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EFFECT OF IRRIGATION MANAGEMENT AND ESTABLISHMENT PERIOD OF AUS RICE - EVALUATION OF THE ORYZA2000 MODEL

S P Ritu*[1], T P Tuong[2] and S U Talukder[3]

[1]*Department of Irrigation and Water Management, Sylhet Agricultural University, Sylhet-3100, Bangladesh*
[2]*Water Science Division, International Rice Research Institute, Los Banos, Manila, Philippines*
[3]*Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensing-2202, Bangladesh*

Abstract

Most of coastal rice land of Bangladesh is cultivated with monsoon season (aman) rice in rainfed condition due to salinity. But short duration pre-mosoon *aus* rice can be an alternative to increase cropping intensity using early rainfall in April and minimum use of shallow ground water. To evaluate the hypothesis, short and long-term effect on crop establishment and water management is needed. Therefore, research on the interactions between establishment and irrigation management on *aus* rice variety BRRI dhan65 performance was initiated, using the dual approach of field experiments and ORYZA2000 crop modelling. This paper presents the results of a comprehensive evaluation of the ORYZA2000 model for its ability to simulate the effects of BRRI dhan65 establishment in different dates and water management, and their interactions in polder 30 of South-West Coastal area (SWCA). The model was evaluated for its ability to predict crop development, grain yield, biomass production over long term climatic data (from 1985 – 2004). Root mean square error ($RMSE_n$) value for biomass, grain and yield at 14 % moisture content were 6, 4 and 7, respectively. ORYZA2000 confirmed that to assure 75 % probability of good crop establishment and yield under rainfed condition seeding of *aus* crop should be at the end of April. For earlier seeding dates, supplementary (with 50 – 100 mm of water) performed better than rainfed rice, with simulated yield of BRRI dhan65 approaching 5 t ha^{-1}.

Keywords: ORYZA2000 crop model, coastal area, aus rice, irrigation management.

Introduction

South-West Coastal Zone (SWCZ) of Bangladesh is affected by soil and water salinity in dry season that reduces the scope of crop production resulting low cropping intensity than any other parts of the country (Mondal, 1997). Circumference embankments or polders were built by the Coastal Embankment Project (CEP), with assistance from the World Bank in 1967 to protect the coastal land from saline water intrusion during high tide reducing salinity hazards within the poldered areas (Nishat, 1988). But, due to risk of soil salinity and lack of fresh water for irrigation, most farmers keep their land fallow in the dry (boro) season. Therefore, most of coastal rice land of Bangladesh is grown with monsoon season (aman) rice, using local varieties in rainfed condition with low yields (2.0 - 2.5 t ha^{-1}) (Mondal *et al.*, 2006). Some farmers cultivate non rice crops, such as sesame, in the dry season, which is often damaged (Mondal *et al.*, 2006) due to heavy rainfall during March or April and poor drainage capacity of the soil (Mondal *et al.*, 2006). Farmers faced total crop loss once in approximately three years. Some farmers grow shrimp (Mondal *et al*., 2006; Karim and Mimura, 2006; Islam, 2004) in the dry season, which has been criticized disastrous to the environments (Karim and Mimura, 2006).

Experience elsewhere proved that the use of short-duration HYV, with proper crop scheduling that matches crop water requirements with water supply (including rainfall) and quality dynamics can increase the cropping intensity and productivity of the rice lands in coastal areas (Tuong *et al*., 1991; My *et al*., 1997). Dry direct seeding has emerged as a viable alternative to transplanting in the rice growing areas in rainfed seasons in places with irrigation water scarcity.

Corresponding author:** ***S P Ritu, *Department of Irrigation and Water Management, Sylhet Agricultural University, Sylhet-3100, Bangladesh, email:sanjidap05@gmail.com*

Growing *aus* rice in the polder area is a new concept. For this reason there have been no detailed studies on water requirement of the aus rice crop in the coastal areas of Bangladesh, especially in relation to yield and to drought stress during establishment. Due to cost and time limitations, field experiments could not be carried out for long period of time to cover different combination of effect of climate on yield and water requirement.

Crop models are useful tools for studying the soil–crop–atmosphere system as affected by management (e.g. sowing date, fertilizer application, irrigation scheduling etc.) and weather variability. They can also be used to extrapolate results to other sites and climates over space and/or time. Simulation models, such as ORYZA2000 (Bouman *et al.*, 2001), after validation under local conditions, can be used to predict rice yield under different times of crop establishment, water supply under the prevailing agro-climatic condition of the area. Simulation models have been useful in evaluating rainfed ecosystems, and to explore management strategies for constraint alleviation (Wopereis *et al.*, 1995; Jongdee *et al.*, 1997). It is expected that the model can also be used to determine appropriate times of *aus* rice establishment, long term aus rice yields and water requirements in different scenarios of water management at the SWCZ of Bangladesh. The crop model ORYZA2000, after being validated at the local conditions, can be used to determine probabilistic yields and water requirements for supplementary irrigation of *aus* rice under different times of crop establishment.

Materials and Methods

Data for model input: Field experiments were carried out with three irrigation regimes during 2006 - 2008 and fully irrigated transplanted rice in 2009. The study site (Polder 30) is located in Batiaghata upazila in Khulna district of SWCZ of Bangladesh. Three irrigation treatments were:

I_1 = Rainfed (RF)

I_2 = Supplemental irrigation (SI) to ensure adequate soil moisture during crop establishment up to 3 weeks after emergence

I_3 = Full irrigation (FI) to ensure that the crop does not suffer from water stress for the whole growing season

BRRI dhan65 was sown in line with the spacing of 20 cm × 20 cm on early-April (D_1), mid-April (D_2), late-April (D_3) during 2006 - 2008 and transplanted on 27 May of 2009. Sixty kg P_2O_5 ha^{-1}, 40 kg K_2O ha^{-1}, 10 kg $ZnSO_4$ ha^{-1} and 60 kg $CaSO_4$ ha^{-1} and urea was applied at 120 kg N ha^{-1} in 4 equal splits at final land preparation, maximum tillering (MT), 5 days before panicle initiation (DBPI) and at heading.

Biomass at maximum tillering (MT), panicle initiation (PI), flowering (FL), grain filling (GF) and physiological maturity (PM) stages and yield data of all treatments including climatic data were collected during the experimental period.

Model (ORYZA2000) simulation procedure

Parameterization: The ORYZA2000 is an eco-physiological model that requires field experimental data for parameterization and validation to stimulate long term output in the actual field situation under consideration. The model was parameterized with the experimental data of aus season rice transplanted on 27 May of 2009 under potential water condition and nitrogen limited condition following the procedure described by Bouman and Van Laar (2006). Development rates of BRRI dhan65, in *aus* season, were derived from the observed dates of emergence, panicle initiation, flowering and physiological maturity. Measured oven dry weight (kg ha^{-1}) of total above ground dry matter (WAGT), stems (WST), green leaves (WLVG), yellow and dead leaves (WLVD) and storage organs (WSO) at different stages of crop development were used to derive partitioning factors of assimilates. The partitioning of assimilates was further fine tuned by model fitting (refining the parameter value until the simulated value within ±20 % of measured biomass values). All other crop parameters were the same as in ORYZA2000's standard crop data file for IR72 (Bouman *et al.*, 2001). Nitrogen recovery fraction in the soil in different development stages and indigenous soil nitrogen supply were adjusted to make balance between simulated and observed biomass and yield. Daily maximum and minimum temperature, sunshine hour, wind speed, rainfall and early morning vapor pressure data of the study area were used in the weather data file. Performance of ORYZA2000 in calibrating the rice crop BRRI dhan65 was evaluated by statistical measures. For the same variables, the slope (α), intercept (β) and coefficient of determination R^2 of the linear regression between observed (X) and simulated (Y) values were computed. The normalized root mean square errors ($RMSE_n$) between simulated and measured values were also computed.

A model reproduces experimental data fit best when α is close to 1, β is close to 0, R^2 is close to 1 and $RMSE_n$ is similar to the coefficient of variation of measured values.

Evaluation and scenario analysis: The model ORYZA2000 was validated using 2006 - 2008 aus crop experimental results for different seeding dates (D_1, D_2 and D_3) and different water regimes (I_1, I_2 and I_3). Model was validated under both water and nitrogen limited condition. The soil hydraulic properties and Van Genuchten parameters were derived from the analyzed mechanical properties (percent silt and percent clay) and organic matter in different soil layers. Observed groundwater data was used and measured seepage and percolation rate was used as a function of groundwater. Other soil parameters were the same as the standard soil file PADDY (Bouman *et al.*, 2001). Measured and simulated WAGT, WSO and total yield at harvest (WRR_{14}) were compared in a 1:1 scatter plot and the coefficient of determination R^2 of the linear regression for all biomass and yield was computed. The normalized root mean square errors ($RMSE_n$) between simulated and measured values and coefficient of variation of measured values were also computed.

$$RMSEn = N^{-2}\sum_{i=1}^{n} p^i - O^i$$

Normalized RMSE (%) = (Absolute RMSE/Observed RMSE) × 100

The third step involved long term scenario analysis for different seeding dates under different water management of aus rice in the coastal areas of Bangladesh. Six different crop seeding dates i.e., 10 April, 20 April, 30 April, 10 May, 20 May and 30 May and three water regimes. Three water regimes used in the model simulation were i.e., (i) rainfed, (ii) supplementary irrigation (10 mm water per application) when soil water potential reached 30 KPa in the top two layers (0 - 10 cm) up to development stage (DVS) 0.40 and then rainfed and (iii) full irrigation (10 mm water per application) when soil water potential reached 30 KPa in the top two layers (0 - 10 cm) up to DVS 0.40 and then 40 mm irrigation when there is no standing water. The model was running for 20 years period based on the weather data of the region (1985 - 2004). The model thus simulated 360 (6 × 3 × 20) level of probabilistic yield and water requirement of aus rice at six different seeding dates and for three water management. For each seeding dates, the model generated 60 sets of data on yield and 40 sets for water requirement. From these simulated data, the expected yield and water requirement were analyzed statistically to find the interaction and the median, range of data; upper quartile (Q_3) and lower quartile (Q_1) were calculated and presented by whisker plot.

Results and Discussion

Optimizing date of seeding of rainfed aus rice using ORYZA2000

Model parameterization and validation: ORYZA2000 model was parameterized and calibrated with the experimental data of transplanted aus season rice transplanted on 27 May of 2009 under potential water condition and nitrogen limited condition following the procedure described by Bouman and Van Laar (2006). The goodness-of-fit parameters between simulated and measured crop variables are presented in Table 1. R^2 values of the linear regression between observed and simulated values were above 0.87. The $RMSE_n$ was low except for green leaves biomass. The slope (α) was deviated more from 1 and the intercept (β) deviated less from 0.

Fig. 1 illustrates the calibrating results with calibrated crop parameters. The measured biomasses were simulated well by ORYZA2000 for the variety in most points of crop growth. The major simulation results are shown in Table 1 and summarized below:

a) The measured and simulated values were almost equivalent at physiological maturity for total above ground biomass, storage organ and green leaves
b) The simulated total above-ground biomass (WAGT) was almost similar at panicle initiation and very small overestimations were noted in grain filling and physiological maturity;
c) The simulated stem biomass (WST) was same as measurement at the panical initiation and grain filling but slight underestimation in physiological maturity;
d) Simulated storage organ biomass (WSO) was a little lower than measured ones at grain filling and physiological maturity;
e) In comparison with measurements, simulated green leaf biomass (WLVG) was higher at panical initiation but was almost closer at grain filling and physiological maturity.

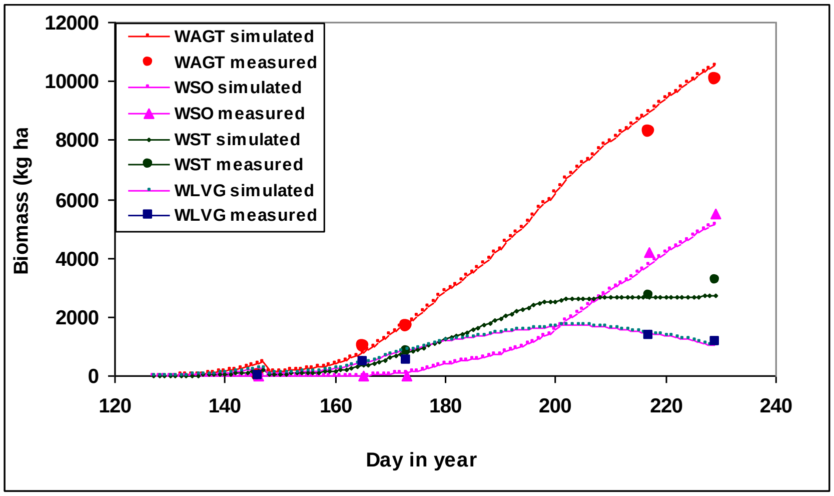

Fig. 1. Measured and simulated biomass of transplanted aus rice. WAGT = total above ground biomass; WST = stem biomass; WLVG = green leave biomass and WSO = storage organ (filled + unfilled) biomass.

Table 1. Quantitative goodness-of-fit parameters for ORYZA2000 simulations of total above ground biomass over the growing seasons and yield at physiological maturity.

Crop Variable[1]	N[2]	$X_{mea}(SD_P)$	X_{sim} (SD_P)	A	β	R^2	$RMSE_n$ (%)
WAGT	5	4204 (4610)	4493 (4856)	70	1.05	0.99	10.20
WSO	5	1934 (2691)	1813 (2471)	37	0.92	0.99	12.41
WST	5	1463 (1433)	1331 (1259)	61	0.87	0.98	18.63
WLVG	5	705 (546)	808 (484)	224	0.83	0.87	29.09

[1] WAGT = total above ground biomass, WSO = biomass of storage organ, WST = biomass of stem, WLVG = biomass of green leaves; [2] N = number of data pairs; X_{mea} = mean of measured values in whole population; X_{sim} = mean of simulated values in whole population; SD_P = standard deviation of population; α = slope of linear relation between simulated and measured values; β = intercept of linear relation between simulated and measured values; R^2 = adjusted linear correlation coefficient between simulated and measured values; $RMSE_n$ = normalized root mean square error

ORYZA2000 model validation: Fig. 2 showed the 1:1 line plot of the measured and simulated biomass on the WAGT, WSO and the grain yields at 14 % moisture content (WRR_{14}) for the rice variety BRRI dhan65 in the treatments (10 treatments) having good data based on higher yield from all aus season experiments of 2006 - 2008. It may be noted that among the ten sets of data, five sets has a 1:1 relationship between measured and simulated WAGT. Simulated WRR_{14} has closer 1:1 relation with the measured data for eight sets out of ten sets. Simulated biomass and yield was overestimated for rainfed rice seeded on mid-April of 2006 that was affected by submergence resulting low yield and biomass. The simulated biomass and storage organ was overestimated the measured values under irrigated treatments of 2007 cropping season which were attacked by soil pest and had low biomass and yield.

The linear regression line between simulated and measured biomass and yield showed a reasonable coefficient of determination (R^2 is 0.68) value. Coefficient of variance (CV) of the measured biomass (WAGT) and yield (WRR14) and the storage organ (WSO) of simulated biomass and yield over measured value is shown in Table 2. It may be noted that coefficient of variance (CV) of the measured biomass and yield was higher than the normalized root mean square error ($RMSE_n$) of simulated biomass and yield over measured values (Table 2), which indicated that the model can confidentially represent the rice growth in field. The model thus can be applied in simulation long term yield and irrigation water requirements under the study site conditions.

Table 2. Coefficient of variation of measured biomass and yield and normalized root mean square error of simulated biomass and yield.

	Crop variable[2]		WRR14
	WAGT	WSO	
CV[1] (%)	13	15	18
RMSEn (%)	6	4	7

[1]CV = coefficient of variation of measurements, RMSEn = normalized root mean square error between simulated and measured values; [2]WAGT = total above ground biomass, WSO = biomass of storage organ, WRR14 = crop yield at 14% moisture content during harvest

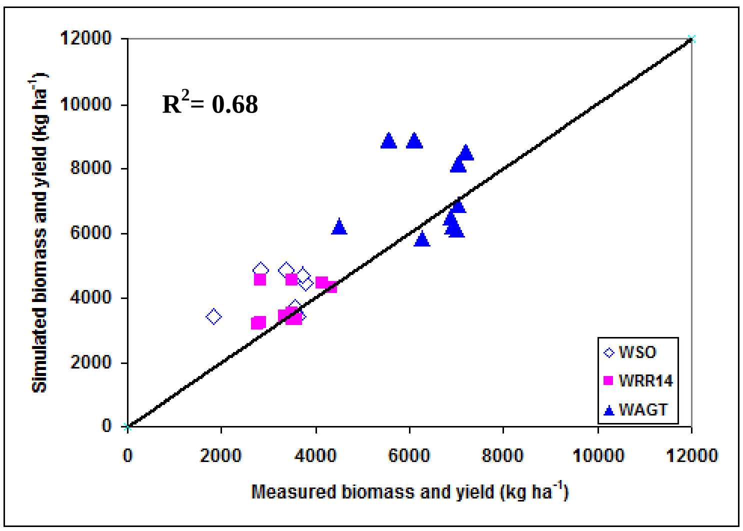

Fig. 2. Simulated vs. measured total above ground biomass (WAGT), storage organ (WSO) and grain yield (WRR_{14}) for 10 observations from all experiments in the study years (2006 - 2008). The solid line indicates 1:1 relationship.

Simulation for dry season soil moisture dynamics: The calibrated ORYZA2000 model was used to simulate the top layer soil moisture dynamics of the coastal area of Bangladesh at the end of dry season from long term (1985 - 2004) weather data. Soil moisture dynamics in the top layer (0 - 5 cm) from 1 April to 31 May is shown in Fig. 3.

Initial soil moisture content was preset between air dry moisture and permanent wilting point at the starting time (1 April) of the simulation. In silt loam soil rice seed emerged well in field capacity to saturation level moisture content. The study assumed that the aus rice has the highest emergence possibility at halfway between wilting point and field capacity because site soil is silty clay in texture. It was observed that dry seeded aus rice can emerge well after 26 April with 75 % confidence as the lower quartile (Q1) reached filed capacity. Median of soil moisture content reached to field capacity (40 % moisture content) level on 21 April, indicating rice has 50 % chance to be well emerged if seeded on 21 April. The upper quartile (Q3) reached to field capacity on 16 April, indicating emergence of 25 % insurance while the seeding date is earlier than 16 April.

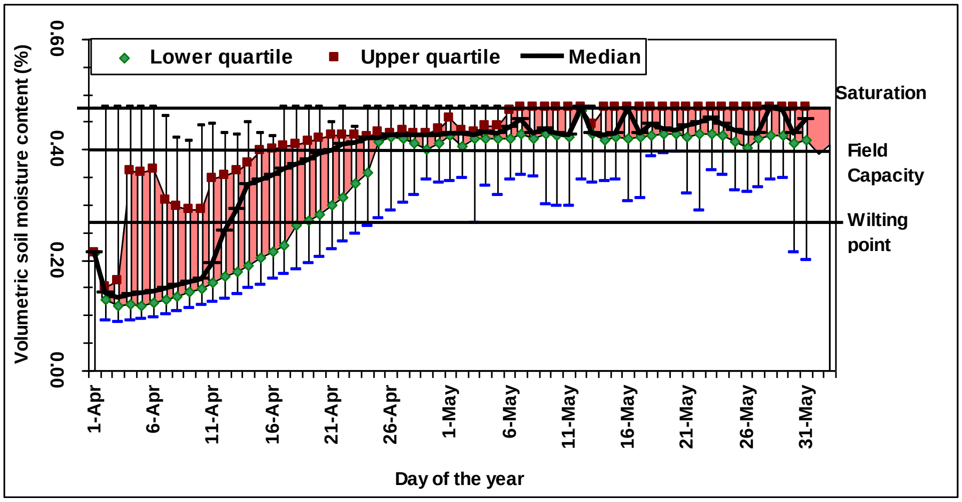

Fig. 3. Volumetric soil moisture content (%) of the top layer (0 - 5 cm depth) in fallow land during April - May at lower quartile (Q_1), median and upper quartile (Q_3) in polder 30. Shaded area is between upper and lower quartile.

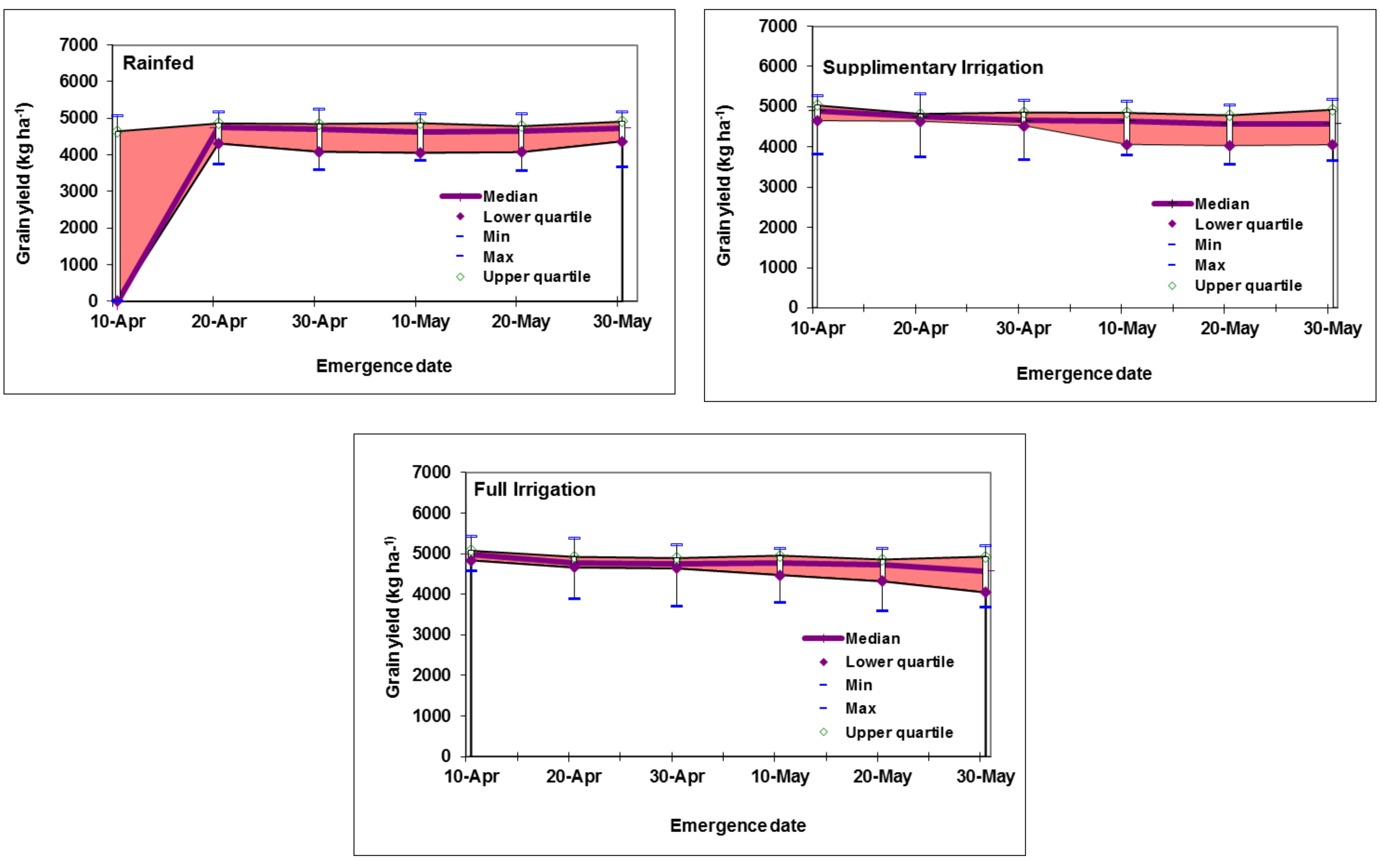

Fig. 4. Simulated grain yield (kg ha^{-1}) by ORYZA2000.

Scenario analysis for yield and water requirement: Long-term (1985 - 2004) yields of aus season rice in the coastal area of Bangladesh estimated by ORYZA2000 under six different emergence date (10 April, 20 April, 30

April, 10 May, 20 May and 30 May) and three water regimes (rainfed, supplementary irrigation and full irrigation) are shown in Fig. 4. It expresses the lower quartile (Q_1), median and upper quartile (Q_3) of direct seeded aus rice. Shaded area in the whisker box remain between upper and lower quartile. Fig. 4 appears that median (with 50 % probability of exceedance) rice yields were about 5 t ha^{-1} at all emergence dates and water regimes except rainfed seeding on 10 April. It indicated that late emerged (or late seeded) (30 May) crop was comparable to that of early emerged (10 April) crop under irrigated condition and seeding on or before 10 April is not suitable under rainfed condition.

Interaction of emergence date and water regimes on long term simulated rice yield was highly significant (Table 3). Emergence date and yield under all water regimes were not significantly different except early seeded rainfed rice. Simulated long-term grain yields showed wide variability from actual yield from seeding dates 10 to 30 April under different water regimes (RF, SI and FI) and three cropping seasons (2006 to 2008) (Fig. 4). Under rainfed condition simulated yield was closer to the measured yield in seeding date 30 April, 2006 at 50 % probability of exceedence. It was also closer in 10 April at 25 % probability of exceedence and 20 April at 50 % probability of exceedence during cropping season 2007. Simulated yield gave closer estimates in 30 April, 2006 and 10 and 20 April under supplementary irrigation during cropping season 2007. Under full irrigation, simulated and measured yields were closer in 20 and 30 April 2007, for other two years the model over estimated the measured yields. Under favorable condition, when rice crop was free from any pest or diseases and submergence, model simulated the yield quite well. But the model did not consider the yield loss of rice crop due to submergence or pest attack and over estimated during those events.

Table 3. Level of significance of aus rice for long-term (1985 - 2004) yield and irrigation as affected by emergence dates and different water regimes.

Effects	Grain yield (kg ha^{-1}) P>F	Irrigation (mm) P>F
Water regimes (I)	<0.001	<0.001
Seeding dates (D)	<0.001	<0.001
I*D	<0.001	<0.001

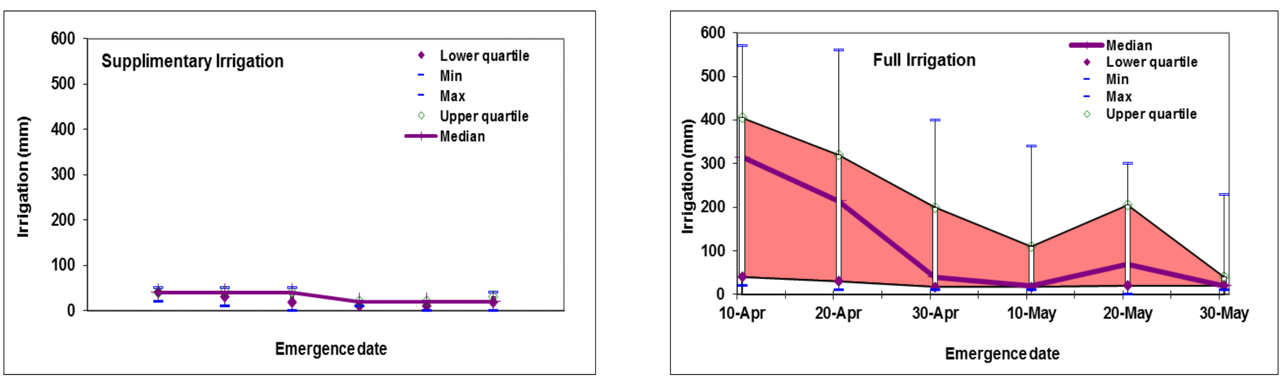

Fig. 5. Simulated irrigation water applied (mm).

Simulated irrigation water applied under supplementary irrigation and full irrigation is shown in Fig. 5. It showed that irrigation amount was almost similar in both supplementary irrigation and full irrigation from the emergence date (30 April) to onwards, because of enough rainfall at later seasons. The interaction of water regimes and date of emergence was highly significant on amount of irrigation water applied (Table 3). Irrigation amount was higher enough in 10 April and 20 April under full irrigation than supplementary irrigation. The simulated median value of supplemental irrigation water for emergence dates from 10 to 30 April was only about 50 mm which was 2 to 3 times lower than the measured water applied. The difference was probably caused by the high actual seapage and percolation (S & P) during April and May, while the simulation used the season-average values of S & P. Under full irrigation, simulated irrigation water requirement was almost similar as the measured irrigation water input in first two emergence dates during 2006 and 2007 cropping season. But it was more than 60% higher compared to the cropping season of 2008. This indicates that applied water was less than the requirement in cropping season of 2008. The median values of irrigation amount were declined from 300 mm for emergence date of 10 April to 50 mm in D_1 of cropping season 2006. But simulated irrigation amount was 0.5 to 0.2 of the measured water applied in all three cropping seasons applied in seeding date of 30 April. Because model considered average rainfall amount from long term data of May but the variability of rainfall in May during the cropping seasons made the difference between the measured and simulated irrigation water amount.

The aus rice experiments were conducted in the polder areas of the south-west coastal zone of Bangladesh (Polder 30 in Batiaghata, Khulna) during 2006 - 2009 under different scenarios of water management (rainfed only, supplemental irrigation during crop establishment, full irrigation throughout the crop season) and different timing of crop establishment. The field experiments were supported by a simulation study using the crop model ORYZA2000 and long term climatic data (from 1985 – 2004) to determine optimum establishment time of the aus crop and its water requirement if irrigation is provided to ensure the aus crop attaining its yields under well watered condition.

The effects of seeding dates and water treatments in the experiments varied from year to year as rainfall at the beginning of the rainy season varied greatly. Simulation with crop model ORYZA2000 proved to be very useful in supporting the experiment results in such variable environment. Once validated, and with long term weather data, the model can provide better knowledge on yield stability, probability of crop establishment success and water requirements of the aus crop under different irrigation regimes.

Seeding in early April exposed the seeds to higher risk of drought, seed could emerged in one out of four years. In areas without suitable water for supplementary irrigation, seeding of aus rice can be delayed until 10 May, followed by transplanting during 1st week of June. This would allow the sustained and steady rainfall to flood the main field before transplanting.

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