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Climate change implications and simulated adaptations in rainfed rice production under sub- humid climate of North Western Himalaya

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ABSTRACT

This study presents outcome of 21 years simulations study to assess the impact of projected climate change on rice yields and simulated adaptations thereof. The InfoCrop model simulation was validated and run for 21 years weather data (1998 to 2018). The elevated levels of CO_2 (50 and 100 ppm) increased rice yield by 7.6 to 20.8%. The yield reduction due to elevated temperature by 1°C and 2°C alone ranged between 6.8 to 25% and 14.8 to 35.6%, respectively for all planting windows. The elevated temperature of 1°C coupled with 420 ppm CO_2 decreased yield up to 8.4% with shortened average growing period up to 6-13 days. The further rise of temperature to 2°C with 50 ppm elevated level of CO_2 showed decrease in simulated yield by 18.4% in simulations from 1998 to 2018 compared to control conditions. Conversely, 100 ppm elevated level of CO_2 than control along with 1°C rise in temperature increased grain yield from 0.97 to 9.8%. However, 2°C rise in temperature coupled with 470 ppm CO_2 the yield decreased from 3.9 to 8.9% in all transplanting windows. 10% reduction in rainfall from recent decade 1998 to 2008 showed nominal decrease in yield in all planting windows but 20% reduction in rainfall decreased yield by 0.5 to 9.4%. Adaptation as one irrigation during 15 days dry spell in the month of August increased yield by 17.4 to 36.6% in transplanting windows of June 20th and 10th whereas, the 30th June and 10th July transplanting decreased yield to the tune of 7.3 to 12.1%. Hence, controlled rice yield imposed by high CO_2 and temperature can be mitigated by altering sowing dates.

1. Introduction

Rice is the most important cereal crop for more than half of the world's population, providing 21% of the total calorie intake (Singh et al. 2017). Worldwide, it occupies an area of about 164 million ha with a production of 758.9 million tonnes during 2017 (Anonymous 2018). It is the staple food for more than two-third of the world's population, especially the people living in Asia where more than 90% of rice is produced and consumed. India is the world's second largest rice consumer and producer next to China. In Himachal Pradesh rice is one of the important cereal crops next to wheat and maize on area basis. The crop is cultivated from foothill plains to an altitude of 2290 m above mean sea level covering an area of 73.70 thousand hectares with a total production of 130.5 thousand tonnes and productivity of 1771 kg ha^{-1} (Anonymous 2019). Rice cultivation is well-suited to countries and regions with low labour costs and high rainfall, as it is labour-intensive to cultivate and requires ample water which is anticipated to become scarce in future. The rice production in future climate change scenarios will experience scarcity of land and water, higher input cost and greater demand for reduced environmental footprints. To assess the impact of future climate change on productivity of rice simulated studies can play pivotal role. Projections of impact and risk due to change in weather parameters should be interpreted in perspective of complexity inherent in using a deterministic model to simulate the highly stochastic

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processes of agro-ecosystems (White et al. 2011). The crop simulation models provide a suitable tool to evaluate crop growth as affected by various environment factors and also their interaction. The significance of crop modeling can be accessed from the fact that approximately 20% of crop modeling studies carried out during the period 1995 to 2002 dealt with climate change (Tubiello and Ewert 2002) and half of them considered responses to CO_2. Thus, there is need to strengthen the physiological assumptions of models, especially with respect to heat stress, responses to CO_2 and genetic diversity and simultaneously more attention to sources of uncertainty as well as the desirability of having standard technique for modeling impacts. The attempt has been made to validate the InfoCrop model and assess the impact of climate change on yield of rice at Palampur region of Himachal Pradesh.

2. Materials and Methods

InfoCrop, a Decision Support System (DSS) is designed to simulate the effects of weather, soils, agronomic management on crop growth and yield. It is user friendly and has simple and easily available requirements *i.e.* crop or variety (coefficients), weather (season, location), climate change scenario (CO_2, temperature and rainfall), dates of planting, seed rate and depth of planting etc. InfoCrop provides several outputs relating to growth and development, water use, soil carbon and greenhouse gas emissions. InfoCrop version includes database of chickpea, cotton, soybean, groundnut, maize, rice, wheat, mustard etc. The basic model is written in Fortran Simulation Translator programming language (FST/FSE; Graduate School of Production Ecology, Wageningen, The Netherlands), a language also adopted by the International Consortium for Agriculture Systems Application (ICASA) as one of the languages for systems simulation (Jones et al. 2001). Another version of the model has been developed to facilitate its greater applications in agricultural research and development by the stakeholders not familiar with programming. The user-interface of this software has been written using Microsoft.Net framework while the back-end has FSE models and databases in MS-Access. More details of the model are provided by Aggarwal et al. (2006a, b).

***Model input requirements**:*

Soil: For three soil layers depth (mm), organic carbon (%), soil texture (sand, silt, clay %), bulk density and NH_4-N and NO_3-N content is needed.

Plant: Seed rate, specific leaf area of variety, grain weight.

Daily weather: Minimum and maximum air temperature (^oC), solar radiation ($KJm^{-2}d^{-1}$), vapour pressure (kPa), wind speed (ms^{-1}) and rainfall (mm).

Crop management: Date of sowing, dates of irrigation and fertilizer application.

Calibration and validation of model:

Calibration and validation of the model for the simulation of crop phenology (days to maturity, days to anthesis) and grain yield of rice, the observed data were recorded at Palampur for four dates of sowings i.e. 10th, 20th, 30th June and 10th July for the period of two years (2000-2001). Simulated and observed days to anthesis, maturity and yield for rice crop at Palampur were compared. An excellent parity between observed and simulated phenological events in varied weather condition reflects the consistency in model performance.

Assessment of impact due to climate change

The seasonal climate scenarios were calculated and used in the model to assess the impact of elevated carbon dioxide, temperature and rainfall variability. The crop model was run for 21 years from 1998 to 2018. The mean yield and coefficient of variance of 21 years simulated yield were worked out. The control mentioned in the table indicates no change in weather parameters and normal CO_2 level of 370 ppm.

3. Results and Discussion

***Validation of model**:*

InfoCrop rice was calibrated using three phenological parameters i.e. days to anthesis, days to maturity and grain yield at Palampur. The field experiments were conducted during 2000 and 2001 following recommended packages and practices. The rice crop was raised as rainfed crop during both the year ensuring pre transplanted irrigation for dates. The normal rainfall from June to October in the region is 1813.2mm (Anonymous 2015). Model simulated (2000-02) the phenological stages very closely with the experimental data. The RMSE values for days to anthesis was 5.88 days (Fig. 1). The simulated days to maturity were 7 to 10 more to the actually observed in the field with RMSE values of 8.93 days (Fig. 2). The economic yield simulated by model corresponded well with that actually observed in the field. The RMSE value for yield was 618.19 kg/ha during *kharif* season at three sowing windows from 2000 to 2002 (Fig. 3).

Simulated impact of climate change on rice

Planting windows

The simulation indicated 20th June transplanted crop to be the best window for rice sowing followed by 30th June under mid hill sub-humid conditions (Table. 1). The days taken for anthesis and maturity during 10th June transplanted crop were 66 and 104 followed by 20th June, 70 and 110, respectively. Whereas, 30th June and 10th July transplanted rice took 72 and 75 days for anthesis and 115 and 120 days for maturity, respectively. In case transplanting delayed by 10 days, time for anthesis and maturity was increased by 4-6 days. Simple adaptation strategies *viz.* change in planting date can reduce the extent of loss caused by high temperatures (Eitinger et al. 2009).

Impact of elevated carbon dioxide levels

Elevated carbon dioxide levels of (50 and 100 ppm) showed an increase in yield of rice in all the transplanting windows from June 10th to July 10th. The 50 ppm and 100 ppm elevated levels of carbon dioxide increased yield by 7.6 to 11.7% and 14.8 to 20.8% in rice crop under rainfed conditions, respectively (Table 2). Plants grown at elevated CO_2 had higher efficiency of water, light and nutrient utilization (Jacob et al. 2001). Another study revealed that elevated CO_2 alone increased the rice yields (Saxena and Kumar 2014).

Impact of elevated temperature

The two levels of temperature 1^{o}C and 2^{o}C were studied. The increase of 1^{o}C temperature showed advancement of 2 to 6 days in anthesis and 7 to 10 days in maturity whereas, 2^{o}C rise in temperature advanced the anthesis by 5 to 9 days and maturity by 12 to 18 days (Table 3). The simulated yield with 1^{o}C and 2^{o}C rise in temperature was compared with no change in temperature of 2000-01 under rainfed conditions. The decrease in yield was 6.8 to 25% with 1^{o}C and 14.8 to 35.6% in 2^{o}C rise in temperature in all transplanting windows (Table 4). However, Rai et al. (2011) observed positive impact on rice yield with increase in temperature up to 2°C but beyond that temperature negative impact in paddy production was observed in mid hill conditions of Nepal. The simulation studies done in Western zone of Tamil Nadu on different planting dates from 1st June to 15th July revealed that temperature increase from 1 to 5°C from current climatic conditions reduced rice yield from 4 - 56% (Bhuvaneswari et al. 2014). Geethalakshmi et al. (2017) revealed that crops grown under modified environment (climate control chamber) with +4°C and CO_2 enrichment of 650 ppm recorded reduced growth characters (leaf area index, dry matter production, number of tillers m^{-2}), lesser dry matter partitioning towards grain yield attributes (number of productive tillers m^{-2}, number of filled grains $panicle^{-1}$) and lower grain yields compared to those grown under ambient condition.

Impact of elevated temperature and carbon dioxide levels

One degree rise in temperature + 50 ppm higher level of CO_2 advanced the maturity of the crop by 6 to 13 days whereas two degree rise + 50 ppm CO_2 advanced the maturity by 12 to 17 days (Table 5). Gowtham et al. (2020) indicated 8 days reduction in duration for rice with 1.5°C warming in Tamil Nadu. In China, the average of flowering durations decreases by 2.8 days (3.9 days), and the maturity period decreases by 11.0 days (14.7 days) under the 1.5 ^{o}C and (2.0 ^{o}C) warming scenarios, respectively (Guo et al. 2019). The temperature rises of 1^{o}C and 2^{o}C coupled with 50ppm elevated carbon dioxide caused reduction in the rice yield in almost all the transplanting windows (Table 5). The yield reduction was more in 2^{o}C (5.6 to 18.4%) than 1^{o}C rise in temperature (5.2 to 8.4%). Gerardeaux et al. (2012) observed positive effects of increased temperature and CO_2 on rice growth. Similarly, Hundal and Kaur (2007) reported enhanced rice grain yield by 2.8% with 2^{o}C increased temperature and doubled CO_2 concentration of 600 ppm from normal (330 ppm). Das et al. (2007) observed about 10% increased rice yield with warmer climates upto 1°C, when coupled with enhanced level of CO_2.

Further increase in carbon dioxide level by 100 ppm from control of 370 ppm showed similar number of days in advancing the maturity period (Table 6). The elevation in CO_2 by 100 ppm with 1^{o}C rise in temperature showed increase in the yield to the tune of 1.0 to 9.8% in all the transplanting windows (Table 6). Agarwal et al. (2006b) reported that with increase in temperature by 1 ^{o}C and at 369 ppm CO_2 concentration, reduced rice yields under irrigated (6.6 to 11.1%) and rainfed (4.6 to 9.4%) conditions at IARI, New Delhi. The combined impact of increased temperature and elevated CO_2 resulted in net decline in yield inspite of CO_2 fertilization. Gowtham et al. (2020) revealed that 1.5°C warming with 360 ppm and 430 ppm CO_2 reduced rice yield by 21% and 17% respectively, under agro-climatic conditions of Tamil Nadu. Similar reduction in rice yields (38.3 to 54.5%) was observed in Punjab when temperature increased (4.5 to 5.8^{o}C) from the ambient environment (Kaur et al. 2019). Aggarwal and Rani (2009) also studied the impact of climate change on the productivity of rice in Punjab (India) and revealed that temperature increase of 1, 2 and 3˚C reduced the grain yield by 5.4, 7.4 and 25.1%, respectively. However, the adverse impacts of climate change on rice yields can be reduced by adopting long duration cultivars and by changing planting date from normal to early under Ludhiana conditions (Saxena and Kumar 2014).

Impact of rainfall reduction

The reduction in rainfall (10 and 20%) did not change number of days for anthesis and maturity when compared with control (Table 7). The total SW-monsoon (June to September) rainfall received at Palampur from past 36 years (1974–2009) is 1810.7 mm. The SW-monsoon rainfall during simulation year was 1456 mm. The 10% reduction in rainfall showed reduction in the rice yield to the tune of 0.7 to 1.5%. Further reduction in rainfall to 20% decreased the crop yield by 0.5 to 9.4% under all the transplanting windows when compared with normal conditions (Table.7). Rainfall has significant effect on rice yield. However, the influences of maximum temperature and minimum temperature are more pronounced compared with that of rainfall (Sarker et al. 2012). The advance weather information on rainfall proved to be profitable for rice crop production in the region (Rana et al. 2005).

Impact of 15 days dry spell on rice yield under rainfed conditions

Under dry spell of 15 days during the month of August the yield of rice crop reduced by 10.7 to 15 % in the entire planting windows (Table. 8). However, the reduction was less in 30th June and 10th July as compared to 10th and 20th June planting window. These results are in concurrence with Rana et al. (2013) who revealed that climate variability influence crop productivity and increase vulnerability in climate dependent agricultural system. The farmers' perceptions delineated changes in climatic parameters cause a shift in crop production from high to low water requiring crops. In Himachal Pradesh, the study on climatic trends also revealed decreasing trends of rainfall and on contrary increase in maximum and minimum temperatures (Rana et al. 2012).

Impact of 15 days dry spell on rice yield under rainfed conditions and irrigation level as adaptation

Under rainfed conditions with the dry spell of 15 days during the month of August, one irrigation assessed as adaptation increased the rice yield to the tune of 17.4 to 36.6% in first two transplanting windows i.e. 10th and 20th June whereas, the 30th June and 10th July transplanting reduced the yield to the tune of 7.3 to 12.1% (Table. 9). The annual precipitation in Palampur is around 1578 mm, out of which nearly 70% is received during South-West monsoon (June-September). Nevertheless, Palam valley also showed decrease of rainfall in all months with significant decrease in July (-16.8 mmy^{-1}) and August (-3.4 mm y^{-1}) (Rana et al. 2012). The study on surface water flow and surplus water balance in Himachal Pradesh by Rana et al. (2014) clearly indicated decrease of water resources due to changes in climatic conditions in mountains during past three decades. Under the scenario, where early withdrawal of monsoon take place then adaptation gains (one irrigation) lead to increased grain yields in first two planting windows compared to latter two. The projected increase in rice yield will also be higher under irrigated conditions due to prevailing low yields under rainfed conditions. In the latter two planting windows (30th June and 10th July) the decrease in rainfall and increase in maximum temperature during reproductive stage of the crop might have accelerated crop senescence and advanced attainment of physiological maturity stage through increased respiration leading to reduced yields.

4. Conclusion

Under rainfed conditions of Himachal Pradesh, 20th June transplanted crop was found to be the best window for rice sowing followed by 30th June. Elevated carbon dioxide levels of 50 and 100 ppm from the ambient, projected an increase in simulated yield of rice in all the transplanting windows from June 10th to July 10th. The rise in temperature by 1^{o}C and 2^{o}C coupled with 50 ppm elevated CO_2 caused reduction in rice yield in almost all the transplanting windows. Reduction in rainfall (10 and 20%) also showed reduction in the rice yield under mid hill sub humid conditions. Under dry spell, the yield of rice crop reduced in early transplanting whereas; there was an increase in observed yield under delayed transplanting windows. The reverse results obtained using one irrigation as adaptation i.e. increase of yield in first two transplanting windows of 10th and 20th June whereas, reduced yield with 30th June and 10th July transplanting. Thus, early sowing with one irrigation proved to be better adaptation for rice under sub-humid sub-temperate and rainfed conditions of Himachal Pradesh.

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Table 1. Impact of planting windows on days to anthesis, maturity and yield of rice crop.

Planting window	Days to anthesis	Days to maturity	Yield (kg/ha)
10th June	66	104	3090.5
20th June	70	110	3788.2
30th June	72	115	3555.5
10th July	75	120	3360.1

Table 2. Impact of elevated CO_2 (420 ppm & 470 ppm) level on rice yield.

Planting window	Control	420 ppm		470 ppm	
		Grain yield (kg/ha)	Percent increase/decrease	Grain yield (kg/ha)	Percent increase/decrease
10th June	3090.5	3455.1	11.7	3745.2	20.8
20th June	3788.2	4070.2	7.8	4360.3	14.8
30th June	3555.5	3845.2	7.6	4110.5	15.1
10th July	3360.1	3680.5	9.8	3921.2	16.4

Table 3. Impact of elevated 1°C and 2°C rise temperature on days to anthesis and maturity of rice crop.

Planting window	Control	Days to anthesis		Days to maturity		
		1 °C	2 °C	Control	1 °C	2 °C
10th June	65	63	60	105	97	93
20th June	72	66	63	112	102	98
30th June	74	68	66	118	106	100
10th July	74	68	67	122	112	106

Table 4. Impact of elevated 1°C and 2°C rise temperature on rice yield.

Planting window	Control	1 °C		2 °C	
		Grain yield (kg/ha)	Percent increase/decrease	Grain yield (kg/ha)	Percent increase/decrease
10th June	3090.5	2325.0	-25	2142.0.0	-35.6
20th June	3788.2	3450.5	-8.9	3240.5	-14.8
30th June	3555.5	3325.4	-6.8	2730.3	-25.1
10th July	3360.1	2798.2	-16.4	2750.5	-18.5

Table 5. Impact of elevated CO_2 (420 ppm) and 1 °C & 2 °C rise temperature on days to anthesis, maturity and grain yield (kg/ha) of rice crop.

Planting window	Days to anthesis			Days to maturity			Grain yield (kg/ha)			Percent increase/ decrease	
	Control	420 ppm		Control	420 ppm		Control	420 ppm		420 ppm	
		1 °C	2 °C		1 °C	2 °C		1 °C	2 °C	1 °C	2 °C
10th June	65	62	60	105	99	93	3090.5	2830.0	2510.9	8.4	-18.4
20th June	72	65	63	112	104	96	3788.2	3590.3	3520.01	-5.2	-7.1
30th June	74	68	65	118	105	101	3555.5	3310.1	3120.4	-6.9	-12.3
10th July	74	70	67	122	112	106	3360.1	3170.5	3015.0	-5.6	-5.6

Table 6. Impact of elevated CO_2 (470 ppm) and 1 °C & 2 °C rise temperature on days to anthesis, maturity and grain yield (kg/ha) of rice crop.

Planting window	Days to anthesis			Days to maturity			Grain yield (kg/ha)			Percent increase/ decrease	
	Control	470 ppm		Control	470 ppm		Control	470 ppm		470 ppm	
		1°C	2°C		1°C	2°C		1°C	2°C	1°C	2°C
10th June	65	62	60	105	98	93	3090.5	3120.5	2870.0	1.0	-7.1
20th June	72	66	64	112	105	99	3788.2	4095.0	3660.0	8.1	-3.4
30th June	74	69	66	118	107	100	3555.5	3905.5	3240.8	9.8	-8.9
10th July	74	72	69	122	114	105	3360.1	3465.2	3255.5	3.1	3.1

Table 7. Impact of rainfall reduction of (-10 % & -20 %) on days to anthesis, maturity and grain yield of rice crop.

Planting window	Days to anthesis			Days to maturity			Grain yield (kg/ha)			Percent increase/ decrease	
	Control	-10% rf	-20 % rf	Control	-10% rf	-20 % rf	Control	-10% rf	-20 % rf	-10% rf	-20 % rf
10th June	65	66	66	105	104	104	3090.5	3070.0	2798.5	-0.7	-9.4
20th June	72	70	69	112	109	110	3788.2	3730.4	3770.0	-1.5	-0.5
30th June	74	71	70	118	112	109	3555.5	3510.5	3501.5	1.3	-1.5
10th July	74	74	72	122	119	117	3360.1	3330.5	3198.5	-0.9	-4.8

Table 8. Impact of 15 days dry spell during August (1-15th August) on rice yield under rainfed conditions.

Planting window	Yield (q/ha)		Percent increase/decrease
	Without dry spell	Dry spell	
10th June	3090.5	2646.0	-14.4
20th June	3788.2	3220.5	-15.0
30th June	3555.5	3140.4	-11.7
10th July	3360.1	3020.6	-10.7

Table 9. Impact of 15 days dry spell on rice yield under rainfed conditions under one irrigation level.

Planting window	Grain yield (q/ha)		Percent increase/decrease
	Dry spell	Dry spell with one irrigation	
10th June	2646.0	3610.0	36.6
20th June	3220.5	3780.5	17.4
30th June	3140.4	3520.6	-12.1
10th July	3020.6	3240.7	-7.3

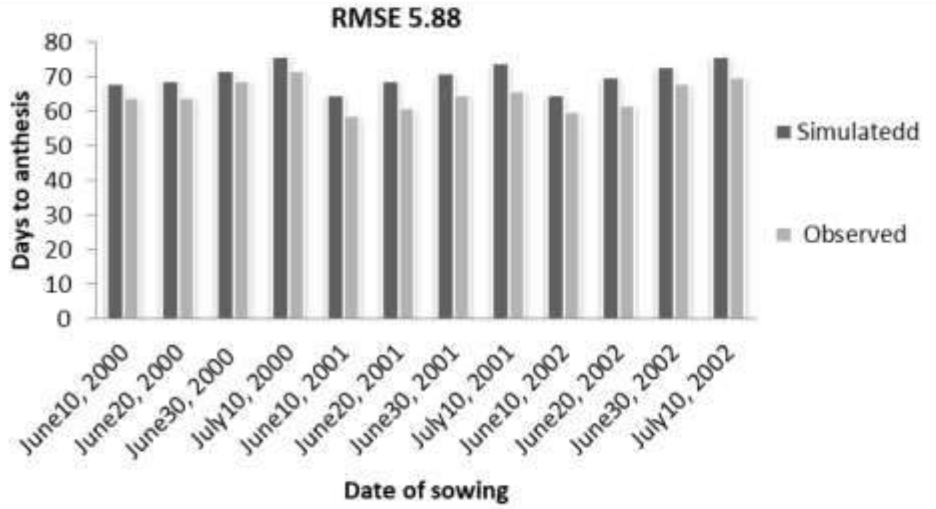

Fig. 1. Validation of InfoCrop model for days to anthesis of rice.

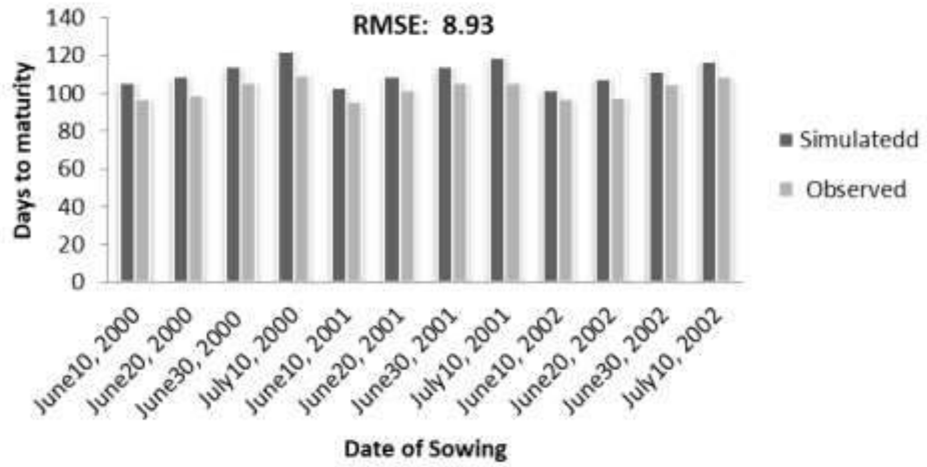

Fig. 2. Validation of InfoCrop model for days to maturity of rice.

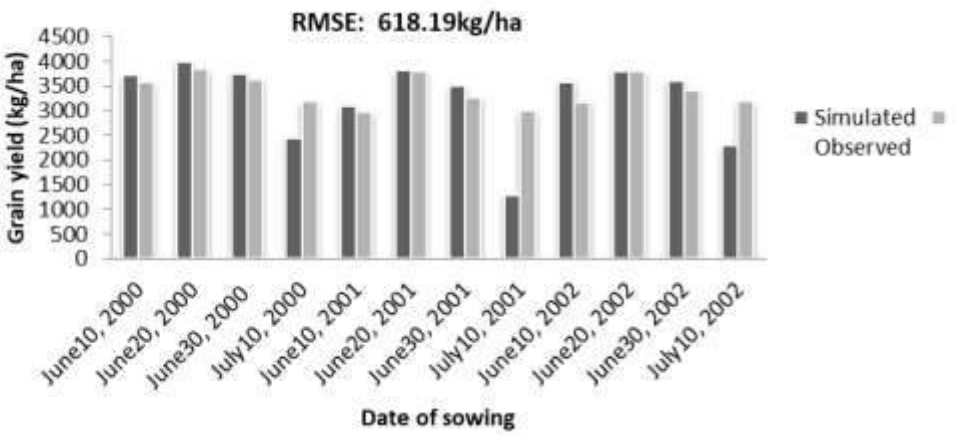

Fig. 3. Validation of InfoCrop model for grain yield of rice.