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Evaluation of the performance of ORYZA2000 and assessing the impact of climate change on rice production in Gangetic West Bengal

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ABSTRACT

A preliminary study has been undertaken to test a crop stimulation model, ORYZA 2000, in a station over Gangetic West Bengal. The model has been verified with the observations of field experiments conducted in the Bidhan Chandra Krishi Vishwavidyalaya's farm for a particular variety IET 4786 in the baro seasons during 1999-2000 and 2000-2001. The simulation has been performed under potential production situation as well as nitrogen limited production situation. The potential production situation predicts high yield around 10 t/ha. On the other hand, under nitrogen limited condition for three different nitrogen application levels namely 0, 120, 140 kg ha^{-1} the model simulates slightly better results, though they are still higher than the experimental values. Keeping the nature of overestimation of yield in view, the model has further been used to investigate the impact of climate change (with changing temperature and carbon dioxide concentration) on rice yields. The model predicts the drastic changes in yield by -10.1%, -45.8% and – 72.1% for temperature changes +1°C, +2°C and +3°C respectively. It also reveals that even with a warmer climate up to 1°C production may increase by about 10% in an atmosphere with doubled CO_2 concentration.

Keywords : Oryza2000, sensitivity test, rice yield, climate change, length of growing period.

Crop growth modeling is an important tool in modern agricultural research. One important aspect of this is validation test, which usually is done by comparing simulation results with observed ones. Validation study will help us to make necessary modifications so that the model can be more widely acceptable. In this aspect many workers (Midmore et al., 1984; Kalra and Aggarwal, 1994; Ortiz-Manasterio et al., 1994; Hundal and Kaur, 2004) have already reported their findings.

Further, agricultural crop is highly sensitive to weather parameters (Rai et al., 2004; Das and Kalra; 1995) despite other factors such as soil characteristics, management procedure, diseases, pest etc. A study conducted by the International Rice Research Institute (IRRI), Philippines in 22 countries over 8-years period suggested that rice yields under irrigated conditions are significantly affected by temperature and solar radiation. An increase of minimum temperature from 18-19°C, there is a decrease in yield by about 0.7t ha^{-1} (SAARC, 1992). For a wide range of sites varying in latitude from 6°N to 31°N, rice yields are reported to have dropped by 10-20% with a rise in minimum temperature of 1-2°C during November- December. Thai scientists have also reported a 15-20% decrease in lowland rice yields for both rainfed and irrigated crops. In the northern India, for example an increase in temperature by 0.5°C would reduce yield due to heat stress by about 10% if rainfall remains same. Researchers(Sinha and Swaminathan, 1991; Bachelet et al., 1993; Warrick, 1988) are more concerned now a days about the possible impact of climate changes, which may cause serious limitation on our agricultural production in the near future. Some work has already been done in assessing rice production under expected climate change scenarios (Das and Lohar, 2005) over the study region. So it is worthwhile to study the possible impact of such changes on the rice production in order to take necessary measures well in advance to meet the increasing food grain demand.

Oryza1 model has been tested in estimating the potential yield of rice in different locations in Asia (Kropff et al., 1994a, b) as well as India. Most of the locations in India belong to North and Northwest part of the country except Cuttack in the east (Matthews et al., 1995) though the eastern part of India such as Assam, Bihar, Orissa, West Bengal etc. are the largest rice- growing regions. Later on, attempts have been made (Aggarwal et al, 2000) for these states and as per their report, the West Bengal condition assures less potential yield (7.2 t ha^{-1} on an average), emphasizing the need for detailed investigation.

Therefore, in the present study, an attempt has been made to test a more recent model (Oryza2000) in West Bengal scenarios as well as to predict the changes in potential yields of rice under projected changes in climatic condition in general, and CO_2 concentration and temperature changes in particular.

MATERIAL AND METHOD

A detailed description of the model including the input data requirement is available in Boumen et al., 2001. So, some of its basic features are described here. The model follows a daily rate calculation scheme for dry matter production of the plant organs and the rate of the phenology development. By integrating these rates over time, the dry matter production of the crop is simulated throughout the growing period. The model simulation is done for the growth and development of rice crop in three production situations, namely, potential, water limited and nitrogen limited. Phenology development is explained through development Stage (DVS) of a plant, which is defined by its physiological age and characterized by the formation of the various organs and their appearances. Finally development stages are calculated by integrating the development rates and expressed in degree-days. In transplanted rice, the situation becomes complicated due to transplanting shock, causing a delay in phenology development. It has taken into consideration by putting the development rate equal to zero for a short period expressed in degree-days.

The main process behind the growth of a crop is photosynthesis, which requires CO_2 assimilation. It is a function of the daily incoming radiation, temperature and leaf area index. Gross CO_2 assimilation rate at different canopy depth 'L' for shaded leaves is calculated using, $A_L = A_m(1-\exp(-\varepsilon I_a / A_m)$ where, A_m is the CO_2 assimilation rate at high saturation, ε is the initial light-use efficiency, and is the amount of absorbed radiation at depth 'L'. On the other hand, CO_2 assimilation for sunlit leaves is calculated using the direct flux intensity as well as the absorbed flux by the shaded leaves. Finally, the daily rate of canopy CO_2 assimilation is calculated in order to get the daily development rate.

DATA AND MODEL SIMULATION

Few cases have been simulated with the model using some input data sets. This input data and results of these simulations are explained as follows. Weather variables such as daily values of maximum and minimum temperatures, rainfall, vapor pressure, wind speed are collected from Bidhan Chandra Krishi Viswavidyalaya's observatory, located at Mohanpur (23° 5′ N, 88° 45′ E) campus. Daily values of irradiances are, however, calculated using the maximum and minimum temperature (Das and Pujari, 1993) due to unavailability of data. Soil data, i.e., soil type, soil texture, hydraulic conductivity, soil moisture etc. are taken from some experiments (Naskar, 2004; Ghosh, 2002) conducted in the same farm.

Crop management or experimental data, i.e., sowing date, harvest date, amount of fertilizer applications, amount of irrigation application, observed LAI, straw yield, total dry matter production etc. have been collected from Narzari (2002). Some of the parameters have been given in the Table 1. Crop data such as different rate parameters i.e. development rate in juvenile phase (DVRJ = .000773 °Cd^{-1}), development rate in photoperiod-sensitive phase (DVRI = .000758 °Cd^{-1}), development rate in panicle development (DVRP = .000784 °Cd^{-1}) and development rate in reproductive phase (DVRR = .001784 °Cd^{-1}), and light use efficiency for the minimum temperature (10°C) and maximum temperature (40°C) are 0.54 and 0.36 respectively (Boumen et al., 2001)have been used in this study. Fraction of total dry matter partitioned to the shoot, root and shoot dry matter partioned to different storage organs i.e. leaves, stems, and panicles are given in Table 2.

RESULTS AND DISCUSSION

Case-I (Simulation for potential production):

Using the basic weather and experimental input data, the model has been run for potential production situation for the period 26th December, 1999 to 15th May, 2000 and 26th December, 2000 to 15th May, 2001. The simulated final potential yield (WRR) for two seasons (Table 2) are slightly less than 10 t ha^{-1} (i.e. 9285 kg ha^{-1} in 1999-2000 and 9087kg ha^{-1} in 2000-2001), falling within the range of 6-10 t ha^{-1} as reported elsewhere (Penning de Vries, 1993; Aggarwal et al., 2000) for the Indian regions. A difference of grain yield in the consecutive two seasons may arise due to different weather conditions in the two periods. The model also provides values of other parameters (Table 3) such as final grain yield (WRR), dry weight of rough rice contains 14% moisture (WRR14), dry weight of storage organs (WSO), and total above ground green dry matter (WAG).

Case-II (Nitrogen limited production):

The simulation has also been performed using similar data sets, with three different levels of nitrogen application, namely, 0kg ha^{-1}, 120 kg ha^{-1} and 140 kg ha^{-1} in order to study the possible effect of nitrogen application on different yield components. It may be mentioned here that the 1/3rd of nitrogen fertilizer has been applied on day 38 as a basal dose, remaining was applied in two split doses namely on day 64 at tillering stage and on day 91 at panicle initiation stage. The detailed results of simulation are presented in Table 4. It is noted that the final yield (WRR) simulated in the 1999-2000 boro seasons is higher than that obtained in 2000-2001 seasons at every level of nitrogen applications. Grain yield increases with the increase of N_2 application. However, with a further increase of N_2 there is no appreciable increase in yield (not shown here).

Case-III (Verification with the observations):

In this case, the model has been simulated with the same management processes as applied for the field experiments. The result (Table 5) indicates that the model estimates much higher yield in the period 1999-2000. On the other hand, the model prediction is better in the period 2000-01 although it is higher than the observed yield. The comparison between the simulated and observed yield reveals that the model overestimates yield which agrees well with the other researchers (Lansigan, 1998; Tripathi, 1996)

Effect of climate change on rice production

The model, calibrated for the variety IET 4786, has been used to investigate the effect of climate changes on rice production. This is done through the evaluation of potential yield components in case of changing temperature situation for fixed CO_2 level (340 ppmv) as well as for the doubled CO_2 level in the atmosphere. In general, the simulated yield components

Table 1:Various crop parameters of rice at different days after planting (DAP) during 1999-2000 and 2000-01.

Parameter*	Experimental year: 1999-2000											
	30 DAP			47 DAP			64 DAP			81 DAP		
	N0	N120	N140	N0	N120	N140	N0	N120	N140	N0	N120	N140
LAI	1.27	1.43	1.70	1.93	3.19	3.74	2.51	3.50	4.78	1.76	2.75	3.47
DMA	26.05	41.4	46.97	67.6	99.8	132.7	75.4	127.8	180.0	66.75	103.0	125.3
DWL	13.64	22.90	33.2	72.97	117.5	134.3	150.6	196.4	233.6	148.5	198.5	221.4
TDW	39.69	64.30	80.17	140.5	217.5	266.9	226.1	324.2	414.7	380.2	487.4	596.6
	Experimental year: 2000-01											
LAI	0.79	1.06	1.21	2.83	3.89	4.11	3.31	4.02	4.26	1.93	2.73	2.71
DMA	16.2	22.95	24.28	79.8	123.3	140.6	123.2	157.0	175.8	67.02	100.3	108.2
DWL	7.08	23.08	24.0	84.21	138.7	166.3	246.7	280.4	336.8	122.5	199.6	214.9
TDW	23.30	46.0	48.3	164.0	261.9	306.9	349.9	437.4	515.6	486.3	566.8	624.7

* LAI - Leaf Area Index, DMA - Dry Matter accumulation in leaf (gm^{-2}), DWL - Dry Weight of Leaf ($g\ m^{-2}$) and TDW - Total Dry Weight (gm^{-2})

Table 2: Fraction of total dry matter partitioned to the shoot and root and fraction of shoot dry matter portioned to various organs is written as a function of developmental stages (DVS)

Development stage	Total dry matter portioned to		Fraction of shoot dry matter portioned to		
	Root	Shoot	Leaves	Stems	Panicles
0.0	0.50	0.50	0.6	0.4	0.0
0.5	0.25	0.75	0.6	0.4	0.0
1.0	0.00	1.00	0.0	0.4	0.6
2.5	0.00	1.00	0.0	0.0	1.0

Table 3: Different potential yield attributes (kg ha^{-1}) as simulated by Oryza2000.

Crop growing seasons	Model simulated potential yield attributes kg/ha)				
	WRR14	WRR	WSO	WAG	WAGT
1999-2000	10797	9285	9974	17517	20609
2000-2001	10566	9087	10023	18331	21666

WRR14 - Dry weight of rough rice (14% moisture), WRR - Dry weight of rough rice (final yield), WSO - Dry weight of storage organs, WAG - Total above ground green dry matter (kg DM ha^{-1}), WAGT - Total above ground dry matter (kg DM ha^{-1})

Table 4 : Simulated nitrogen limited yields (kg ha^{-1}) for various parameters during two consecutive boro seasons.

Nitrogen application levels	WRR14		WRR		WSO		WAG		WAGT	
	1999-2000	2000-01	1999-2000	2000-01	1999-2000	2000-01	1999-2000	2000-01	1999-2000	2000-01
N0	5454	3821	4690	3286	5185	3829	8816	6780	10895	8318
N120	10271	9003	8833	7742	9492	8558	16833	15772	19680	18034
N140	10405	9051	8949	7784	9622	8600	16714	16237	20113	18707

N0 - 0 kg ha^{-1} nitrogen application, N120 - 120 kg ha^{-1} nitrogen application and N140 –140 kg ha^{-1} nitrogen application.

Table 5 : Comparison between the observed and model simulated yields.

Year	Field experiment			Model simulation		
	Grain yield (t ha^{-1})					
	N0	N120	N140	N0	N120	N140
1999-2000	2.08	3.53	4.08	4.69	8.63	8.95
2000-2001	3.88	5.42	6.98	4.86	8.96	9.01

Table 6: Predicted final yield changes (%) with mean temperature change under fixed scenarios (1xCO_2 and 2xCo_2).

CO_2 levels	Temperature change in ^{0}C								
	-3	-2	-1	0	+1	+2	+3	+4	+5
1 x CO_2	+8.0	+7.2	+4.2	0	-10.1	-45.8	-72.1	-76.2	-77.3
2 x CO_2	+40.7	+39.6	+35.0	+26.4	+10.9	-31.5	-46.9	-69.7	-71.1

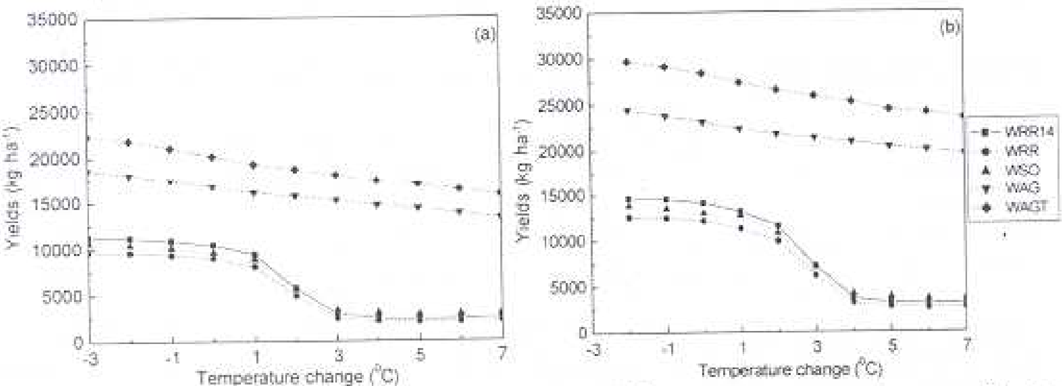

Fig.1: Simulated yield components (kg ha^{-1}) for different temperature changes with (a) 1xCO2 and (b) 2xCO2 environment.

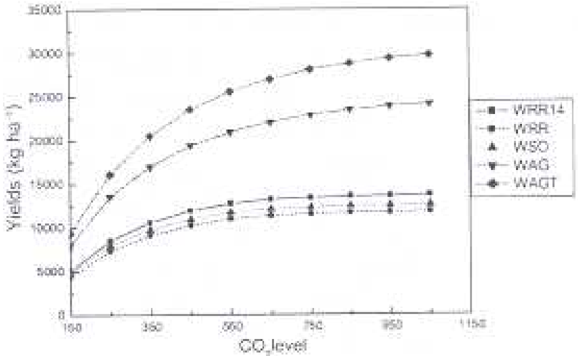

Fig.2 : Variation of yield components with different levels of CO_2 concentrations with fixed environmental conditions.

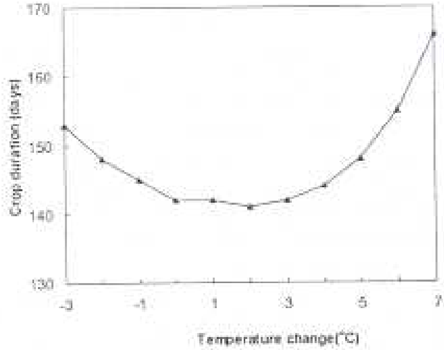

Fig.3 : Changes in growing period (days) for respected temperature changes

increase with the increase in mean temperature and vise-versa under both the current and doubled CO_2 levels. In case of current CO_2 level and with the present weather condition, the simulated potential yield gets reduced drastically from 8948 kg ha^{-1} to 2496 kg ha^{-1} due to a 3° C rise in mean temperature. On the other hand, it does not increase so much when the mean temperature reduces by about 3°C (Fig. 1). Simulations have also been performed to investigate the effect of CO_2 concentrations in the atmosphere. The amount of various yield components is more in case of higher CO_2 concentrations, may be as a result of enhanced photosynthesis rate (Fig. 2). Combined effect of temperature and CO_2 concentration change shows an interesting result. Even with the warmer climatic situation (up to a temperature change of + 1°C) predicted final yield is enhanced by about 10% in a doubled CO_2 concentration environment (Table 6). Length of the growing period (Fig. 3) shows a marginal change in case the mean temperature rises about 2°C unlike the findings of Hundal and Kaur (1995).

CONCLUSIONS

The potential production (~ 10 t ha^{-1}) appears to be more even than the highest reported value (9 t ha^{-1}) for indica/japonica in West Bengal conditions (Bardhan Ray, 2000). Application of fertilizer under nitrogen limited situation assures more yields (about 8-9 t ha^{-1}) up to a limit of 140 kg ha^{-1}. Further increase of N_2 application has less impact on the production, indicating an optimized amount of nitrogen fertilizer as 120-140 kg ha^{-1}. On the other hand, in water-limited situation, predicted yield components are less (7 t ha^{-1}) even with the application of optimized amount of N_2 fertilizer. The results highlight the importance for proper care in irrigation management towards better production of yield components. Since the study area experiences weather disturbances such as western disturbances during winter (transplanting and early growing period) and premonsoon thunderstorm activity during the late growing season (Sadhukhan and Lohar, 2000), more care is needed in irrigation management. However, verification study indicates (Table 4) that the model estimation is higher than the observed values. The results are important when a temperature increase of 0.5-1.0 °C per °C change in global mean temperature change has been estimated for 2025 (an average of the period 2011-2040) during the growing season of boro cultivation (Das and Lohar, 2005) over the study area. Most of the General Circulation Models indicate an increase in global mean temperature by about 2-3 °C. As a result, the study area will experience a warming climate as per the projection in 2025, resulting a reduction of yield components, if not drastically.

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