MULTI STAGE WHEAT YIELD ESTIMATION USING DIFFERENT MODEL UNDER SEMI ARID REGION OF INDIA

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ABSTRACT

Crop yield estimation before harvest is required for marketing, pricing, storage, import, export etc. Productivity of cropping systems under various weather, management and policy scenarios can be predicted successfully by simulation models. Due to increase in input cost of agricultural operation, agriculture produces become costly. Therefore, crop yield estimation in the agriculture becomes essential. Weather variability causes the losses in the yield. Therefore, model based on weather parameters, soil parameter and crop parameters can provide reliable crop yield estimation in advance. For estimating the multi stage wheat crop yield, experiments were conducted at research farm of IARI, New Delhi during *Rabi* 2016-17 and *Rabi* 2017-18. Crop yield were estimated by weather based and crop simulation model. Percentage deviation of estimated yield by observed yield at flowering and grain filling stage was -5.1 and 2.0 by weather based model, 4.3 and 2.1 by InfoCrop model, 10.2 and 9.0 by DSSAT model during *Rabi 2016-17* and 5.3 and 5.9 by weather based model, 2.3 and 2.2 by InfoCrop model, -10.8 and -9.6 by DSSAT model during *Rabi* 2017-18 respectively. Among the three models opted for estimating the yield at flowering and grain filling stage, InfoCrop model gave better results followed by weather based and DSSAT model. Therefore, this model can be used for multi stage wheat crop yield estimation at district as well as regional level

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is an important cereal crop in India occupying second place, next to rice in production, which plays a critical role in food security. Among all commercially grown crops, it occupies largest land area, i.e. more than 240 million ha and it ranks highest in terms of production. Wheat is grown in almost all the states of India. It is grown in *Rabi* season in the northern India. Estimation of crop production at different stages of crop growth before harvest is useful for farmers and planners for preparing advance planning, formulation and its implementation in regard to crop procurement, distribution, price structure and import/export decisions. Productivity of cropping systems under various weather, management and policy scenarios can be predicted successfully by simulation models. The main factors affecting crop yield are weather, soil and genetic coefficient of the crop. Weather plays an important role in crop growth. Therefore, crop simulation model based on weather parameters, soil parameter and crop parameters can provide reliable forecast in advance for crop yield.

Crop yield estimation is typically issued at different stages between the time of planting and time of harvest. The success of the crop yield estimation strongly depends on the crop simulation model’s ability to quantify the influence of weather, soil and management conditions on crop yield and on the system’s ability to properly integrate model simulation results over a range of spatial scales. The spatial and temporal Variability of weather conditions are an important source of uncertainty when applying models over large areas. Efforts in the past has been made by several researchers to develop statistical models based on time series data on crop yield and weather variables for pre harvest crop yield forecast. Agrawal et al. (2012) have developed forecast models for wheat yield in Kanpur district using discriminant function analysis of weakly data on weather variables. Ghosh et al (2014) reported that the performance of the district level yield forecast model developed using composite weather indices in predicting yields at district level for various major crops in different states of the country is quite satisfactory. Vashisth, et al (2015) reported that percentage deviation of the average observed yield by average estimated yield done at twenty days before harvest by InfoCrop in maize crop was 5.5 and 2.9 % in maize and mustard respectively. Vashisth, et al (2014) reported that the statistical models based upon the weather indices could successfully simulate pre harvest yield forecast of wheat under semi-arid region. The percentage deviation between observed and simulated yield was ranged from 5 to 11 and the correlation coefficient was 0.93 to 0.99. Therefore it can be used for district, agro climatic zone and state level forecast. InfoCrop has been successfully adapted, calibrated and validated for rice, (Aggarawal et al., 2006), potato (Singh et al., 2005), cotton (Hebbar et al., 2008) etc. The prime aim of this study is to develop, calibrate and validate crop yield estimation for wheat at flowering and grain filling stage based on the field experiment at IARI research farm using Weather based, InfoCrop and DSSAT model.

2. MATERIALS AND METHODS

Field experiments were conducted at IARI, New Delhi research farm during *Rabi* 2016-17 and *Rabi* 2017-18 seasons respectively for estimating multi stage crop yield for wheat

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using, weather based, InfoCrop and DSSAT model. The climate of the station is semiarid with dry hot summers and cold winter. Three varieties of wheat viz., HD-2967, HD-3086 and PPW-723, were sown on three different dates to generate the weather variability at different phenological stages during *Rabi* 2016-17 and *Rabi* 2017-18. The crop was raised following the standard agronomic practices with three replications in a randomized block design. Number of days required to attain different phenological stages were recorded. Genetic coefficients (specific leaf area, relative growth rate of leaf area, index of greenness of leaves, root growth rate, radiation use efficiency etc.) were measured for running crop simulation models for multi stage crop yield estimation. InfoCrop model is used for simulation of yield. The input requirement for InfoCrop models are sowing depth, seed rate (kg/ha), sowing date, germination date, flowering date, maturity date, harvesting date, days/interval of irrigation, amount of irrigation, days/interval and amount of fertilizer, maximum and minimum temperature, wind speed, rainfall, solar radiation, morning and evening relative humidity. Daily weather data were collected from the agromet observatory located in the research farm of IARI, New Delhi. The soil data required for crop models are soil texture, structure, depth, profile, level of soil nutrients, and other related variables that describe the soil-water balance and nutrient dynamics during crop growth and development. Soil physical characteristics such as hydraulic conductivity determine the movement of water in the soil. Besides, field capacity, wilting point, bulk density are also required. Soil samples were collected from experimental location of IARI, New Delhi for characterization and testing of models. The soil was sandy loam. Estimation of crop yield was done at flowering and grain filling stage using weather based statistical model, InfoCrop model and DSSAT model. Percentage deviation of estimated yield was done by the observed yield using the following formula:

% Deviation = [(Estimated Yield –Observed Yield)*100]/Observed yield

The crop yield forecast models used stepwise regression analysis. Weather variables are used as independent variables which are related to crop responses such as yield and to account for the technological changes, function of time is used as independent variables.

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

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

Where

r_{iw} is correlation coefficient of yield with i-th weather variable in w-th period
$r_{ii'w}$ is correlation coefficient (adjusted for trend effect) of yield with product of i-th and i'-th weather variables in w-th period
m is period of forecast
p is number of weather variables used
e is random error distributed as N $(0,\sigma^2)$

Weather indices used for developing weather-based model is given in table as below

Simple weather indices					
	Tmax	Tmin	Rain	RH I	RH II
Tmax	Z10				
Tmin	Z120	Z20			
Rain	Z130	Z230	Z30		
RH I	Z140	Z240	Z340	Z40	
RH II	Z150	Z250	Z350	Z450	Z50
Weighted weather indices					
	Tmax	Tmin	Rain	RH I	RH II
Tmax	Z11				
Tmin	Z121	Z21			
Rain	Z131	Z231	Z31		
RH I	Z141	Z241	Z341	Z41	
RH II	Z151	Z251	Z351	Z451	Z51

Model performance was evaluated by calculating the different statistical parameters viz. root mean square error (RMSE), correlation coefficient and standard deviation. RMSE describe the mean absolute deviation between observed and simulated and accuracy of model is characterized by lower RMSE.

3. RESULTS AND DISCUSSION

Weather during *Rabi* 2016-17 at IARI, New Delhi

The maximum temperature during different standard meteorological weeks in the *Rabi* 2016-17 was observed to be lower than normal except during 47th, 48th, 1st, 3rd to 10th and 12th to 16th standard meteorological week it was found to be higher than normal. The difference between normal and observed maximum temperature was -2.3 to 5.4 in different standard meteorological weeks. The minimum temperature remain lower than normal except during 1st, 3rd to 10th and 12th to16th standard meteorological weeks it was higher than normal. The minimum temperature was 0.2 to 5.3°C higher than normal and -5.2 to -2.0°C lower than normal in different standard meteorological weeks. The difference between observed and normal maximum temperature was -5.2 to 5.3°C during different standard meteorological weeks. Total rainfall of 89.9 mm (normal value 102.9 mm) was received during *Rabi* 2016-17 on 1st, 4th, 10th, 11th and 14th standard meteorological weeks. The rainfall during the *Rabi* season was less than the normal. However, the rainfall was received in 5 out of 22 weeks of this season. Bright sunshine hours were found to be lower than normal except during 1st , 2nd, 7th, 8th, 9th, 11th to 13th , 15th and 16th standard meteorological week it was higher than normal. The bright sunshine hours was 0.1 to 1.3 hours higher than normal and -8.5 to -0.2 hours lower than normal in different standard meteorological weeks. Evaporation during different weeks in the *rabi* 2016-17 was observed to be lower than normal except during 1st, 2nd, 3rd, 5th to 9th and 13th standard meteorological weeks, it was more than normal. During 10th and 12th standard meteorological weeks, it was equal to the normal value. The difference between observed and normal pan evaporation was -2.2 to 1.2 mm/day during different standard meteorological weeks. The pan evaporation was 0.0 to 1.2 mm/day higher than normal and -2.2 to -0.3 mm/day lower than normal in different standard meteorological weeks. Wind speed was found to be lower than normal except 48th, 1st to 4th, 6th, 8th to 10th and 13th to 16th standard meteorological weeks it was higher than normal value. During 7th standard meteorological weeks, it was equal to the normal value. The difference between observed and normal wind speed was -2.7 to 2.8 km/hours during different standard meteorological weeks. The wind speed

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was 0.4 to 2.8 km/hours higher than normal and -2.7 to -0.2 km/hours lower than normal in different standard meteorological weeks. Relative humidity measured at 7.21 AM was found to be higher than normal, except 48th standard meteorological weeks it was lower than normal value. The difference between observed and normal maximum relative humidity during different standard meteorological weeks was -0.9 to 16.1. The maximum relative humidity was 0.0 to 16.1 higher than normal and -0.9 lower than normal in different standard meteorological weeks. Relative humidity measured at 2.21 PM was found to be higher than normal, except 47th, 51th, 52th, 2nd and 8th standard meteorological weeks it was lower than normal value. The Relative humidity measured at 2.21 PM was 0.6 to 25.9 higher than normal and -8.4 to -2.1 lower than normal in different standard meteorological weeks. The difference between observed and normal minimum relative humidity during different standard meteorological weeks was -8.4 to 25.9.

Date of Sowing	Regression Equation	Predicted Yield (kg/ha)	Observed Yield (kg/ha)	% Deviation
Estimated yield of wheat crop at flowering stage				
Normal Sowing	2023.8+1.60*Z231+3.57*Z121+48.04*Time	5015	4916	2.0
Late Sowing	1520.9+1.66*Z231+0.49*Z141+50.9*Time	4907	4566	7.5
Very late Sowing	2063.11+0.19*Z351+0.45*Z141+48.74*Time	4347	4645	-6.4
Average		4756.1	4709.0	1.01
Estimated yield of wheat crop at grain filling stage				
Normal Sowing	2684.41+0.09*Z351+64.9*Z21+41.55*Time	4666	4916	-5.1
Late Sowing	4150+0.09*Z351+52.13*Z11+42.67*Time	4574	4566	0.2
Very late Sowing	2279.83+0.11*Z451+0.47*Z141+49.60*Time	4425	4645	-4.7
Average		4554.7	4709.0	-3.27

Table 1: Percentage deviation of observed yield from estimated yield of wheat crop by weather based model (*Rabi* 2016-17)

Date of sowing	Predicted Yield (kg/ha)	Observed Yield (kg/ha)	% Deviation
Estimated yield of wheat crop at flowering stage			
Normal Sowing	5126	4916	4.3
Late Sowing	4825	4566	5.7
Very late Sowing	4785	4645	3.0
Average	4912.0	4709.0	4.31
Estimated yield of wheat crop at grain filling stage			
Normal Sowing	5017.8	4916	2.1
Late Sowing	4818.0	4566	5.5
Very late Sowing	4494.0	4645	-3.3
Average	4776.6	4709.0	1.44

Table 2: Percentage deviation of observed yield from estimated yield of wheat crop by InfoCrop model (*Rabi* 2016-17)

Multi Stage Wheat Crop Yield Estimation Using Weather Based Statistical, InfoCrop and DSSAT Model During *Rabi* 2016-17

Wheat crop yield estimation done at flowering and grain filling stage by weather based statistical model is given in table 1. Percentage deviation of estimated yield done at flowering and grain filling stage as compared with the observed yield after harvest was 2.0, 7.5, -6.4 and -5.1, 0.2, -4.7 respectively for normal, late and very late sown crop. The percentage deviation of average yield estimation done at flowering and grain filling stage was 1.01 and -3.27 as compared to the average observed yield after harvest. Using InfoCrop model, percentage deviation of estimated yield done at flowering and grain filling stage as compared with the observed yield after harvest was 4.3, 5.7, 3.0 and 2.1, 5.5, -3.3 respectively for normal, late and very late sown crop (Table 2). Percentage deviation of average estimated yield from average observed yield done at flowering and grain filling stage by InfoCrop model was 4.31 and 1.44 respectively. Using DSSAT model the percentage deviation of estimated yield done at flowering and grain filling stage as compared with the observed yield after harvest was -10.2, -9.8, -15.7 and -9.0, -8.2, -12.3 respectively for normal, late and very late sown crop. Percentage deviation of average estimated yield from average observed yield at flowering and grain filling stage was -9.7 and -8.4 respectively (Table 3).

Date of sowing	Predicted Yield (kg/ha)	Observed Yield (kg/ha)	% Deviation
Estimated yield of wheat crop at flowering stage			
Normal Sowing	4415	4916	-10.2
Late Sowing	4119	4566	-9.8
Very late Sowing	3918	4645	-15.7
Average	4250	4709	-9.7
Estimated yield of wheat crop at grain filling stage			
Normal Sowing	4472	4916	-9.0
Late Sowing	4191	4566	-8.2
Very late Sowing	4073	4645	-12.3
Average	4312	4709	-8.4

Table 3: Percentage deviation of observed yield from estimated yield of wheat crop by DSSAT model (*Rabi* 2016-17)

Weather during *Rabi* 2017-18 at IARI, New Delhi

The maximum temperature during different standard meteorological weeks in the *Rabi* 2017-18 was observed to be lower than normal except during 52nd to 3rd, 5th to 14th and 16th standard meteorological week it was found to be higher than normal. The difference between normal and observed maximum temperature was -3.3 to 5.0 in different standard meteorological weeks. The minimum temperature remain lower than normal except during 8th, 9th, 12th to 14th and 16th standard meteorological weeks it was higher than normal. The minimum temperature was 0.2 to 2.3° C higher than normal and -4.9 to -0.1° C lower than normal in different standard meteorological weeks. Total rainfall of 32.4 mm (normal value 95.4 mm) was received during *Rabi* 2017-18 on 50th, 4th, 14th, and 15th standard meteorological weeks. The rainfall during the *Rabi* season was less than the normal. However, the rainfall was received in 4 out of 24 weeks of this season. Bright sunshine hours were found to be lower than normal except during 2nd, 3rd, 5th, 12th, and 13th standard meteorological week it was higher than normal. The bright sunshine hours was 0.1 to 1.8 hours higher than normal and -9.0 to -0.1 hours lower than normal in different standard meteorological weeks. Evaporation during different weeks in the *Rabi* 2017-18 was observed to be lower than normal except during 2nd to 9th and 12th standard meteorological weeks it was higher than normal. The difference between observed and normal pan evaporation was -3.7 to 0.9 mm/day during different standard meteorological weeks. The pan evaporation was 0.1 to 0.9 mm/day higher than normal and -3.7 to -0.1 mm/day lower than normal in different standard meteorological weeks. Wind speed was found to be lower than normal except 2nd, 4th, 5th, 7th, 9th, 10th, 13th and 16th standard meteorological weeks it was higher than normal value. During 51st and 12th standard meteorological weeks it was equal to the normal value. The difference between observed and normal wind speed was -3.2 to 1.8 km/hours during different standard meteorological weeks. The wind speed was 0.1 to 1.8 km/hours higher than normal and -3.2 to -0.1 km/hours lower than normal in different standard meteorological weeks. Relative humidity measured at 7.21 AM was found to be higher than normal, except 49th, 51st, 13th, 14th and 16th standard meteorological weeks it was lower than normal value. The difference between observed and normal maximum relative humidity during different standard meteorological weeks was -3.7 to 12.1. The maximum relative humidity was 0.0 to 12.1 higher than normal and -3.7 lower than normal in different standard meteorological weeks. Relative humidity measured at 2.21 PM was found to be higher than normal, except 51st, 2nd, 3rd, 5th, 6th, 8th, 10th to 14th and 16th standard meteorological weeks it was lower than normal value. The Relative humidity measured at 2.21 PM was 2.0 to 19.0 higher than normal and -11.4 to -0.1 lower than normal in different standard meteorological weeks. The difference between observed and normal minimum relative humidity during different standard meteorological weeks was -11.4 to 19.0.

Date of Sowing	Regression Equation	Predicted Yield (kg/ha)	Observed Yield (kg/ha)	% Deviation
Estimated yield of wheat crop at flowering stage				
Normal Sowing	Yield=2692+47.9*Time+1.39*Z231+0.48*Z251	4380	4623	5.3
Late Sowing	Yield = 2270.2 +43.9 * Time +0.22 * Z351 +0.28 * Z151	4438	4474	0.8
Very late Sowing	Yield=2781.1+47.5* Time + 0.28* Z351	4452	4198	-6.1
Average		4423.2	4431.3	0.18
Estimated yield of wheat crop at grain filling stage				
Normal Sowing	Yield = 2056.8 +46.3 * Time + 0.16 * Z351 +0.21* Z141	4351	4623	5.9
Late Sowing	Yield = 2162.9 +46.1 * Time + 0.16 * Z351 +0.25 * Z141	4354	4474	2.7
Very late Sowing	Yield =2427 + 42.7 * Time + 0.12 * Z351 +0.84 * Z151 -0.10 *Z150	4427	4198	-5.5
Average		4377.5	4431.3	1.21

Table 4: Percentage deviation of observed yield from estimated yield of wheat crop by weather based model (*Rabi* 2017-18)

Multi Stage Wheat Crop Yield Estimation Using Weather Based Statistical, InfoCrop and DSSAT Model During *Rabi 2017-18*

Wheat crop yield estimation done at flowering and grain filling stage by weather based statistical model is given in table 4. Percentage deviation of estimated yield done at flowering and grain filling stage as compared with the observed yield after harvest was 5.3, 0.8, -6.1 and 5.9, 2.7, -5.5 respectively for normal, late and very late sown crop. The percentage deviation of average yield estimation done at flowering and at grain filling stage was 0.18 and 1.21 as compared to the average observed yield after harvest.

Date of sowing	Predicted Yield (kg/ha)	Observed Yield (kg/ha)	% Deviation
Estimated yield of wheat crop at flowering stage			
Normal Sowing	4725	4623	2.2
Late Sowing	4726	4474	5.6
Very late Sowing	4338	4198	3.3
Average	4634.3	4431.3	4.58
Estimated yield of wheat crop at grain filling stage			
Normal Sowing	4725.0	4623.0	2.2
Late Sowing	4725.5	4473.5	5.6
Very late Sowing	4046.5	4197.5	-3.6
Average	4499.0	4431.3	1.53

Table 5: Percentage deviation of observed yield from estimated yield of wheat crop by InfoCrop model (*Rabi* 2017-18

Date of sowing	Predicted Yield (kg/ha)	Observed Yield (kg/ha)	% Deviation
Estimated yield of wheat crop at flowering stage			
Normal Sowing	4122	4623	-10.8
Late Sowing	4027	4474	-10.0
Very late Sowing	3471	4198	-17.3
Average	3873.3	4431.7	-12.59
Estimated yield of wheat crop at grain filling stage			
Normal Sowing	4179	4623	-9.6
Late Sowing	4099	4474	-8.4
Very late Sowing	3626	4198	-13.6
Average	3967.7	4431.7	-10.46

Table 6: Percentage deviation of observed yield from estimated yield of wheat crop by DSSAT model (*Rabi* 2017-18)

Using InfoCrop model, percentage deviation of estimated yield done at flowering and grain filling stage as compared with the observed yield after harvest was 2.2, 5.6, 3.3 and 2.2, 5.6, -3.6 respectively for normal, late and very late sown crop (Table 5). Percentage deviation of average estimated yield from average observed yield done at flowering and grain filling stage by InfoCrop model was 4.58 and 1.53 respectively. Using DSSAT model the percentage deviation of estimated yield done at flowering and grain filling stage as compared with the observed yield after harvest was -10.8, -10, -17.3 and -9.6, -8.4, -13.6 respectively for normal, late and very late sown crop. Percentage deviation of average estimated yield from average observed yield at flowering and grain filling stage was -12.59 and -10.46 respectively (Table 6).

4. CONCLUSION

Results from the simulated studies showed that the statistical models based upon the weather indices could successfully estimate multistage yield of wheat under semi-arid region. This model is simple, does not required any sophisticated statistical tools, required only weather data for crop growing periods, yield data for past thirty year and provides good multi stage crop yield estimation. This model is most consistent. Therefore, it can be used for district, agro climatic zone and state level crop yield estimation. From the studies, it was concluded that among the three models opted for estimating the yield at flowering and grain filling stage, InfoCrop model gave better results followed by weather based model and DSSAT model. Hence, InfoCrop model can be used for multistage crop yield estimation.

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