from State Department of Agriculture, Government of Uttar Pradesh and Ministry of Agriculture & Farmers' Welfare, Government of India, New Delhi.

### Meteorological data

The long term historical daily weather data (2002-2012) at district level were collected from National Data Centre, IMD-Pune, Meteorological Centre, Lucknow and Agromet Field Units (AMFUs) of Uttar Pradesh for the variables;

- Maximum Temperature (°C)
- Minimum Temperature(°C)
- Rainfall (mm)
- Bright Sun Shine (Hours) /Solar Radiation (MJm<sup>-2</sup>) (but some districts are not available)

The main function of the weather module is to read or generate daily weather data. It reads in daily weather values (maximum and minimum air temperature, solar radiation and precipitation) from the daily weather file. Hourly weather values are computed for use by the modules which require them. Solar radiation is derived from sunshine hour's data using Angstrom method [10]. This module generates daily weather data using the WGEN [11, 12] or SIMMETEO23, 24 weather generators. In-season time series of daily weather data at district level is received from Meteorological Centres of IMD and AMFUs.

### Crop experiment data and Minimum data sets

The crop and soil related information was taken from Agromet Field Units (AMFUs) for running the model Minimum data sets required are collected from AMFUs of IMD.

### Crop Attributes

Sowing date, Anthesis date, Physiological maturity date, Grain yield at maturity (kg ha<sup>-1</sup>), weight of grains (mg/unit), No. of grains/m<sup>2</sup>, No. of grains/spike, Maximum Leaf Area Index, Tops weight at maturity kg ha<sup>-1</sup>, Bi-product harvest- kg ha<sup>-1</sup>, Grain N at maturity %, Tops N at maturity kg ha<sup>-1</sup>, Stem at maturity kg ha<sup>-1</sup>, Grain N at maturity kg ha<sup>-1</sup>.

### Management aspects considered in the study

Planting depth, Row spacing & Plant population at seeding, Plant method & distribution, Fertilizer 120 kg Nitrogen applied half as basal dose and rest in two splits, Irrigation schedule in Table 2. Two *cultivars* PBW-343 and Malviya – 234 were selected for the study. The model was run for six

sowing dates on seven days interval i.e. 30 October, 06, 13, 22 & 27 November and 5 December and increasing level of (five) irrigations.

### Soil Parameters

Soil inputs include physical and chemical description of the soil profile with separate information for each horizon, soil reflection coefficient, soil water drainage constant, USDA SCS runoff curve number, thickness of soil layer, permanent wilting point, field capacity, saturated water content, bulk density ( $\text{gm/cm}^3$ ), organic carbon content (%), pH for each layer of the soil profile, root distribution weighing factor in different layers and initial soil water soil water content for the different soil layers.

### Genetic Coefficients

Crop genetic input data, which explains how the wheat cultivar during its life cycle responds to the environment, has been developed for different cultivars PBW-343, Malviya-234 [1].

## RESULT AND DISCUSSION

### Different Sowing Date

CERES-wheat model (DSSAT v 4.6-Decision Support System for Agrotechnology Transfer) was calibrated for wheat (PBW-343 and Malviya-234) at different Agroclimatic zones of using data collected under different management practices (Date of sowing x Irrigation) during 2002-2012. The model was run for 6 sowing dates starting on 30 October and repeated every 7 days until 5 December using long-term district level station and gridded level historical weather data from different district. In Bundelkhand agroclimatic zone (ACZ) highest mean yield 4173 to 5186  $\text{kg ha}^{-1}$  in 22 and 27 November sowing date respectively and lowest 2560  $\text{kg ha}^{-1}$  in 30 October early sown date in all districts of Bundelkhand ACZ. The simulation yield was over simulated from observed yield from districts at par with the districts in Bundelkhand ACZ (Table-3, Fig-1 & Map 1). The range of RMSE value was 1330 to 2540  $\text{kg ha}^{-1}$  (Table-3). The goodness of fit was not significant except Lalitpur and Jalaun districts. Simulated yield was ranged between 2436.0 to 4338.7  $\text{kg ha}^{-1}$  for Central plain zone. The RMSE value was ranged 522 to 1526  $\text{kg ha}^{-1}$  and goodness of fit is non-significant in almost all districts. In this agroclimatic zone the sowing dates of 22 Nov was sowing higher yields, while lower yield are seen in 30 October sowing date in all districts of central plain ACZ (Table-3, Fig-1 & Map 1). Simulated yield was ranged between 2491.7 to 4135.5  $\text{kg ha}^{-1}$  for Eastern plain zone. The RMSE value was ranged 506.3 to 1570.4  $\text{kg ha}^{-1}$  and goodness of fit is non-significant in almost all districts. In this agroclimatic zone the sowing dates of 22 Nov was sowing higher yields, while lower yield are seen in 30 October sowing date in all districts of eastern plain ACZ. In Mid Western Plain agroclimatic zone highest mean yield is 4254.3 to 4231.9  $\text{kg ha}^{-1}$  on 6 and 13 November sowing date respectively and lowest 3539.1

$\text{kg ha}^{-1}$  in 5 December late sown dates in all districts except Barelley, Badaun and Moradabad where 30 October sowing dates shows lower yield (Table-3, Fig-1 & Map 1). SD was ranged 254.2 to 500.0  $\text{kg ha}^{-1}$  and CV ranged 5.9 to 16.2 percent of the different sowing date. The RMSE was ranged 370.6 to 1271.6  $\text{kg ha}^{-1}$  and this goodness of fit is not significant. The district yield was under estimated as per with simulated yield. The early (30 October) and late sowing (5 December) dates shows less yield, but normal sown date having higher yield. The higher yield shows on 22 Nov except Sharbatinagar, Gonda and Baharich district (Table-3, Fig-1 & Map-1). The RMSE value ranged 343.3 to 1927.2 at these districts and was not significant. All districts in South Western Plain zone shows higher yield on 13 November sowing date and lower yield shows on early date of sowing. 13 November should be considered as normal sowing date in all districts of south western plain zone. The range of RMSE value was 812 to 1068  $\text{kg ha}^{-1}$ . The maximum yield depicts on 22 November except Mirzapur district in Vindhyan zone and lower yield shows on early date of sowing. The RMSE value ranges 1277.3 to 1714.9  $\text{kg ha}^{-1}$  and only one was significant of Sonbhadra district. The RMSE value showed higher than the districts yield was under estimate from simulate district yields. The early sown date (30 October) shows lower yield in all districts of western plain zone and shows higher yield on 13 November sowing date except Bagpat and Bulandsahar districts. The RMSE value ranged 248.4 to 783.2  $\text{kg ha}^{-1}$  at these districts and was not significant (Table-3). In Bhabhara & Tarai zone; the highest yield was 4538.7  $\text{kg ha}^{-1}$  on 6 Nov in Sarbatinagr and the lowest yield was 3361.6  $\text{kg ha}^{-1}$  on 5 Dec in Saharanpur district (Table-3, Fig-1 & Map-1). The range of RMSE was 354  $\text{kg ha}^{-1}$  in Saharanpur to 2174  $\text{kg ha}^{-1}$  in Sarbatinagar district. The SD and CV was 333.2  $\text{kg ha}^{-1}$  and 9.0 percent in same of all sowing dates in Bhabhara & Tarai zone (Table-3). The simulated yield was over estimated from district yield for sowing date all agroclimatic zones except western plain zone in Uttar Pradesh but simulated yield was underestimated from district yield for sowing dates (Fig-1).

### Different Irrigation

In Bundelkhand agroclimatic zone the highest yield 4592.3  $\text{kg ha}^{-1}$  was on  $I_4$  except Hamirpur district where highest yield 4110.5  $\text{kg ha}^{-1}$  was on  $I_3$  irrigation, after fourth irrigation no variation of the yield has been seen in the districts of Bundelkhand ACZ on 22 and 27 November sowing date. The SD & CV was ranged between 200.4 to 525.6  $\text{kg ha}^{-1}$  and 4.8 to 23.7 percent. The RMSE value ranges 1511.0 to 2396.4  $\text{kg ha}^{-1}$ . The simulated yield ranged between 2185.5 to 3724.3  $\text{kg ha}^{-1}$  on 30 October and lowest yield seen on the  $I_2$ . The SD & CV was ranged between 309.9 to 495.7  $\text{kg ha}^{-1}$  and 12.2 to 17.5 percent. The RMSE value ranges 678.07 to 1462.4  $\text{kg ha}^{-1}$ . Overall result showed the high yield was at normal sowing with three irrigations, but late sowing is more with five irrigations but yield compare to

normal sowing date is less. In central plain zone, the simulated yield ranged between 1270.3 to 3962.4 kg ha<sup>-1</sup> on 30 October and highest yield seen on I<sub>2</sub> and I<sub>3</sub> irrigation. The SD & CV was ranged between 127.2 to 643.2 kg ha<sup>-1</sup> and 5.4 to 14.4 percent. The RMSE value ranges 101.0 to 889.7 kg ha<sup>-1</sup>. In Eastern Plain Zone, the simulated yield ranged between 1694.7 to 3846.8 kg ha<sup>-1</sup> on 30 October and lowest yield seen on I<sub>2</sub> and I<sub>3</sub> irrigation. The SD & CV was ranged between 151.7 to 339.3 kg ha<sup>-1</sup> and 7.2 to 14.2 percent. The RMSE value ranges 72.3 to 521.7 kg ha<sup>-1</sup> (Table 3 & Fig.2). In Eastern plain agroclimatic zone the highest yield 3957.0 kg ha<sup>-1</sup> was on I<sub>3</sub> after third irrigation no variation of the yield has been seen in the districts of Eastern plain ACZ on 22 November sowing date. The SD & CV was ranged between 221.9 to 854.6 kg ha<sup>-1</sup> and 4.8 to 47.3 percent. The RMSE value ranges 24.3 to 1004.1 kg ha<sup>-1</sup>. In Mid western plain zone the highest yield ranges from 3554.7 to 4453.4 kg ha<sup>-1</sup> on 6 and 13 November and highest yield seen on I<sub>3</sub> and I<sub>4</sub> irrigation. The SD & CV was ranged between 179.2 to 1066.5 kg ha<sup>-1</sup> and 3.9 to 39.5 percent. The RMSE value ranges 91.8 to 1049.9 kg ha<sup>-1</sup>. Under late condition, the simulated yield ranged between 1694.7 kg ha<sup>-1</sup> to 3846.8 kg ha<sup>-1</sup> on 5 December and lower yield seen on I<sub>4</sub> irrigation (Table-3 & Fig-2). The SD & CV was ranged between 239.5 to 979.1 kg ha<sup>-1</sup> and 7.1 to 42.1 percent. The RMSE value ranges 16.2 to 489.9 kg ha<sup>-1</sup>. In North Eastern Plain zone the highest yield ranges from 3128.6 kg ha<sup>-1</sup> to 4457.5 kg ha<sup>-1</sup> on 22 November and highest yield seen on I<sub>3</sub> irrigation (Fig-2). The SD & CV was ranged between 240.8 to 854.6 kg ha<sup>-1</sup> and 3.4 to 47.3 percent. The RMSE value ranges 24.3 to 1259.2 kg ha<sup>-1</sup>. Under early sown condition yield at I<sub>3</sub> irrigation is maximum on 30 October while under late sown condition 5 December yield is maximum on I<sub>4</sub> irrigation (Table-3). In North Eastern Plain zone the highest yield ranges from 4341.5 kg ha<sup>-1</sup> to 4479.0 kg ha<sup>-1</sup> on 13 November and high yield seen in I<sub>5</sub> in most of the districts of SW plain zone. The SD & CV was ranged between 246.8 to 755.0 kg ha<sup>-1</sup> and 5.7 to 33.3 percent. The RMSE value ranges 558.3 to 829.4 kg ha<sup>-1</sup>. Under early sown condition the highest yield ranges from 3690.7 kg ha<sup>-1</sup> to 3961.0 kg ha<sup>-1</sup> on 30 October and highest yield seen on I<sub>3</sub> irrigation (Table-3 & Fig-2). The SD & CV was ranged between 208.3 to 554.2 kg ha<sup>-1</sup> and 8.7 to 18.4 percent. The RMSE value ranges 156.9 to 492.9 kg ha<sup>-1</sup>. In Vindhyan

zone overall the result showed that maximum three irrigation needed for all different date of sowing. The maximum yield was normal sowing date and early and late sown yield was less than the normal sowing date. The highest yield ranges from 3852.0 kg ha<sup>-1</sup> to 3971.9 kg ha<sup>-1</sup> on 22 November and high yield seen in I<sub>3</sub> in most of the districts of Vindhyan zone. The SD & CV was ranged between 193.6 to 468.2 kg ha<sup>-1</sup> and 5.4 to 28.7 percent. The RMSE value ranges 462.8 to 1321.9 kg ha<sup>-1</sup>. Under early sown condition the highest yield ranges from 2442.0 kg ha<sup>-1</sup> to 3206.5 kg ha<sup>-1</sup> on 30 October and highest yield seen on I<sub>2</sub> irrigation. The SD & CV was ranged between 244.2 to 471.0 kg ha<sup>-1</sup> and 11.6 to 16.6 percent. The RMSE value ranges 462.8 to 1321.9 kg ha<sup>-1</sup>. In Western Plain zone the highest yield ranges from 3579.0 kg ha<sup>-1</sup> to 3914.0 kg ha<sup>-1</sup> on 13 November and high yield seen in I<sub>3</sub> in most of the districts of Western plain zone. The SD & CV was ranged between 216.2 to 786.6 kg ha<sup>-1</sup> and 6.3 to 35.1 percent. The RMSE value ranges 60.8 to 518.4 kg ha<sup>-1</sup>. Under early sown condition the highest yield ranges from 2496.1 kg ha<sup>-1</sup> to 3375.5 kg ha<sup>-1</sup> on 30 October and highest yield seen on I<sub>2</sub> & I<sub>3</sub> irrigation (Fig-2). The SD & CV was ranged between 247.8 to 415.7 kg ha<sup>-1</sup> and 7.4 to 17 percent. The RMSE value ranges 200.3 to 1395.4 kg ha<sup>-1</sup>. The highest yield was 3958.5 kg ha<sup>-1</sup> in 13 Nov but the lowest yield was 3581.6 kg ha<sup>-1</sup> on 05 Dec on Bhabhara & Tarai zone. The mean yield was 3813 kg ha<sup>-1</sup> and SD was 141.2 kg ha<sup>-1</sup> and also CV was 3.7 percent (Table-3). The highest yield was I<sub>4</sub> (4148 kg ha<sup>-1</sup>) as followed I<sub>3</sub> (4119 kg ha<sup>-1</sup>) in Bhabhara & Tarai zone in Uttar Pradesh (Fig-2). In Irrigation conditions, normalized RMSE were 520.7 kg ha<sup>-1</sup>, 549.9 kg ha<sup>-1</sup>, 564.8 kg ha<sup>-1</sup>, 693.6 kg ha<sup>-1</sup>, 748.4 kg ha<sup>-1</sup>, 831.3 kg ha<sup>-1</sup>, 894.6 kg ha<sup>-1</sup>, 1514.0.3 kg ha<sup>-1</sup> and 1687.9 kg ha<sup>-1</sup> for SW plain zone, Western plain zone, Mid western plain zone, Central plain zone, NE plain zone, Eastern plain zone, Bhabhara & Tarai zone, Vindhyan zone, and Bundelkhand zone respectively (Table-3). Optimum sowing window was different among districts. Simulation results depicts that 22 November is the optimum sowing date for Bundelkhand, Central Plain zone, Eastern plain zone, NE Plain zone and Vindhyan zone and 13 November for Mid western plain zone, SW plain zone, Bhabhara & Tarai zone and Western plain zone.

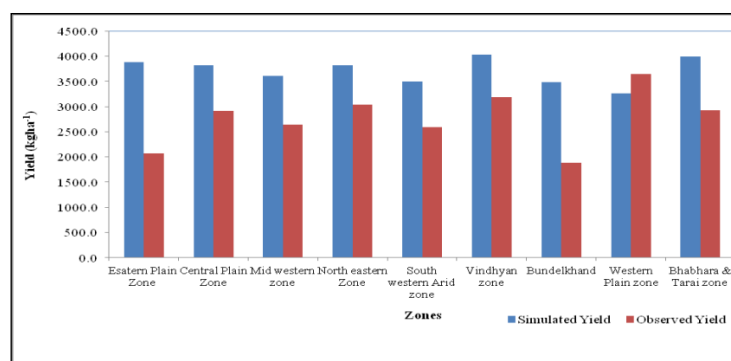


Fig-1: Mean of yield (kg ha<sup>-1</sup>) of different sowing dates of wheat crop of different agroclimatic zones

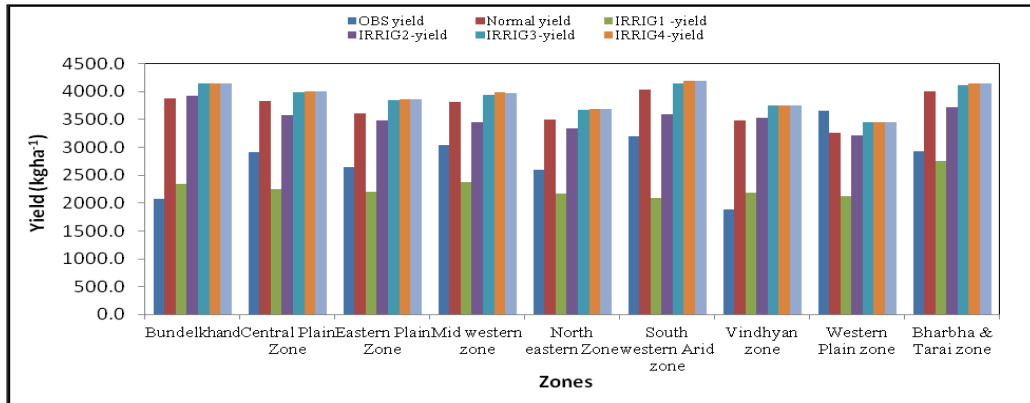
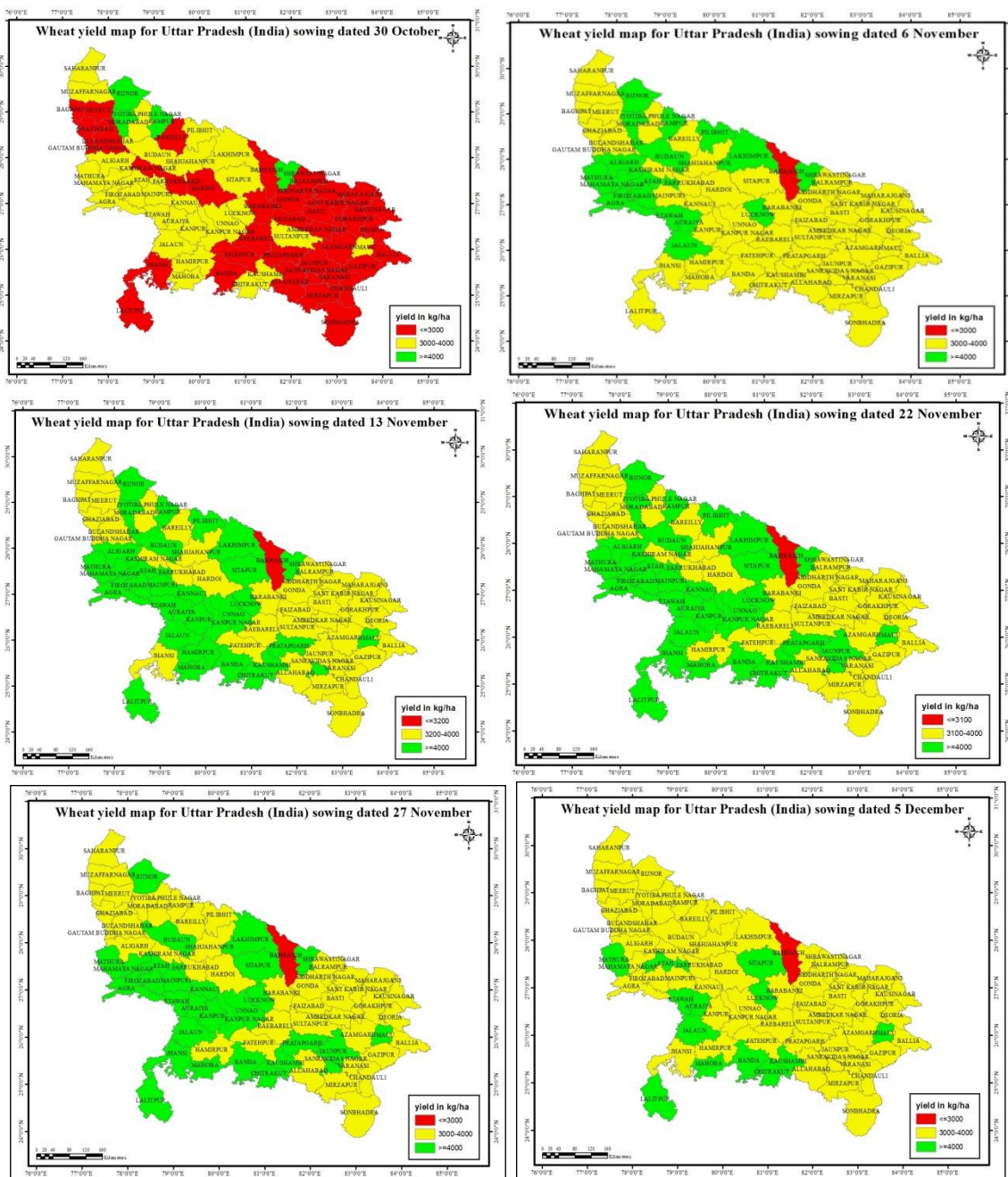


Fig-2: Mean of yield (kg ha<sup>-1</sup>) of different Irrigation of wheat crop of different agroclimatic zones



**Table-1: Districts under different Agroclimatic zones of Uttar Pradesh**

Sl. no	Agroclimatic Zones	Districts
1.	Bundelkhand Zone	Banda, Lalitpur, Mahoba, Chitrakoot, Hamirpur, Jalaun, Jhansi
2.	Central Plain Zone	Auraiya, Etawah, Farrukabad, Fatehpur, Hardoi, Kannur, Kanpur Dehat, Kanpur Urban, Kaushambhi, Lakhimpur, Lucknow, Pratapgarh, Raibareilly, Sitapur, Unnao
3.	North Eastern Plain Zone	Baharich, Balrampur, Basti, Deoria, Gonda, Kaushinagar, Mahamayanagar, Maharajganj, Sant Kabir Nagar, Sidarthnagar
4.	Vindhyan Zone	Allahabad, Mirzapur, Sonbhadra
5.	Eastern Plain Zone	Ambedharnagar, Azamgarh, Ballia, Barabanki, Chandauli, Faizabad, Gazipur, Gorakhpur, Jaunpur, Kashiram Nagar, Mau, Sant Ravidas Nagar, Sultanpur, Varanasi
6.	Mid Western Plain Zone	Bareilly, Bijnour, Badaun, Jyotibaphule Nagar, Rampur
7.	South Western Plain Zone	Agra, Aligarh, Etah, Firozabad, Hathras, Mainpur, Mathura
8.	Bhabhari & Tarai Zone	Saharanpur, Pilibhit, Bijnour, Sarbatinagar
9.	Western Plain Zone	Bagpat, Bulandsahar, Ghatampur, Ghaziabad, Meerut, Muzaffarnagar

**Table-2: Irrigation scheduling of wheat crop**

Irrigation	Stage	Duration
I <sub>1</sub>	CRI Stage (50 mm)	CRI = 21 days,
I <sub>2</sub>	CRI + Booting (50 mm)	CRI = 21 days, + Tillering = 45 days,
I <sub>3</sub>	CRI + Tillering + Booting (50 mm)	CRI = 21 days, + Tillering = 45 days,+ Booting = 75 days
I <sub>4</sub>	CRI + Tillering + Booting + Milking (50 mm)	CRI = 21 days, + Tillering = 45 days,+ Booting = 75 days + Flowering = 85 days
I <sub>5</sub>	CRI + Tillering + Jointing + Flowering + Milking (50 mm)	CRI = 21 days, + Tillering = 45 days,+ Booting = 75 days + Flowering = 85 days + Milking = 100 days

**Table-3: Yield (Kg ha<sup>-1</sup>) using DSSAT model of different sowing dates with different irrigation of different Agroclimatic zones, Uttar Pradesh**

Bundelkhand Agroclimatic zones Yield (kg ha <sup>-1</sup> )								
Date	OBS	Normal	IRRIG1	IRRIG2	IRRIG3	IRRIG4	IRRIG5	Mean
30-Oct	2073.9	2915.0	2418.3	3398.4	3404.5	3389.9	3383.3	3151.6
6-Nov	2073.9	3745.6	2598.4	4040.2	4103.2	4104.6	4104.6	3782.8
13-Nov	2073.9	4160.9	2485.9	4279.2	4399.5	4401.4	4401.4	4021.4
22-Nov	2073.9	4224.0	2229.3	4077.0	4383.5	4397.2	4397.2	3951.4
27-Nov	2073.9	4187.9	2176.8	3953.7	4311.7	4325.3	4325.3	3880.1
5-Dec	2073.9	4062.6	2153.9	3796.7	4217.1	4234.7	4234.5	3783.2
Mean	2073.9	3882.68	2343.8	3924.2	4136.6	4142.2	4141.1	3761.7
SD		504.9	183.1	302.1	375.3	385.1	387.7	313.2
CV		13.0	7.8	7.7	9.1	9.3	9.4	8.3
RMSE	1687.9							

Central Plain Zone Yield (kg ha <sup>-1</sup> )								
Date	OBS	Normal	IRRIG1	IRRIG2	IRRIG3	IRRIG4	IRRIG5	Mean
30-Oct	2912.4	3123.3	2230.4	3505.6	3529.1	3523.9	3529.2	3240.3
6-Nov	2912.4	3844.0	2340.1	3878.4	4068.2	4081.5	4082.1	3715.7
13-Nov	2912.4	4036.8	2330.9	3858.0	4182.3	4192.0	4192.3	3798.7
22-Nov	2912.4	4051.0	2236.8	3509.2	4087.8	4129.1	4129.1	3690.5
27-Nov	2912.4	4012.7	2223.4	3409.9	4069.5	4108.9	4108.4	3655.5
5-Dec	2912.4	3879.3	2151.4	3266.4	3941.5	3986.8	3986.3	3535.3
Mean	2912.4	3824.51	2252.17	3571.2	3979.74	4003.69	4004.58	3606.0
SD		354.1	71.6	246.4	233.7	244.4	242.4	198.8
CV		9.3	3.2	6.9	5.9	6.1	6.1	5.5
RMSE	693.6							

Eastern Plain Zone Yield (kg ha <sup>-1</sup> )								
Date	OBS	Normal	IRRIG1	IRRIG2	IRRIG3	IRRIG4	IRRIG5	Mean
30-Oct	2641.6	2814.9	2145.9	3179.7	3225.3	3225.3	3225.3	2969.4
6-Nov	2641.6	3561.9	2285.1	3658.3	3878.1	3880.4	3881.6	3524.2
13-Nov	2641.6	3823.3	2263.7	3771.1	4061.4	4074.0	4073.9	3677.9
22-Nov	2641.6	3878.3	2171.1	3545.2	4014.2	4037.1	4037.1	3613.8
27-Nov	2641.6	3865.3	2179.1	3450.5	3987.0	4009.2	4010.1	3583.5
5-Dec	2641.6	3701.2	2118.8	3307.7	3874.3	3903.4	3903.4	3468.1
Mean	2641.6	3607.5	2193.9	3485.41	3840.06	3854.9	3855.24	3472.8
SD		406.3	66.1	219.7	310.3	317.6	317.7	257.0
CV		11.3	3.0	6.3	8.1	8.2	8.2	7.4
RMSE	831.3							

Mid Western Zone Yield (kg ha <sup>-1</sup> )								
Date	OBS	Normal	IRRIG1	IRRIG2	IRRIG3	IRRIG4	IRRIG5	Mean
30-Oct	3034.3	3577.9	2188.7	3612.0	3791.3	3794.6	3755.8	3453.4
06-Nov	3034.3	3960.9	2328.9	3742.5	4132.8	4146.3	4133.6	3740.8
13-Nov	3034.3	3974.8	2390.4	3534.8	4083.7	4135.4	4138.8	3709.7
22-Nov	3034.3	3930.3	2439.0	3327.5	3966.2	4035.6	4037.7	3622.7
27-Nov	3034.3	3850.6	2438.3	3292.3	3896.2	3967.9	3967.9	3568.9
05-Dec	3034.3	3607.6	2417.5	3192.9	3735.1	3791.8	3791.8	3422.8
Mean	3034	3817	2367	3450	3934	3979	3971	3586
SD		179.2	96.5	212.1	157.7	158.0	165.8	130.5
CV		4.7	4.1	6.1	4.0	4.0	4.2	3.6
RMSE	564.8							

North Eastern Plain Zone Yield (kg ha <sup>-1</sup> )								
Date	OBS	Normal	IRRIG1	IRRIG2	IRRIG3	IRRIG4	IRRIG5	Mean
30-Oct	2591.4	2685.8	2030.3	3045.8	3064.0	3065.2	3064.4	2825.9
6-Nov	2591.4	3443.0	2192.3	3530.8	3682.3	3686.7	3687.0	3370.4
13-Nov	2591.4	3699.2	2230.0	3667.6	3878.3	3884.2	3884.3	3540.6
22-Nov	2591.4	3764.9	2213.9	3434.8	3868.7	3869.2	3869.4	3503.5
27-Nov	2591.4	3745.0	2217.0	3299.8	3836.4	3854.6	3850.1	3467.2
5-Dec	2591.4	3628.8	2100.7	3068.5	3715.2	3737.4	3737.4	3331.4
Mean	2591.4	3494.4	2164	3341.2	3674.2	3682.9	3682.1	3339.8
SD		412.9	80.4	250.8	309.8	312.8	312.7	264.0
CV		11.8	3.7	7.5	8.4	8.5	8.5	7.9
RMSE	748.4							

Western Plain Zone Yield (kg ha <sup>-1</sup> )								
Date	OBS	Normal	IRRIG1	IRRIG2	IRRIG3	IRRIG4	IRRIG5	Mean
30-Oct	3648.2	2549.2	1938.1	2850.5	2860.6	2872.2	2863.6	2655.7
06-Nov	3648.2	3306.3	2126.4	3445.3	3539.9	3527.3	3527.3	3245.4
13-Nov	3648.2	3546.0	2135.4	3524.7	3716.4	3719.2	3719.2	3393.5
22-Nov	3648.2	3497.8	2155.4	3216.8	3571.6	3587.6	3587.6	3269.5
27-Nov	3648.2	3434.7	2254.7	3184.7	3562.7	3563.2	3563.2	3260.5
05-Dec	3648.2	3256.4	2123.1	3005.4	3396.3	3388.7	3388.7	3093.1
Mean	3648	3265	2122	3205	3441	3443	3442	3153
SD		367.7	102.7	255.3	302.1	299.2	302.5	261.7
CV		11.3	4.8	8.0	8.8	8.7	8.8	8.3
RMSE	549.9							

South Western Arid Zone Yield (kg ha <sup>-1</sup> )								
Date	OBS	Normal	IRRIG1	IRRIG2	IRRIG3	IRRIG4	IRRIG5	Mean
30-Oct	3190.7	3517.3	2127.6	3704.4	3844.4	3851.1	3851.1	3482.7
6-Nov	3190.7	4169.6	2193.6	3995.5	4333.7	4362.3	4347.0	3900.3
13-Nov	3190.7	4272.0	2131.6	3797.4	4370.9	4413.9	4417.2	3900.5
22-Nov	3190.7	4206.1	2075.3	3454.9	4215.5	4263.0	4272.3	3747.8
27-Nov	3190.7	4147.8	2046.3	3372.7	4177.8	4251.9	4251.1	3708.0
5-Dec	3190.7	3909.5	1993.1	3255.6	3952.5	4031.9	4031.8	3529.1
Mean	3190.7	4037.1	2094.6	3596.7	4149.1	4195.7	4195.1	3711.4
SD		282.8	71.1	282.0	209.8	213.8	212.8	178.0
CV		7.0	3.4	7.8	5.1	5.1	5.1	4.8
RMSE	520.7							

Vindhyan Zone Yield (kg ha <sup>-1</sup> )								
Date	OBS	Normal	IRRIG1	IRRIG2	IRRIG3	IRRIG4	IRRIG5	Mean
30-Oct	1890.2	2524.1	2105.5	3025.8	3025.8	3025.8	3025.8	2788.8
6-Nov	1890.2	3315.1	2286.5	3590.5	3673.1	3679.8	3679.8	3370.8
13-Nov	1890.2	3723.2	2279.8	3854.7	3975.2	3976.5	3976.5	3631.0
22-Nov	1890.2	3812.2	2142.8	3671.3	3970.8	3973.3	3973.3	3590.6
27-Nov	1890.2	3802.4	2124.5	3563.1	3931.0	3933.0	3933.9	3548.0
5-Dec	1890.2	3712.9	2136.2	3422.2	3900.8	3902.2	3902.2	3496.1
Mean	1890.2	3481.7	2179.2	3521.3	3746.1	3748.4	3748.6	3404.2
SD		503.7	81.5	281.3	370.2	370.7	370.8	314.7
CV		14.5	3.7	8.0	9.9	9.9	9.9	9.2
RMSE	1514.0							

Bhabhara & Tarai Zone Yield (kg ha <sup>-1</sup> )								
Date	OBS	Normal	IRRIG1	IRRIG2	IRRIG3	IRRIG4	IRRIG5	Mean
30-Oct	2927.6	3983.8	2559.8	3929.4	4153.0	4156.5	4103.3	3814.3
06-Nov	2927.6	4165.7	2662.5	3957.4	4314.6	4324.6	4322.6	3957.9
13-Nov	2927.6	4171.0	2804.8	3803.3	4309.0	4331.8	4331.2	3958.5
22-Nov	2927.6	4041.9	2844.3	3603.2	4109.8	4144.4	4148.5	3815.3
27-Nov	2927.6	3912.0	2876.7	3576.8	3983.2	4072.0	4076.5	3749.5
05-Dec	2927.6	3690.5	2799.6	3432.9	3844.6	3860.6	3861.4	3581.6
Mean	2928	3994	2758	3717	4119	4148	4141	3813
SD		180.0	121.6	211.5	184.0	175.2	174.9	141.2
CV		4.5	4.4	5.7	4.5	4.2	4.2	3.7
RMSE	894.6							

## CONCLUSION

The model was run for 6 sowing dates starting on 30 October and repeated every 7 days until 5 December using long-term district level station and gridded level historical weather data from different district. Results showed that optimum sowing date (13th Nov.) was found better as compared to early (30 October) and late (5 December) sowings. The model performance was found good and satisfactory having 3-4 irrigations ( $I_3$  and  $I_4$ ). On an average, the performance of model for  $I_4$  was found good. This showed that model worked better under optimum sowing with optimum irrigation. The error per cent by CERES-wheat model showed that in majority of the cases the models had underestimated wheat yield. The results showed that the model worked better under optimum sowing with optimum irrigation as compared to early/late sowing and moisture stress conditions. Optimum sowing window was different among districts.

Simulation results depicts that 22 November is the optimum sowing date for Bundelkhand, Central Plain zone, Eastern plain zone, NE Plain zone and Vindhyan zone and 13 November for Mid western plain zone, SW plain zone, Bhabhara & Tarai zone and Western plain zone.

## LIMITATIONS

The model does not include the other nutrient factors, i.e. phosphorus, potassium and plant essential micronutrients. These nutrients and micronutrients are assumed to be in abundant supply in the soil so as not to cause any stress on the crop, which is often not true. Similarly, losses due to weeds, pests and diseases are also not included in the model. Due to favourable weather conditions, pest infestation and diseases may cause losses to the crops, which cannot be simulated at present using the model.



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