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Short Communication

Determining Potential Yield and Effect of Change of Transplanting Date on Yield of *Kharif* Rice through Crop Growth Simulation Model

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ABSTRACT

Among different available crop growth models, WOFOST model was used to determine the year-wise variation of potential yield and change of it due to changing sowing dates. Two commonly grown rice cultivars of New Alluvial Zone of West Bengal, namely, IR-36 and *Khitish* were validated for the said zone. For both of the varieties, the modeled yield is close to actual experimental yield and modeled biomass is also close to the actual ones. The simulated output has also shown that July-end transplanted crop performed better than mid-July transplanted crop. Again mid-July transplanted crop performed better than 1st July transplanted crop. The yield gap between potential yield and District's average yield was in the range of 1101 to 2510 kg/ha. Thus, there is a great potential to increase yield of *Kharif* rice in the lower Gangetic basin of West Bengal.

Key words: Rice, Simulation model, WOFOST, Potential yield

Introduction

The population growth along with increased urbanization and change in the weather pattern are threatening the food security of different parts of the world including India. Monsoon reports of 2009 and 2010 have shown that there is a considerable decrease in rainfall amount in the Gangetic West Bengal (India Meteorological Department, 2011). Moreover, the erratic rainfall pattern in the said zone causes a great impact on annual food-grain production (Revadekar and Preethi, 2011). In this situation, farmers are facing the problem of growing *Kharif* rice, which is mostly rainfall dependent. To assess the crop-dependence on weather, dynamic crop models can be used successfully (Jones *et al*., 1998; Hoogenboom *et al*., 1999). Several dynamic crop growth simulation models such as CERES,

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WOFOST, SUCROS, and APSIM have been developed during later part of the last century. These models integrate the effects of different factors on productivity and have been used to determine the production potential, optimize crop management practices, to study the effect of climatic change and many others (Matthews and Stephens, 2002). Considering the ability of the crop growth models, the present study aims to calibrate and validate of WOFOST model for *Kharif* rice grown in the Gangetic West Bengal and to use this model to determine the year-wise variation of potential yield due to year-wise rainfall. Moreover, the change of potential yield due to changing sowing dates has also been observed.

Material and methods

Study Region: The study was conducted for Nadia District, which falls under New Alluvial Zone of West Bengal. In the district, *Kharif* rice is the main crop and the water requirement for this crop in the region is met mainly from the rainfall, although farmers have to depend upon irrigation due to erratic rainfall distribution. The main water resource of the district is ground water. The depth of ground water varies from 10-12 ft below ground surface level during monsoon and post monsoon period. The climate of the zone is sub-tropical with an average annual rainfall of 1500 mm ranging from 1200 to 1690 mm. The maximum rainfall is received from South-West monsoon during the months of June to September. The soil of the region is mainly alluvial in nature (Entisol), silty clay in texture and well drained.

The model: The WOFOST (WOrld FOod STudies) model was used to simulate growth and production of the rice. WOFOST was originally developed as a crop growth simulation model for the assessment of the yield potential of various annual crops in tropical countries (Boogaard *et al*., 1998). The WOFOST model considers three growth levels correspond to crop production, namely, potential production, limited production and reduced production. In the case of limited production, in addition to irradiation, temperature and plant characteristics, the effect of the availability of water and plant nutrients is considered. If the supply of water or nutrients is sub-optimal during the growing season, this leads to water-limited and/or nutrient-limited production, which is normally lower than potential production.

The potential production represents the absolute production ceiling for a given crop and variety when grown in a given area under specific weather conditions. In the present study the variation of potential production of rice in the Gangetic West Bengal was considered to determine the yield gap of the region.

Inputs for crop growth modeling: In this study, IR-36 and *Khitish*, two commonly grown rice cultivars of the New Alluvial Zone of West Bengal were considered. Secondary information on the phenological characteristics, thermal time requirement for different phenophases, yield, yield attributes, etc., for a period of 1998 to 2000 along with soil data were collected for validating crop simulation model (AICRPAM, 1998, 1999 and 2000). The weather data were collected from Kalyani Observatory (Latitude-22°57′ North and Longitude 88°20′ East). The normal package of practices followed in Nadia district for *Kharif* rice was considered for running the model.

Statistical analysis: For validation of WOFOST model, the Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) were worked out. The equations used are given as follows:

$$MAE = \frac{\sum_{i=1}^{M}\left(\left|Obs,i - \Pr e,i\right|\right)}{M} \quad \ldots(1)$$

$$RMSE = \left[\frac{\sum\left(Obs,i - \Pr e,i\right)^2}{M}\right]^{0.5} \quad \ldots(2)$$

where, Obs = Observed values of yield or biomass (kg ha^{-1}), Pre = Predicted values of yield or biomass (kg ha^{-1}), M= total number of observations.

Table 1. Validation of WOFOST model for IR-36 variety

Treatment (Date of sowing)	Grain Yield (kg ha^{-1})		Biomass yield (kg ha^{-1})	
	Actual	Modeled	Actual	Modeled
D_1 – 10 July, 1998	3750.8	3749.0	11582.0	10174.0
D_2 – 24 July, 1998	4148.3	3563.0	12420.0	10297.0
D_3 – 7 August, 1998	3897.0	3870.0	11389.0	10631.0
D_4 – 10 July, 1999	3835.8	3751.0	11431.0	10849.0
D_5 – 24 July, 1999	4124.5	3965.0	12010.0	10991.0
D_6 – 7 August, 1999	3829.3	4127.0	11004.0	11217.0
D_7 – 10 July, 2000	3921.0	3761.0	11521.5	11185.0
D_8 – 24 July, 2000	4081.5	3812.0	13040.2	11214.0
D_9 – 7 August, 2000	3200.8	4026.0	12123.8	11462.0

Results and Discussion

Validation of WOFOST model for IR-36 and Khitish

For validation of WOFOST model, the grain yield and biomass production data of nine treatments (for the years 1998, 1999 and 2000) were compared with model output for each of two varieties as mentioned in materials and methods. The nine treatments are of different dates of sowing (three DOS in each year) for three consecutive years. The wide range of DOS was considered to thoroughly evaluate the model to simulate yield and biomass.

Table 1 shows the variation of simulated yield and biomass against actual ones for IR36 variety. In some cases, especially for all the treatments in the year 1998, the modeled grain yields matched well with actual experimental yields. The range of simulated yield was 3563 kg/ha to 4127 kg/ha whereas the actual yield in the experimental field ranged from 3537 kg/ha to 4148.3 kg/ha. The actual biomass was also comparable with simulated biomass.

Table-2 shows the variation of simulated yield and biomass against actual ones for *Khitish* variety. In some cases, especially for all the treatments in the year 1998 and 1999, the modeled grain yields matched well with actual yields. The range of simulated yield was 3702 kg/ha to 4050 kg/ha whereas the actual yield ranged from 3501.3 kg/ha to 3925.1 kg/ha. The biomass production of *Khitish* rice was well matched with simulated biomass.

Once the grain yield (actual experimental yield and modelled yield) were plotted on 1:1

Table 2. Validation of WOFOST model for *Khitish* variety

Treatment (Date of sowing)	Grain Yield (kg ha^{-1})		Biomass yield (kg ha^{-1})	
	Actual	Modeled	Actual	Modeled
D_1 – 10 July, 1998	3618.3	3746.0	10979.0	8702.0
D_2 – 24 July, 1998	3775.8	3766.0	12086.0	9017.0
D_3 – 7 August, 1998	3702.3	3702.0	11075.0	8885.0
D_4 – 10 July, 1999	3501.3	3751.0	10850.0	9139.0
D_5 – 24 July, 1999	3823.3	4029.0	11508.0	9368.0
D_6 – 7 August, 1999	3746.0	3889.0	11026.0	9134.0
D_7 – 10 July, 2000	3615.2	3868.0	10250.5	9702.0
D_8 – 24 July, 2000	3925.1	4050.0	12105.0	9854.0
D_9 – 7 August, 2000	3722.4	3924.0	11241.3	9571.0

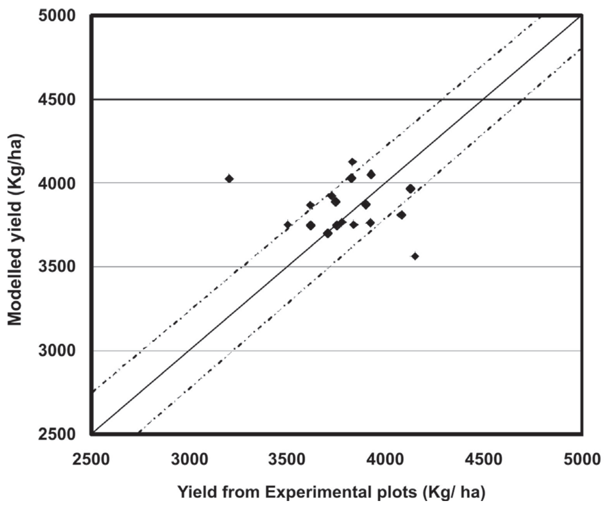

Fig. 1. Comparison of observed and modelled rice yield with 1:1 line. The dotted lines denote ± SE lines

line, it is observed that most of the points are within ± SE line (Fig. 1). Hence the model can be used safely for predicting yield. Moreover the RMSE value for prediction of IR36 is 371.75 kg/ha and MAE value is 267.87 kg/ha. For Khitish, the RMSE and MAE values are 170.51 kg/ha and 146.17 kg/ha, respectively. The low RMSE and MAE values indicate that the crop growth model can be used successfully for predicting yield.

Determination of potential yield and crop growth period

After proper validation of the WOFOST model for the said two varieties of *Kharif* rice, the model was used for simulating the effect of date of transplanting on crop yield. Three sowing dates were considered for the study, viz; 1st July, 15th July and 30th July. The model output of 13 years (1997 to 2009) showed that July-end transplanted crop performed better than mid-July transplanted crop for both the varieties. Again mid-July transplanted crop performed better than 1st July transplanted crop (Table-3 and Table-4). For IR36 variety the average yields were 3575.69, 3751.46, and 4235.23 kg/ha for 1st July, 15th July and 30th July transplanted crops, respectively. For *Khitish* variety the average yields were 3752.31, 3817.77, and 4166.62 kg/ha for 1st July, 15th July and 30th July transplanted crops, respectively.

Table 3. Effect of days of transplanting on yield performance of IR-36 variety

Year	Yield (kg ha^{-1})		
	1st July	15th July	30th July
1997	3916	4616	5409
1998	3520	3717	3658
1999	3496	3851	3763
2000	3517	3889	3746
2001	3604	3577	4061
2002	3768	4072	4838
2003	3436	3401	3592
2004	3588	3765	5005
2005	3665	3500	3688
2006	3485	3614	4068
2007	3335	3622	4082
2008	3522	3439	4190
2009	3632	3706	4958
Average	3575.69	3751.46	4235.23

Table 4. Effect of days of transplanting on yield performance of *Khitish* variety

Year	Yield (kg ha^{-1})		
	1st July	15th July	30th July
1997	3797	4431	5244
1998	3572	3858	3722
1999	3765	3899	4141
2000	3714	3947	4023
2001	3687	3795	3989
2002	3942	3954	4560
2003	3814	3552	3663
2004	3808	3881	4594
2005	3773	3617	3754
2006	3933	3745	4155
2007	3455	3701	3934
2008	3841	3553	4087
2009	3679	3698	4300
Average	3752.31	3817.77	4166.62

Comparison of district average and potential yield

The yield data of *Kharif* rice for Nadia district were collected from Department of Agriculture, Government of West Bengal, India and compared with the simulated year-wise yields. The comparison between district average and the average of simulated potential yield of IR36

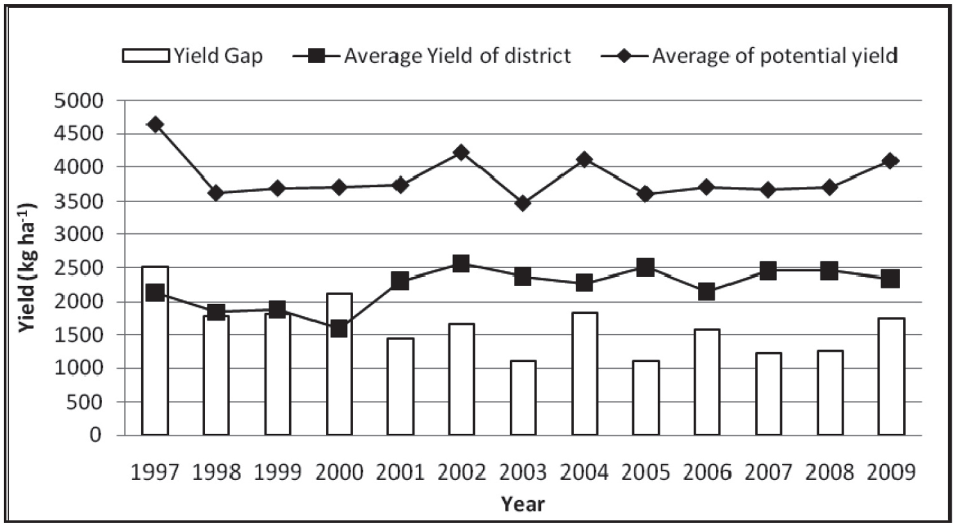

Fig. 2. Comparison of district average and potential yield of IR36 variety

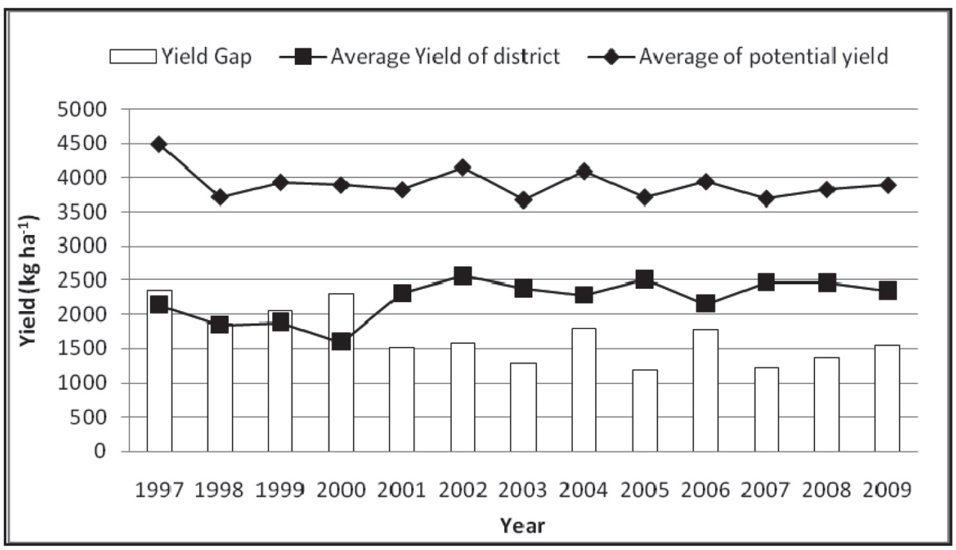

Fig. 3. Comparison of district average and potential yield of *Khitish* variety

showed that the yield gap between actual (district average) and potential yield varied from 1101.33 to 2510 kg/ha (Fig. 2). Likewise considering potential yield of *Khitish* variety, the yield gap varied from 1200.67 to 2353.67 kg/ha (Fig. 3). Thus there is an immense potentiallity to increase the yield of *Kharif* rice in the lower Gangetic West Bengal, India.

Conclusions

It can be concluded that the WOFOST model can be used to predict the yield of paddy and the model is very much useful to determine the potential yield of a region and to find out the optimum sowing window. In the new alluvial zone of West Bengal, the district average yield is much lesser than the predicted potential yield. Hence there is a huge scope of increasing productivity in the study zone.

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