INCREASING IRRIGATED RICE PRODUCTION AND WATER PRODUCTIVITY IN COASTAL AREAS OF BANGLADESH

AUGMENTER LA PRODUCTION DU RIZ IRRIGUE ET LA PRODUCTIVITE DE L'EAU DANS LES REGIONS COTIERES DU BANGLADESH

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ABSTRACT

Quantifying water requirement and water productivity is important to determine whether dry season rice (Boro rice) crop can be grown in large scale in the coastal Bangladesh. This study used a two-season field experiment to parameterize and evaluate the model ORYZA2000, which was then used to quantify probabilistic yields and water requirements of Boro rice over a 20 year period in a typical coastal polder. The dimensions of canal networks within the polder were measured to quantify their capacity to store water for irrigation when river water became saline. Rice crop planted in October suffered from cold temperature, resulting in low harvest index (HI). Oryza2000 simulated satisfactorily the leaf area index, total biomass, evapotranspiration and water requirement of Boro rice. Rice planted in November yielded satisfactorily (~5 tons ha^{-1}). Delaying the planting after 10 November did not result in yield gain but increased the water requirement from the canal storage substantially. Optimum planting time for highest water productivity with respect to storage water was from 1 to 10 November. At probability of exceedence (P_e) of 50%, the area of boro rice that can be irrigated from water storage was about 16% of the cultivatable land area of the polder, which can be increased to 40% if the canals are dredged.

Key words: *Dry season (Boro) rice, ORYZA2000 model, Polder, Irrigation water requirement, Bangladesh.*

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RESUME

La quantification des besoins en eau et la productivité de l'eau sont les facteurs importants pour déterminer si le riz (boro) de la saison sèche peut être cultivé à grande échelle dans les régions côtières du Bangladesh. Cette étude utilise une expérimentation menée sur le terrain dans deux saisons pour décider les paramètres et d'évaluer le modèle ORYZA2000 utilisé pour quantifier les rendements probabales et les besoins en eau du riz Boro durant une période de 20 ans dans un polder typique côtier. Les dimensions des réseaux de canaux dans le polder sont calculées pour quantifier leur capacité de stocker l'eau pour l'irrigation lorsque l'eau du fleuve est devenue saline. Le riz planté en octobre était affecté par la température froide, résultant en faible indice de culture (HI). L'Oryza2000 a simulé de façon satisfaisante l'indice de surface foliaire, la biomasse totale, l'évapotranspiration et les besoins en eau du riz Boro. Le riz plané en novembre a donné un rendement satisfaisant (~ 5 tonnes ha-1). Le retard dans le semis après le 10 Novembre n'a pas augmenté le rendement, mais a augmenté les besoins en eau stockée du canal. La période du 1 au 10 novembre était optimale pour le semis concernant la haute productivité de l'eau par rapport à l'utilisation de l'eau stockée. A la probabilité de dépassement (Pe) de 50%, 16% de la superficie cultivable du polder était utilisée pour cultiver le riz boro utilisant les eaux du réservoir, qui peut être augmentée à 40% si les canaux sont dragués.

Mots clés: *Riz (Boro) de la saison sèche, modèle ORYZA2000, Polder, besoins en eau d'irrigation, Bangladesh.*

1. INTRODUCTION

1.1 Background

Agriculture is the single most important sector of Bangladesh's economy; engaging 80% of the population and 60% of the labour force. The present food grain production being less than requirements, Bangladesh faces an enormous challenge in trying to achieve food self-sufficiency for its growing population. The coastal zone of Bangladesh covering an area of 2.83 million hectares is the least productive in terms of agriculture and has potentials for development. Mondal, et al., (2006) showed that with proper water management, additional *Boro* (dry season or winter) rice could be grown after the *Aman* (wet season) rice in the coastal polder areas, giving an additional yield of about 3.5 t ha^{-1}. The introduction of the *Boro* rice in the area involves two distinct stages of irrigation. The first stage is gravity irrigation by letting river water in through sluices utilizing the river water head at high tide (when EC of water < 4dS m^{-1}, usually before mid-February). The second stage is irrigation by pumping canal water when the river water salinity > 4dS m^{-1}. River water could be taken into and stored in the on-farm canal network before the water becomes too saline. The possibility of large scale adoption of *Boro* rice cropping and increasing water productivity has not been systematically investigated. How large the area and where the technology can be applied, depends on several factors: (i) the water requirement of the Boro rice crop, (ii) determination of optimum planting time for better yield of crop, (iii) the storage capacity of the internal canal networks of polder, and (iv) the time when river water becomes too saline for irrigation.

There have been no detailed studies on water requirement of the *Boro* rice crop in the coastal areas of Bangladesh, especially in relation to yield and planting time to avoid cold stress during flowering. Due to cost and time limitations, field experiments could not be carried out for long periods of time to cover different combination of effect of climate on yield and water requirement. Bouman, et al., (2001) demonstrated that the crop model ORYZA2000, after validation at the local conditions, can be used to predict rice yield under different times of crop establishment, water supply and the prevailing agro-climatic condition of the area. The crop model might be used in determining appropriate times of *Boro* rice crop establishment and water requirements in the polder areas of Bangladesh. The irrigated area could also be increased by increasing the storage area of the canal through widening and deepening, excavating new canals and ponds/ditches, etc., but needed field studies.

1.2 Objectives of the Study

The main objective of the study was to determine the potential for increased *Boro* rice production in the polder areas in the coastal zones of Bangladesh through effective utilization of the available land and water resources. The specific objectives of the study were :

1. To determine the yield and water requirement of Boro rice crop under different times of crop establishment and varieties.
2. To determine the storage capacity of the internal hydraulic system of the Polder 30 from field survey data and data from Bangladesh Water Development Board (BWDB).
3. To quantify, using ORYZA2000, the probabilistic rice yields and water requirements of irrigated *Boro* rice for different dates of crop establishment and to determine the most appropriate rice cropping calendar for increasing water productivity, and
4. To quantify the area that can be grown with *Boro* rice cropping through effective management of the available land and water resources under the prevailing agro-climatic conditions in the polder area.

1.3 Methods

The study site (Polder 30) is located in Batiaghata Upazila (sub district) in Khulna district in south western Bangladesh. The Polder 30 lies between latitude 22^0 37' 00'' and 22^0 46' 00'' N and longitude 89^0 27' 00'' and 89^0 33' 00'' E. The gross area of the polder is about 7,725 ha with a net cultivable area of about 4,867 ha (IPSWAM, 2007). The polder is protected from high tide by an embankment 40 km long and 4.3 m wide at the crest. The water level of the rivers fluctuates daily due to tidal effects. During high tide, the water level could rise 1 to 2.8 meters above the general land elevation, creating opportunities for gravity irrigation in both wet and dry seasons.

The research was organized to accomplish three key important activities, 1) field experiments for yield and water requirement determination of HYV *Boro* rice at different times of crop establishment; 2) probabilistic yield and water requirement determination of *Boro* rice through the ORYZA2000 crop simulation model; and 3) possible storage capacity assessment of the internal hydraulic system of Polder 30 as schematically shown in Figure 1.

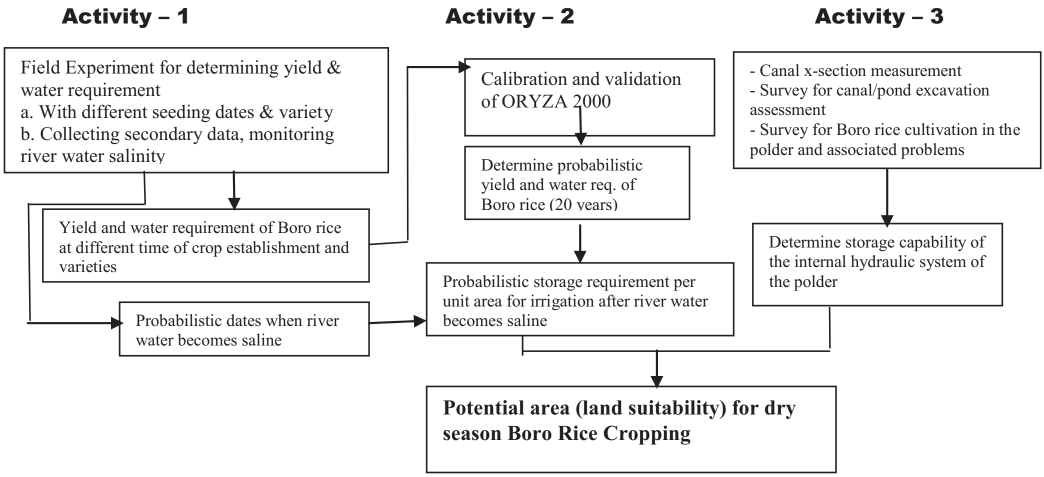


Fig. 1. Flow chart of the key research activities in the coastal zone of Bangladesh.

Samples of the surface soils (0 to 15 cm depth) of each block were analyzed for major elements and salinity in established soil laboratory in Bangladesh.
The experimental treatments were :

Main-plot factor : Date of Crop Establishment (4)

D_1 = Seeding on 22nd October, D_2 = Seeding on 1st November

D_3 = Seeding on 7th November, D_4 = Seeding on 15th November

Sub-plot factor : Variety

V1 = BRRI dhan 28 (popularly known as BR-28) and V2 = PVS B8

Seedlings were transplanted at 3 to 4 seedlings per hill at a spacing of 20 cm x 20 cm when 4 leaves were seen on 9, 21, 30 November and 11 December in D_1, D_2, D_3 and D_4 treatments at seedling ages of 18, 21, 23 and 27 days respectively. Two 1m x 1m GI tank (40 cm height and 22 gauge thicknesses), one with bottom and one bottomless, were installed in the sub-plots of 4 main plots for the measurement of evapotranspiration (ET) and percolation (P). Water subsidence technique was used in determination of ET and P rates. Same irrigation water depth was applied in the GI tanks as that of the main field. V-notch was used to measure the irrigation water applied in the field. Pan evaporation method was also used for ET determination from recorded evaporation data from one USWB evaporation pan installed in the field.

Crop Data Measurement was carried out for crop phenology, sequential biomass, leaf area index (LAI), yield components and grain yield following standard procedures. The data were analyzed with standard split-plot analysis of variance (ANOVA) techniques with date of seeding as the main factor and variety as the sub-plot factor. The least significant difference (LSD) test was used to compare significant differences between treatment means. The level of significance was set at 5% level in all cases.

The ORYZA2000 was parameterized and calibrated with the experimental data of 2006-07 *Boro* rice for D_3 treatment following the procedure described by Bouman and Van Laar (2006). After parameterization and calibration the model was evaluated using 2006-07 *Boro* rice crop experimental results for rest of the seeding dates (D_1, D_2 and D_4) and 2005-06 *Boro* rice crop experimental data sets. Computation for slope (X), intercept (ß), and coefficient of determination R^2 of the linear regression between simulated (Y) and measured (X) values of total above ground biomass and grain yield were done. A model simulated experimental site data best when α is close to 1, ß close to 0 and R^2 close to 1. The third step involved long term (20 years) scenario analysis for different seeding dates of *Boro* rice in the coastal areas of Bangladesh. Eight different crop seeding dates, starting from 15 October and after every five days interval and two experimental rice varieties (BR-28 and PVS-B8) were used to run the model simulation.

2. STUDY RESULTS

2.1 Crop Output

The harvest index was very low for the 22 October seeding (only 0.07 to 0.08) in 2006-07. The harvest index was significantly higher for 07 and 15 November seeding in 2006-07 than in 2005-06 (Figure 1). The differences in average grain yield between varieties and interaction effect was significant in both the seasons. Grain yield varied from 2,709 kg ha^{-1} to 5,630 kg ha^{-1} with the highest yield in 07 November seeding for variety PVS-B8. The highest yield for variety BR-28 was 5,591 kg ha^{-1} for 15 November seeding. The lowest yield of 2,709 Kg ha^{-1} was observed in 22 October seeding for variety BR-28. The average yield of variety BR-28 was significantly higher than the variety PVS-B8 (Table 1). Like grain yield, all the yield components were severely affected in D_1 and partially in the D_2 treatments resulting to significantly lower yields than that of the D_3 and D_4 treatments. The rice crop yield was negatively affected by low temperatures at the reproductive stage (panicle initiation to flowering).

Table 1. Yield of Boro rice in the study site at Batiaghata,

Seeding Dates	2005-06 Cropping Season			2006-07 Cropping Season		
	Variety			Variety		
	BR-28	PVS-B8	Difference	BR-28	PVS-B8	Difference
22 Oct (D_1)	2709 c[1]	4027 b	*	703 d	940 d	ns
01 Nov (D_2)	4943 a	3161 c	*	2394 c	2878 c	*
07 Nov (D_3)	5006 a	5630 a	ns	5036 a	5218 a	ns
15 Nov (D_4)	5591 a	4226 b	*	4501 b	5111 a	*

1 In each column and each season, means followed by the same letter are not significantly different at the 5% level using LSD. Mean values are averaged over 4 replications in each crop growing season.

* = Significant at 5% level by LSD, and ns = not significant.

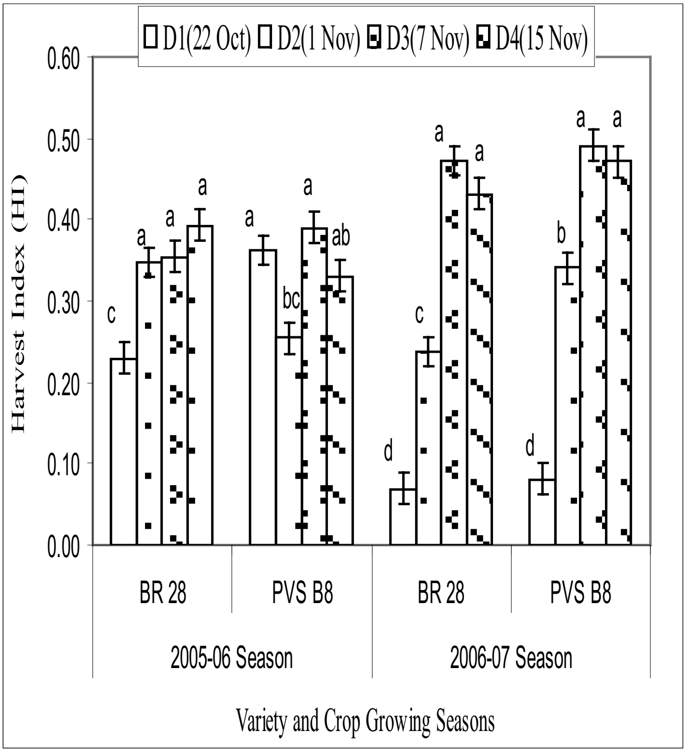


Fig 1. Harvest index of Boro rice crop

2.2 Irrigation Water Requirement

The average total amount of water required in 2006-07 varied from 621 to 761 mm in the study site. The 22nd October seeding (D1 treatment) required significantly lower water amounts than the other treatments in 2006-07. The average total amount of water required in 01, 07 and 15 November seeding were in the increasing order. The highest water requirement was 761.3 mm in last seeding (D_4 treatment) in 2006-07 in the study site. Higher amount of water required from the canal storage for late planting crops and similar situation observed in both the seasons. The water productivity varied widely among the different seeding dates and very low water productivity was observed for the 22 October seeding in 2006-07 (0.15 g kg^{-1}). The highest water productivity was for the 07 November seeding (0.7 g kg^{-1}) for both rice varieties. Irrigation water input from the canal water storage increased from 30% in the 1st seeding (D_1) to around 60% in last seeding (D_4). The difference of maturity period for first and last seeding crops was about 15 days; but almost twice the amount of irrigation water was taken from the canal storage in last seeding compared to first seeding (Table 2). River water remained suitable for irrigation (EC of water < 4.0 dS m^{-1}) until the end of January and the 1st seeded crops availed of the maximum opportunity to source the water directly from the river. Because of late planting, the last seeded plots had a higher dependency on canal storage water to meet the irrigation water demand after January until end of the crop season in April.

Table 2. Total water input (mm) for Boro rice cultivation in Polder 30, Batiaghata, Khulna, Bangladesh.

Seeding dates	Land Prep. Water	Irrigation Water Input			Rainfall	Total Water Input	Water Productivity (g kg^{-1})
		River Water	Storage water	Total			
2005-06 crop growing season							
22 Oct (D_1)	NA	348.6 a[1]	147.0 c	495.6 a	15.8	--	--
01 Nov (D_2)	NA	268.8 b	202.3 b	471.1 a	15.8	--	--
07 Nov (D_3)	NA	238.2 b	220.2 b	458.4 a	15.8	--	--
15 Nov (D_4)	NA	179.4 c	268.7 a	448.1 a	15.8	--	--
2006-07 crop growing season							
22 Oct (D_1)	31.5	351.4 a	142.7 c	494.1 a	95.6	621.2 b	0.11 (V_1) 0.15 (V_2)
01 Nov (D_2)	80.5	322.7 ab	223.1 b	545.8 a	95.6	721.9 a	0.33 (V_1) 0.40 (V_2)
07 Nov (D_3)	129.7	265.7 bc	267.8 a	533.5 a	95.6	758.8 a	0.66 (V_1) 0.69 (V_2)
15 Nov (D_4)	172.8	214.6 c	278.3 a	492.9 a	95.6	761.3 a	0.59 (V_1) 0.67 (V_2)

1 In each season and in each column mean values followed by same letter are not significantly different at 5% level by LSD. Mean values are averaged over 4 replications and NA means not available. V_1 = variety BR-28, and V_2 = variety PVS-B8.

2.3 Water Storage and Availability

The storage capacity of the canal system as determined under the present silted condition is estimated that out of 2,592,164 m^3 of total canal system volume, about 2,137,445 m^3 will be available for the storage of irrigation water for dry season use. If the canals are dredged, total storage will increase to about 6,968,897 m^3 from 2,592,164 m^3 under the present silted situation, or a 268% volume increase. The available volume for irrigation water storage will increase to 5,575,118 m^3 from 2,137,445 m^3 (261% increase in storage capacity). This will also meet minimum water demand for fish cultivation in all the canals. The long-term salinity data analysis and the probability results indicated that the river water can be safely be used for irrigation until the 1st week of February which can be extended to the 2nd week at moderate levels of risk. The safe period for storage of river water within the hydraulic system of Polder 30 is the 1st week of February.

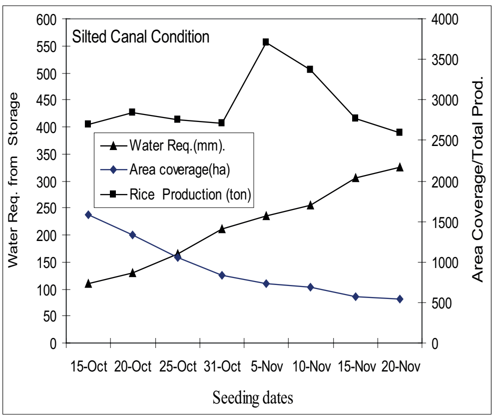
2.4 Model Operation

ORYZA2000 model found to fit well for the study site in Batiaghata, Bangladesh in respect of LAI, total biomass and ET except grain yield. Grain yield computed from total biomass using the relationship of harvest index (HI) with minimum temperature from panicle initiation to flowering.

The highest simulated mean yield was for the 05 November seeding (4,900 kg ha^{-1} for BR-28 and 5,116 kg ha^{-1} for PVS-B8). The lowest simulated mean yield was for the 15 October seeding (1,583 kg ha^{-1} for BR-28 and 1,830 kg ha^{-1} for PVS-B8). The long-term water productivity at 50% PE for storage water of the polder appears to be highest for the 05 November seeding for both rice varieties. This is almost equal to the water productivity in of the 10 November seeding. There is lower water productivity for earlier seeding and late seeding relative to 05 - 10 November, due to low grain yield and higher water requirements respectively.

2.5 Future Potentiality

Under the present silted condition of the canal networks, the highest potential area coverage is 1,581 ha (33% of net and 63% of potential area) for first seeding in 15 October. For the dredged canal scenario, the potential area increases to 2,500 ha which is 84% coverage of net area for first seeding in 15 October (Figure 4). Considering the most appropriate seeding periods for Polder 30, i.e., 01 to 10 November, the mean expansion area for Boro rice is 750 ha (16% of net area and 30% of PA) and 1,924 ha (40% of net area and 77% of polder area) respectively, under present silted and moderate dredged condition of the canal network with due consideration to fish cultivation water needs. If 20% losses of water from the canal networks is assumed, total *Boro* rice production is expected to increase by 3,700 metric ton and 9,500 metric ton under silted and dredged condition of the canal for the desirable seeding periods (Figure 4).



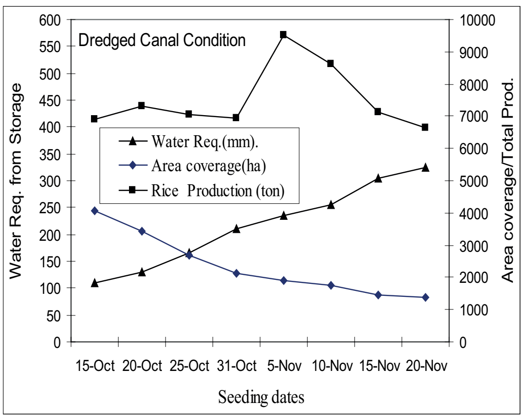


Fig. 4. Long term (1985-86 to 2004-05) irrigation water requirement (mm) from polder storage, expected *Boro* rice area coverage (ha) and total rice production (m ton) at 50% probability of exceedence in the study site area under present silted condition, and dredged condition of the canal networks

3. CONCLUSIONS AND RECOMMENDATIONS

3.1 Conclusion

Experimental results and long-term simulation analysis using ORYZA2000 identified 01 to 10 November as the optimum planting time for *Boro* rice in Polder 30 to obtain the highest rice yields and consequent higher water productivity. Seeding before November are susceptible to very low yields due to cold stress at the critical reproductive stages of *Boro* rice (from PI to FL). On the other hand, late-seeding (starting from 10 November) will not limit yield but constraints on water availability and suitability will greatly reduce the irrigated area coverage. Low salinity river water needs to be stored in the canal system of the polder within January. Irrigation using river water may be continued safely until the 1st week of February which may be extended to the 2nd week if salinity levels permit (EC of river water < 4 dS m^{-1}). The storage capacity of the polder canal system could provide the required quantities of irrigation water during critical latter part of the crop seasons (from 2nd week of February until harvest) when river water becomes too saline. The storage capacity of the polder could be greatly increased through moderate levels of dredging of the silted canals. In turn, this will significantly increase the cultivable area of irrigated *Boro* rice in the polder areas.

3.2 Recommendations

Based on the study results, the following are recommended for to expand the irrigated Boro rice crop area in the polders of the coastal regions of Bangladesh.

1. *Boro* rice crop should be planted during 01 to 10 November periods to avoid grain loss from cold temperature effects and to ensure satisfactory levels of grain yield.

2. The silted up canals should be dredged to required depths and width to increase the storage capacity of the canal system in each polder. This in turn will increase the area planted to irrigated *Boro* rice.

3. Storage of low-saline river water (EC < 4 dS m^{-1}) within the canal system of the polder should be completed within January.

4. The use of river water for irrigation should be completed within the 1st week February after evaluating the EC level of river water (should be < 4 dS m^{-1}).

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