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Simulation of wheat crop at different irrigation levels using DSSAT model for Prayagraj

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Abstract
The present investigation was carried out during the Rabi seasons of 2018-2019 with the prime objective simulation of wheat crop of different irrigation levels using the DSSAT model after calibrating yield coefficients of wheat (PBW- 502) under the Argo-climatic conditions of Prayagraj. The experiment was laid out in a randomized design block (RBD) with three dates of sowings (D1, D2, and D3) and 5 irrigation levels (I1 to 15) as sub-plot treatment with three replications. The results obtained during the track of study, discovered that the different dates of sowing and irrigation had played, a significant role in deciding the yield of wheat. However, the date of sowing and irrigation variables affected the crop growth, development, and yield differences in different phenophases during its growth period. The results, regarding different dates of sowing as well as irrigation attributing characters of wheat variety as influenced by different treatments, showed a good agreement for simulated development and growth parameters for the Rabi wheat with their respective observed data five irrigations are applied at the time of CRI (I1) +Tillering (I2) +Jointing (I3) +Anthesis (I4) +Maturity (I5) proved to be better for higher growth and yield of the wheat at the period 2018-2019. On November 17 (D1) sowing, performed well whereas their performance was poor in the second and last sowing dates. A validated DSSAT model can be used to estimate phenophases, growth parameters, and yield of wheat.

Keywords: wheat, DSSAT model, different date of sowings, irrigation, RBD design, variety (PBW-502), growth, yield

Introduction
Wheat ranks first among the world food crops, in terms of cultivated area (223.813 million ha), production (733.144 million tons) and which productivity of (3280 kg ha-1) (USDA 2016). It can be grown from below sea level to 5000 m altitude and in areas where rainfall ranges between 300-1130mm. Wheat contributes more calories (20%) and more protein to the world's diet than any other food crop and is staple food in at least 43 countries the availability of wheat has increased from about 79gm capita^{-1} day^{-1} to more than 185 gm capita^{-1} day^{-1} despite the doubling of the population since 1961 (Bhardwaj *et al*., 2010). Production trends of wheat in India during last five decades have clearly shown a very rapid rate of increase in area, production and productivity, which could be attributed to the advent of fertilizer responsive dwarf and semi-dwarf high yielding varieties in mid-sixties and matching production technology. (Bhardwaj *et al*., 2010).
In India, wheat is the second most important cereal crop next only to rice and a key crop of the green revolution and post green revolution era. India stands second among wheat producing countries after China. During the crop year 2013-14, wheat was grown over an area of 31.18 million ha with the production of 95.91 million tons with an average productivity of 3.07 tons ha^{-1} (DAC 2014-15).
Uttar Pradesh with the total area of 24.09-million-hectare, wheat is cultivated as a Rabi crop. Wheat is UP's main agriculture produce and the state contributes around 32% of the country total wheat production the latest wheat production data available with the agriculture directorate for the current year shows that wheat production in the state stands at 357.19 lakh MT which is up by around 7.50lakh MT produced during the previous year. The productivity has gone up 35.38quintal per hectares last year to 36.50 quintal per hectares this time. Both production and productivity are higher but the sowing area has decreased this year. Wheat was sown on total area of 97.86 lakh hectares of land against 98.85 lakh hectares during 2016-17. (DAC 2014-15).
Wheat crop occupies 21.8% of the total area under food grains. The normal national productivity of wheat is 2703 kg/ha.

The share of wheat in total food grain production is 35.5% which is next to rice. (Dubey 2014).
Total Wheat cultivated area of Prayagraj is 2,11,378 ha. The area production and productivity of wheat in the Prayagraj is 4,69,115 mt and 22.19 qt/ha respectively. (Dubey 2014).

Material and Methods

The details of materials used and experimental techniques adopted during the course of investigation on "Simulation of Wheat Crop at Different Irrigation Levels Using DSSAT Model for Prayagraj" are elaborated in this chapter.

Location and Climate

Prayagraj is located in the South-East part of Uttar Pradesh, India. Allahabad comes under agro-climatic zone-IV, which is named as "Middle-Gangetic Plains". Soil of this region is sandy loam and slightly alkaline. The site of experiment is located at 25.57^0 N latitude, 81.51^0 E longitude and 90 meter above the sea level. This region has Sub-tropical climate with extreme of summer and winter. The temperature falls down to as low as 1-2 ^{0}C during winter season especially in the month of December and January. The Mercury rises up to 46-48 ^{0}C during summer. The Allahabad receives the mean annual rainfall of about 886 mm. More than 70 per cent rains are received during S-W monsoon season, 5–10 per cent rains is received in winter, 10–15 per cent in pre monsoon and 5–10 percent during post monsoon season. Normal rainy days exceed 40 annually. Summer monsoon rainfall comes in down pours while winter rainfall comes in light drizzles and is easily absorbed in soils. During crop season of 2018-19, the quantum of rainfall of 0.2 mm & that was received in 12th SMW.

Table 1: Meteorological data recorded during experimental period (*Rabi* 2018-19)

STD. Weeks	Dates	T MAX (^{O}C)	T MIN (^{O}C)	RH-I (%)	RH-II (%)	RAINFALL (mm)
46	12NOV- 18 NOV	32.8	11.8	91.5	56	0
47	19NOV -25 NOV	31.6	11.9	93.71	55.86	0
48	26NOV- 02 DEC	28.5	12.4	94	60	0
49	03 DEC- 09 DEC	27.4	11.3	92.85	57.14	0
50	10 DEC- 16 DEC	27.1	11.3	93	57.5	0
51	17 DEC- 23 DEC	26.1	9.63	93	58.71	0
52	24 DEC- 31 DEC	24.6	7.38	93.37	57.25	0
1	01 DEC - 07 JAN	23.6	7.37	84.28	59.57	0
2	08 JAN - 14 JAN	23.7	6.74	93.85	61.57	0
3	15 JAN - 21 JAN	23.0	6.17	93.71	61.43	0
4	22 JAN - 28 JAN	22.6	10.4	94.85	63.14	15.6
5	29 JAN - 04 FEB	25.7	11.8	91.25	52	0
6	05 FEB - 11 FEB	25.7	13.5	91.14	52	1.6
7	12 FEB - 18 FEB	27.2	13.3	89.85	47	2
8	19 FEB - 25 FEB	27.1	13.3	88.42	53	0
9	26FEB -04 MAR	25.5	13.1	88.75	52	4
10	05MAR -11MAR	30.0	13.5	86.71	39.71	0
11	12MAR -18MAR	35.1	14.5	83.85	34.29	0
12	19MAR -25MAR	36.4	15.2	84.42	33	0
13	26MAR– 01APR	38	18.3	84.57	33.57	8
14	02APR – 08 APR	40.1	20.4	81.14	30.57	0

Source: Agro-meteorological Observatory Unit, College of Forestry, SHUATS, Prayagraj.

Experiment details:
Crop : Wheat (*Triticum aestivum* L.)
Variety : PBW-502
No of treatment : 15
Replications : 03
Total number of plots : 45
Experimental design : Factorial RBD
One plot size : 2 x 2 m
Size of bunds : 0.3 m
Width of main irrigation channel : 1.0 m
Width of sub irrigation channel : 0.5 m
Seed rate : 44-132 kg/ha.
Plant to plant spacing : 3 cm.
Row to row spacing : 23 cm.
Method of sowing : line sowing
Length of plot : 38 m
Width of plot : 9 m
Gross area : 342 m^2.

- D_1= date of sowing [17th November]
- D_2= date of sowing [2nd December]
- D_3= date of sowing [17th December]

Design and Layout

The wheat crops were sown for three different dates i.e., 17 November, 2 December and 17 December with split plot design having three replications, The irrigation was given at different stages in wheat crop. The first irrigation was given at crop water requirement and irrigation water requirement of wheat crop.

	R1					R2					R3				
MAIN IRRIGATION CHNNEL 1.0 m	D_1I_1	D_1I_2	D_1I_3	D_1I_4	D_1I_5	D_1I_4	D_1I_3	D_1I_2	D_1I_5	D_1I_1	D_1I_2	D_1I_3	D_1I_5	D_1I_4	D_1I_1
	Sub irrigation channel 0.5 m														
	D_2I_1	D_2I_2	D_2I_3	D_2I_4	D_2I_5	D_2I_4	D_2I_3	D_2I_2	D_2I_5	D_2I_1	D_2I_2	D_2I_3	D_2I_5	D_2I_4	D_2I_1
	Sub irrigation channel 0.5 m														
	D_3I_1	D_3I_2	D_3I_3	D_3I_4	D_3I_5	D_3I_4	D_3I_3	D_3I_2	D_3I_5	D_3I_1	D_3I_2	D_3I_3	D_3I_5	D_3I_4	D_3I_1

Fig 1: Layout of the experimental plot

Table 2: critical stages of wheat and different date of sowings

I_1 - CRI stage I_2 -CRI + Tillering stage I_3 –CRI + Tillering + flowering stage I_4- CRI + Tillering + flowering + milking stage I_5- CRI + Tillering + flowering + milking stage + dough stage	D_1= First date of sowing *i.e.*, 17th November D_2= Second date of sowing *i.e.* 2nd December D_3= Third date of sowing *i.e.* 17th December

Results and Discussions

The present investigation was carried out during the *Rabi* seasons of the 2018-2019 with the prime objective of estimating the wheat yield using the CERES Wheat model after calibrating genetic coefficients of wheat (PBW- 502) under the Agro-climatic conditions of Prayagraj. The CERES-Wheat model embedded in DSSAT v 4.7 was used in this study. The calibration and validation are two pre-requisite processes before the model application. For the calibration and validation independent data sets are required. Several steps are required for model simulation like model initialization, model calibration, model validation and model application. The details of data output and its analysis are present below in sub heading. Weather conditions of Prayagraj region during different growing environment for wheat crop

The weather that prevailed at Prayagraj during the investigation period was assessed graphically in terms of various meteorological parameters viz., mean air temperature, relative humidity, wind speed and rainfall. The average mean was worked out for each of these weather parameters for the sake of better graphical presentation and to know the overall trend in weather elements. However, while explaining the variations in the weather elements daily values of the respective parameters were also considered as weekly according to meteorological weeks. The weather conditions as revealed by the respective graphs are described below:

1. A close observation of meteorological data revealed that in general, the environmental conditions for the crop season were favorable for optimum growth and yield of wheat. By comparing the mean daily temperature, it is observed that during the crop season the mean maximum temperature ranged between 14ºC-33.8ºC. The average maximum temperature observed during the crop period, *rabi* 2018-2019 under different date of sowing were 28.2 ^{0}C, 27.06 ^{0}C and 29.1 ^{0}C respectively in the first, second and third date of sowing. The average minimum temperature observed during the crop period, *rabi* 2018-2019 under different date of sowing were 11.8 ^{0}C, 11.3 ^{0}C and 12.7 ^{0}C respectively in the first, second and third date of sowing.
2. During the crop season, the total weakly rainfall received was 31.2 mm from November to April and total number of rainy days was nineteen. Figure 2 shows that highest rainfall reached at 85th day at 4th meteorological week, due to this there is a maximum relative humidity and minimum reference evapotranspiration is showed on 85th day.
3. Relative Humidity is a measure of atmospheric moisture content. It plays a major role in the crop production. The maximum relative humidity was occurred were occurred on 85th day with 84% and minimum relative humidity occurs at 53% in the month of April. Relative humidity during the emergence and growth phase was very good for growth, development and yield. It has a relation with rainfall. It is important parameter about rainfall variability during the crop growing season for better crop production. Relative humidity during the emergence and growth phase was very good for growth, development and yield.
4. The average wind speed worked out for the crop growing season showed an increasing trend from the early date of sowing to other sowings. The average wind speed worked out for the crop growing season showed an increasing trend from the early date of sowing to other sowings. The average wind speed was and 1.0, 0.98 and 1.04 kmph in the first second and third of sowing respectively in 2018-2019.

Table 3: Effect of sowing time on days taken to physiological stages of wheat.

	Physiological Events (DAS)					
Treatments	**CRI**	**Tillering**	**Jointing**	**Anthesis**	**Physiological Maturity**	**Harvestable Maturity**
Sowing Time						
17Nov (D1)	23.2	44	69.9	77.4	113.4	132.9
02Dec (D2)	23.8	45.1	65.7	72.7	101.9	124.7
17Dec (D3)	23.2	45.8	68.7	69.6	100	123.9
S.Em. ±	0.2	0.6	0.3	0.3	0.3	0.2
C.D (P=0.05)	N/S	N/S	0.9	0.9	1.0	0.7
Irrigation Levels						
I_1	23.6	43.8	64.1	68.5	102.4	126.6
I_2	23.5	44.3	67.5	70.8	103.6	126.2

I_3	23.2	45.2	70.6	73.1	105.7	128.6
I_4	23.4	46	69.2	76.4	106.6	129.3
I_5	23.3	45.4	69.1	77.3	107.2	125.1
S.Em. ±	0.3	0.8	0.4	0.4	0.4	0.3
C.D (P=0.05)	N/S	N/S	1.2	1.2	1.3	0.9
Interaction (Days after sowing x Irrigation levels)						
S.Em. ±	0.6	1.5	0.7	0.7	0.7	0.5
C.D (P=0.05)	N/S	4.5	2.1	2.1	2.2	1.7

Table 4: Influence of different days after sowing and irrigation levels on plant height (cm) of wheat.

Treatments	30 DAS	60 DAS	90 DAS
Days after sowing			
D1 – 17 Nov	35.25	51.51	64.56
D2 – 02 Dec	26.53	47.57	61.20
D3 – 17 Dec	28.34	49.85	60.69
S.Em. ±	0.8	0.6	0.9
C.D (P=0.05)	2.3	1.8	2.8
Irrigation Levels			
I_1	27.62	46.99	61.18
I_2	31.36	44.78	59.46
I_3	30.32	48.58	60.99
I_4	28.44	53.15	63.92
I_5	32.47	54.72	65.20
S.Em. ±	1.0	0.8	1.2
C.D (P=0.05)	3.0	2.3	3.6
Interaction (Days after sowing x Irrigation levels)			
S.Em. ±	1.8	1.3	2.1
C.D (P=0.05)	5.2	N/S	N/S

Table 5: Influence of different days after sowing and irrigation levels on number of tillers per plant of wheat.

Treatments	30 DAS	60 DAS	90 DAS
Days after sowing			
D1 – 17 Nov	3.0	6.98	7.5
D2 – 02 Dec	2.8	6.91	7.4
D3 – 17 Dec	2.9	6.71	7.52
S.Em. ±	0.05	0.09	0.04
C.D (P=0.05)	N/S	N/S	0.1
Irrigation Levels			
I_1	2.7	6.6	7.2
I_2	2.5	6.5	7.4
I_3	2.9	6.8	7.5
I_4	3.1	7.1	7.6
I_5	3.2	7.2	7.7
S.Em. ±	0.06	0.1	0.05
C.D (P=0.05)	0.18	0.3	0.1
Interaction (Days after sowing x Irrigation levels)			
S.Em. ±	0.11	0.2	0.09
C.D (P=0.05)	N/S	N/S	N/S

Table 6: Influence of different days after sowing and irrigation levels on test weight of wheat.

Treatments	Test weight
Days after sowing	
D1 – 17 Nov	0.239
D2 – 02 Dec	0.209
D3 – 17 Dec	0.205
S.Em. ±	0.006
C.D (P=0.05)	0.019
Irrigation Levels	
I_1	0.197
I_2	0.200
I_3	0.211
I_4	0.246
I_5	0.234
S.Em. ±	0.008
C.D (P=0.05)	0.024
Interaction (Days after sowing x Irrigation levels)	

S.Em. ±	0.014
C.D (P=0.05)	N/S

Table 7: Effect on sowing time and irrigation levels on yield and harvest index of wheat at harvest.

Treatment	Grain yield Kg/ha	Straw yield Kg/ha	Biological yield Kg/ha	Harvest Index Kg/ha
Days after sowing				
D1 – 17 Nov	3640.5	9548.8	10575.3	44.4
D2 – 02 Dec	3395.9	9351.5	10273.3	42
D3 – 17 Dec	3784.2	9187.7	10186	44.5
S.Em. ±	74.9	464.6	415.1	0.2
C.D (P=0.05)	218.3	N/S	N/S	0.7
Irrigation Levels				
I_1	3987.6	6427.4	6757.7	44.4
I_2	1646.6	8403.3	9563.3	42.7
I_3	3393.5	9816.7	10580	42.6
I_4	5331.1	10769.8	12227.7	43.7
I_5	5675.5	11396.1	12595.5	44.7
S.Em. ±	96.8	599.8	535.9	0.3
C.D (P=0.05)	281.9	1746.6	1560.5	0.9
Interaction (Days after sowing x Irrigation levels)				
S.Em. ±	167.7	1038.9	1894	0.5
C.D (P=0.05)	N/S	N/S	N/S	N/S

Table 8: Statistical indices derived for evaluating the performance of CERES-Wheat model in predicting phenology, growth and yield of wheat variety PBW 502 under different sowing dates and five irrigations.

Indices	D1				D2				D3			
	Obs	Sim	RMSE	PE (%)	Obs	Sim	RMSE	PE (%)	Obs	Sim	RMSE	PE (%)
Germination	4	3	1	33.3	6	3	1	33.3	7	3	2	133.3
Anthesis	78	80	1.41	2.5	75	82	2.6	8.5	73	80	2.6	8.8
Maturity	110	128	2.8	6.25	110	125	0	0.0	11	118	1.4	1.7
LAI	1.6	3.3	1.3	51.5	1.7	4	1.5	57.5	1.9	3.7	1.3	48.6

Table 9: Observed and simulated wheat grain yield (kg/ha).

Treatments		Observed	Simulated	RMSE	NRMSE	PE
T1	D1 I1	1203	902	0.52	0.015	0.083
T2	D1 I2	1808	2598	1.01	0.029	0.055
T3	D1 I3	3668	4115	0.78	0.023	0.027
T4	D1 I4	5573	4159	0.51	0.015	0.017
T5	D1 I5	5950	4168	0.48	0.014	0.016
T6	D2 I1	959	1358	1	0.029	0.104
T7	D2 I2	1641	3514	1.51	0.044	0.060
T8	D2 I3	3386	4936	1.02	0.030	0.029
T9	D2 I4	5320	5027	0.66	0.019	0.018
T10	D2 I5	5673	5742	0.66	0.019	0.018
T11	D3 I1	801	1223	1.07	0.031	0.124
T12	D3 I2	1491	2296	1.08	0.0319	0.067
T13	D3 I3	3126	4754	1.07	0.0316	0.031
T14	D3 I4	5100	4968	0.68	0.020	0.019
T15	D3 I5	5403	5030	0.65	0.0192	0.018

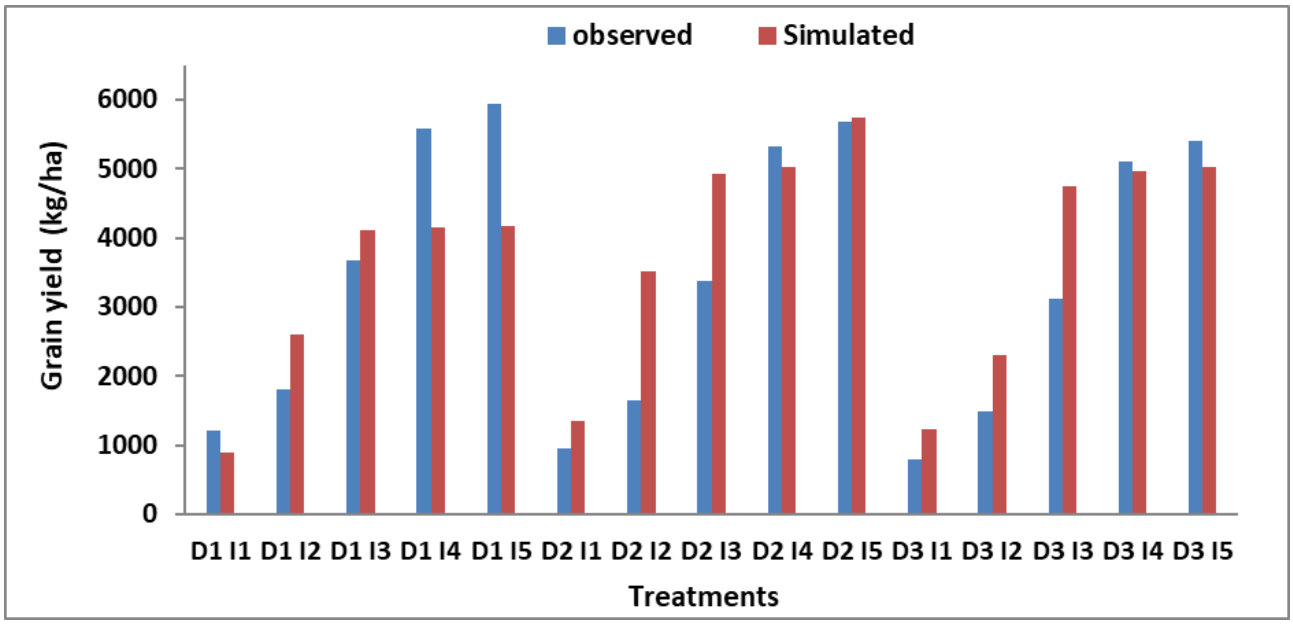

Fig 2: Comparison of observed and simulated grain yield for different treatments

Conclusion

Grain yield

Significant difference among the days after sowing in terms of yields was noticed. The grain yield in the first date of sowing was significantly higher (3640.4 kg ha-1) followed by those in second date (3395.8 kg ha-1) and third date of sowing (3184.2 kg ha-1). Higher performance of wheat crop in the first date of sowing was mainly attributed to more agreeable weather conditions in case of that treatment as compared with weather conditions prevailed in case of second and third date of sowing. Among irrigation treatments significantly higher yield was observed in I5 as compared with other irrigation treatments, which indicated good agreement of simulated results with the actual ones. The error per cent was relatively low in case of the first date of sowing when compared with that for other dates of sowing. This shows good performance of model under sub-optimal conditions in estimating wheat yields.

The CERES-Wheat model (v4.5) was used to simulate the growth, development and yield of wheat crop sown under different thermal regimes and maximum irrigation regime. The model successfully predicted growth, phenology and yield of crop with least error values.

The genetic coefficients calibrated are reasonably accurate with good RMSE, NRMSE and PE for emergence, anthesis, maximum leaf area index, maturity stage, grain yield and harvest index which will useful to represent the various irrigation treatments for further simulations in future using DSSAT programme.

Anthesis indicate that the observed duration (days) to anthesis was 78 days, while that simulated value was 76 days for early date of sowing. The average values for RMSE for anthesis date were 1.41, 1 and 1.73%, respectively. The observed average yield was 3407 kg ha-1 while simulated grain yield was 3641.7 kg ha-1, respectively. The model was validated with the help of these genetic coefficients using early date of sowing with other date of sowing for the field experimental period 2018-2019. The performance of the model was tested for crop growth and development parameters collected from field experiments. Simulated growth, yield attributes, crop duration and grain yield were close to observed parameters for the irrigation treatments.

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