J. Sylhet Agril. Univ. 3(1):101-112, 2016 **ISSN: 2308-1597**

INCREASING CROP PRODUCTIVITY THROUGH DOUBLE CROPPING IN COASTAL REIGION

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Abstract

Agricultural land in coastal zone of Bangladesh grows a low yielding single rice crop (*aman*) during the rainy season, due to lack of fresh water in dry season. To develop a double rice cropping system with an *aus* crop grown at the onset of the rainy season followed by an *aman* crop, a field experiment was conducted during 2006 - 2008 at Batiaghata in Khulna, to test the hypothesis that high system productivity can be achieved by: (i) dry seeding a short-duration *aus* variety and applying supplemental irrigation during establishment, and (iii) transplanting a high-yielding *aman* variety after harvest of the *aus* crop. Treatments in *aus* season included three water regimes, i.e., rainfed ($I_{1)}$; supplemental irrigation (I_2), full irrigation (I_3) and three sowing dates viz. early-April (D_1), mid-April (D_2), late-April (D_3). In *aman* season, two high yielding varieties namely BR11 and BRRI dhan53 were evaluated. Yields with full and supplemental irrigation were comparable (4 t ha^{-1}) and were greater than those of fully rainfed *aus* (2 t ha^{-1}) when there were dry spells after sowing. Supplemental irrigation required much less irrigation water (100 - 200 mm) than full irrigation (660 - 1042 mm) but had similar yield. The average incremental irrigation water productivity varied from 0 to 1.3 kg grain ha^{-1} mm^{-1}. Delayed planting of *aman*, decreased the growth duration of BRRI dhan53 and reducing yield compared to yield of earlier transplanting. The duration of BR11 was less affected by sowing date and had similar yield level (> 4 t ha^{-1}) to that of BRRI dhan53 with early April sowing. Under favorable conditions, *aus-aman* cropping system yield ranged from 8.0 to t ha^{-1} yr^{-1}.

Keywords: Cropping system, direct seeding, dry seeding.

Introduction

Agricultural lands in the coastal zone of Bangladesh has less productive due to soil and water salinity in dry season, waterlogging during monsoon and lack of knowledge of modern agricultural interventions (Karim *et al.*, 1990). The salinity constraints are acute and widespread in the south west coastal zone (SWCZ) in Khulna Division. Farmers in the SWCZ usually cultivate low-yielding (2.5 t ha^{-1}) traditional *aman* varieties in the monsoon season.

The coastal area is affected by soil and water salinity in the dry season, thus reducing the scope of crop production and resulting in low cropping intensity (Mondal, 1997). Soil salinity and lack of fresh water for irrigation force the farmers to keep their land fallow in the dry (*boro*) and pre-monsoon (*aus*) seasons. Therefore, most of the coastal rice land in Bangladesh is utilized to grow with rice in monsoon season (*aman*). The local varieties of rice, cultivated under rainfed conditions give low yields (2 - 3 t ha^{-1}).

Some farmers grow nonrice crops such as sesame in the dry season, but these are often damaged (Mondal *et al.*, 2006) by heavy rainfall in March or April and by the poor drainage capacity of the soil. Once in approximately 3 years, farmers usually face total crop loss.

Advances in agricultural science and technology offer opportunities for increasing rice production especially through increased cropping intensity in the SWCZ of Bangladesh. These include the use of high-yielding, early-maturing, and

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abiotic stress-tolerant rice varieties along with techniques for effective management of water and fertilizer (Chowdhury, 1999). Several attempts have been taken to improve the productivity of SWCZ, either by improving existing cropping systems or establishing new ones. The cultivation of HYVs in the wet season was introduced in 2001 in the southwest region replacing the low-yielding local *aman* rice, where yield of HYV was at least doubled and growth duration was reduced. The short duration of *aman* also facilitated early dry-season rice establishment (Mondal *et al.,* 2004; Karim and Mimura, 2006). However, the expansion of this cropping system is constrained in the coastal zone due to limited amount of fresh water that can be stored in the canal networks to grow a *boro* crop. Another risk is salinity if the sluice gates are not properly closed and if the river water becomes saline (Mondal *et al.,* 2015).

Experience elsewhere proved that the use of short-duration HYVs with proper crop scheduling that matches crop water requirements with water supply (including rainfall) and water quality dynamics can increase the cropping intensity and productivity of rice lands in the coastal areas (Tuong *et al.*, 1991; My *et al.,* 1997). Dry direct seeding has emerged as a viable alternative to transplanting during rainfed seasons in rice-growing areas where irrigation water is scarce. It makes better use of early rainfall and enables relatively earlier crop establishment and early harvest compared with wet seeding and transplanting. Due to the early harvest, another crop may be grown after the first one. In many rainfed areas, dry direct seeding is instrumental for double cropping of rice during the rainy season, thereby increasing farm productivity (Tuong and Bouman, 2003; Saleh and Bhuiyan, 1995; My *et al.,* 1997; Tuong, 1999).

Thus another option for increasing the productivity of the SWCZ using less irrigation water could be by intensifying an *aus-aman* cropping system. This system is practised in many parts of Bangladesh (SRDI 2004), but not in the SWCZ. The *aus* crop needs to be established early enough so that the *aman* crop can be planted on time for maximum yield. However, early *aus* establishment usually requires irrigation. In the SWCZ, the river water is too saline for irrigation for early (April - May) *aus* establishment.

Dry seeding (direct seeding into dry tilled soil) instead of transplanting into puddled soil may enable early *aus* establishment. In water scarce areas of other parts of Asia, the use of dry seeding has enabled double cropping of rice during the rainy season, thereby increasing farm productivity (Tuong and Bouman 2003; Tuong 1999). Dry seeding enables early crop establishment on the pre-monsoon rains, rather than waiting until there has been enough rain to puddle the soil for wet seeding or transplanting.

Therefore, the present study was undertaken with the hypothesis that with the use of a short-duration dry-seeded HYV *aus* variety followed by HYV *aman* is possible to intensify to a highly productive *aus-aman* system in the SWCZ. Successful implementation would require knowledge of the optimum time for establishment of dry seeded *aus*. In such situations, the use of non-saline groundwater could be used to help establish the crop. But the availability of non-saline groundwater in the coastal zone is limited, and pumping is costly, therefore sowing and management practices that minimize irrigation water requirement would be needed. Most commonly available *aman* varieties in Bangladesh are photoperiod-sensitive; late establishment of those would reduce grain yield. One possible solution is the use of photoperiod-insensitive *aman* varieties.

Therefore, experiments were carried out to test the feasibility of an *aus-aman* cropping system in the SWCZ, and to develop a technology package that would lead to stable and high yield with minimum irrigation water requirement to establish the *aus* crop. The specific objectives were: (i) to evaluate the effects of date and method of *aus* establishment and *aus* irrigation management on the growth and yield of both crops in an *aus–aman* system, (ii) to evaluate *aman* varieties for the *aus-aman* system, and (iii) to determine the effects of sowing date and water management on irrigation water requirement of dry seeded *aus*.

Materials and Methods

Experimental site: Experiment was conducted in Batiaghata upazila of Khulna district during 2006 - 2008 at Basurabad village. The soil at study site was silty clay and fairly uniform to the sampling depth (90 cm), with 45 – 53 % clay and 44 – 54 % silt (Table 1).

The topsoil (0 - 15 cm) of the study site was slightly alkaline, with 2.0 - 2.6 % organic matter (Table 2). Total N content of the topsoil was low at 0.1 %, while available P and exchangeable K content were adequate. Micronutrient content (S, B, Cu, Fe, Mn and Zn) of the topsoil at both sites was low. Haque (2006) also found that most saline soils of the coastal zone have low to very low organic matter, N, P and micronutrient (Zn, Cu) contents.

Table 1. Bulk density and texture of the soil profile.

Depth (cm)	Bulk density (g cm^{-3})	Sand (%)	Silt (%)	Clay (%)	Texture
0 – 15	1.4	1.2	47.8	51.1	Silty clay
15 – 30	1.6	5.2	49.8	45.1	Silty clay
30 – 45	1.5	3.2	53.8	43.1	Silty clay
45 – 60	1.3	3.2	47.8	49.1	Silty clay
60 – 75	1.4	3.2	46.8	50.1	Silty clay
75 – 90	1.4	3.2	43.8	53.1	Silty clay

Table 2. Chemical properties of the top soil (0 - 15 cm) at the experimental site.

	pH	Total N (%)	Organic matter (%)	Exchangeable			Avail. P	S	B	Cu	Fe	Mn	Zn
				K	Ca	Mg							
				(meq[2] 100 g^{-1} soil)			(µg g^{-1})						
Mean	8.0	0.1	2.0	0.4	24.4	3.6	13.8	125	0.7	3.6	20.7	10.3	0.7
SE[1]	0.1	0.0	0.1	0.0	1.3	0.1	2.0	12.8	0.1	0.2	1.5	0.9	0.1

[1]SE = standard error of the mean; [2]meq = mili equivalant

Experimental design: The experiment was designed to evaluate the effects of *aus* sowing date, *aus* irrigation management and *aman* variety on the performance of the *aus-aman* cropping system. For the *aus* crop, a short duration, salt tolerant variety BRRI dhan65 was established by dry seeding, while the *aman* crops were transplanted about 7 days after harvest of the *aus* crops.

Aus treatments

Mainplots: Irrigation (I)
I_1 = rainfed (RF)
I_2 = supplementary irrigation (SI) to ensure adequate soil moisture during crop establishment up to three weeks after emergence
I_3 = full irrigation (FI) throughout the growing season

Subplots: Date of sowing (D)
D_1 = early-April (5 - 10 April)
D_2 = mid-April (10 - 15April)
D_3 = late-April (25 - 30 April)

Aman treatments

Main plots: Variety (V)
V_1 = BR11 (planted in the *aus* I_3 plots)
V_2 = BRRI dhan53 (planted in the *aus* I_2 plots)

Subplots: Date of transplanting (D)
D_1 = 10 August
D_2 = 15 August
D_3 = 30 August

BR11 was selected as it is one of the highest yielding *aman* rice varieties and only slightly photoperiod sensitive, with a nominal growth duration of 145 days. BRRI dhan53 was also selected as it has the same yield potential as BR11, but with 5 days less growth duration.

The *aman* varieties were randomly assigned to the I_2 and I_3 main plots, and transplanting dates were randomized within each *aman* variety in main plot. The I_1 plots were also planted with *aman* crops to avoid border effects. The size of each experimental unit (subplot) in both seasons was 8 m × 6 m. The main plots and internal bunds were 50 cm ×20 cm and 20 cm × 20 cm, respectively, and were compacted to prevent seepage between adjacent plots.

Management practice: The land was ploughed under dry conditions for the dry seeded *aus*, and was puddled for transplanted *aman* crops. The seedbeds for transplanted *aman* rice were prepared in separate places outside the experimental fields (BRRI 2009b).

Basal fertilizers at 60, 40, 10 and 60 kg P_2O_5, K_2O, $ZnSO_4$ and $CaSO_4$ ha^{-1}, respectively, were applied into the soil during the last harrowing of both crops. Urea was applied to both crops at 120 kg N ha^{-1} in four equal splits ─ 15 days after emergence (DAE), mid-tillering (30 DAE), 5 days before panicle initiation (DBPI, 45 DAE), and at heading in the *aus* season, and at basal, mid-tillering (35 days after transplanting, DAT), 5 DBPI (45 DAT), and heading in *aman* season.

Good weed control was achieved in dry seeded rice by applying the pre-emergence herbicide Longstar 25 EC @ 0.2 kg active ingredient (*ai)* ha^{-1} to the moist soil 1 DAS, followed by post-emergence herbicides Ronstar 25 EC and Longstar 25 EC @ 0.2 kg *ai* ha^{-1} after two weeks of emergence, plus hand weeding as needed.

Attacks of insects, pests and diseases were closely monitored and control measure was taken as per needed. Despite these measures, yield loss due to pests and diseases occurred in some treatments in some years.

Monitoring

Soil salinity: Salinity of the topsoil (0 - 15 cm) was determined before each *aus* seeding and at 15 days intervals during the period of *aus* establishment (April - June), and monthly at other times. Electrical conductivity of the saturation extract was determined using the American Society of Agronomy (AAS) and Soil Science Society of America (SSSA) (1982) method at the Soil Resource Development Institute laboratory at Khulna.

Crop performance: Yield components (panicles density, total spikelets $panicle^{-1}$, % filled spikelets, 1000-grain weight on oven dry weight basis) were determined from 16 hills following the procedures of Cassman (1994) and IRRI (1994). Grain yield was determined in 4 m × 2 m areas in the middle of each sub plot during 2006 - 2008. Grain yield was calculated at 14 % moisture content (Gomez 1972).

Irrigation amount: Groundwater (EC<2 dS m^{-1}) was used for irrigation *aus* crop. At each irrigation, water was applied until the topsoil was saturated. The discharge rate of the tubewell was determined by volumetric method (Michael 1978). Total irrigation during the growth of rice was determined by summing the amount of water applied during each irrigation.

Weather data: A manual rain gauge and a USWB Class A evaporation pan were installed near the experimental field and monitored daily from 2006 to 2008. Monthly totals of rainfall and evaporation were calculated. The measured data was compared with long-term data of the study area.

The wet season started in May in all years except 2007, when it started in June, and usually ended between late September and mid-October (Fig. 1). Annual rainfall varied from 1600 mm in 2008 to 2000 mm in 2006, about 80 % of which occurred from June to October, compared with the long term (1999 to 2006) average of 1685 mm. Rainfall was unusually high in July 2006 and September in all years, and unusually low in April in all years except 2007. Evaporation was usually similar to the long term values, except for unusually high evaporation during the relatively dry rainy season (May - August) in 2008. Monthly evaporation ranged from 55 to 65 mm in January and December each year to around 180 mm in May - August of 2008.

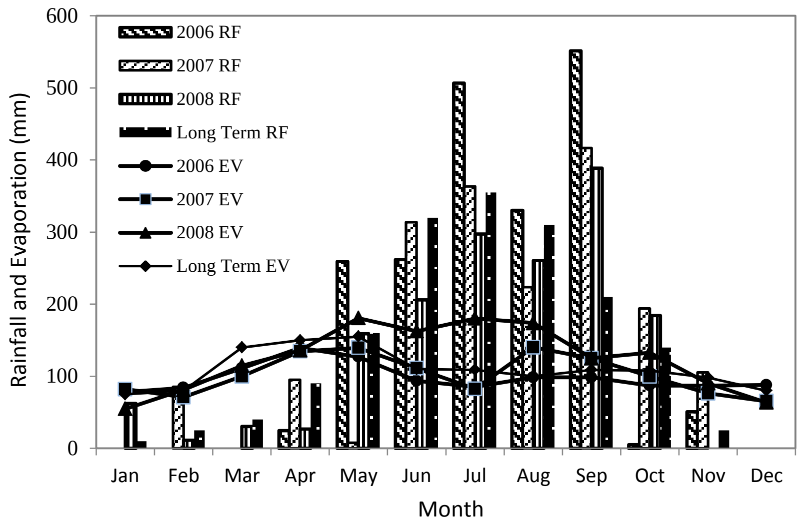


Fig. 1. Monthly total rainfall (RF) and evaporation (EV) in comparison to the long term (1999 - 2006) data for Khulna City.

Results and Discussion

Soil salinity: Top soil EC generally varies from about 4 to 6 dS m^{-1}, with higher values in April and June 2007 as a result of the late onset of the monsoon rains (Fig. 2). Salinity decreased to 2 - 3 dS m^{-1} during the rainy season in some but not all years.

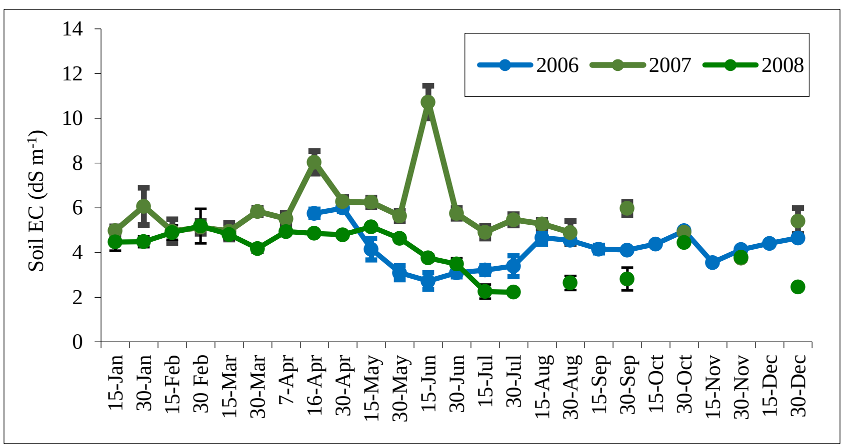


Fig. 2. Top soil (0 - 15 cm) EC (dS m^{-1}) of the study area during the study period (2006 - 2008). Vertical capped bars are standard errors of the means.

Effect of sowing date and irrigation method and establishment method on *aus* crop performance

Insect, pest and disease infestation: For irrigated dry seeded *aus*, soil moisture fluctuated between saturated and field capacity most of the time during the early establishment period. This created a conducive environment for soil pests (cutworms and ants). Whenever the soil surface became dry, insects were visible in the field. Cutworms cut the roots of the young plants and the problem only became visible when the hills became yellowish, and ants removed the sown seed. Severe cutworm damage occurred in the irrigated treatments of the early sown (D_1) 2007 *aus*. Severe infestation also occurred in all sowing date treatments in the 2008 cropping season, mainly affecting I_3. Repeated application of systemic insecticides at double the usual rate did not stop the attack in 2008, probably due to adulteration of the insecticide. In *aus* 2006, cutworms were not a problem, probably due to the higher rainfall in May.

Yield and yield components: Grain yield of the sowing date by irrigation management treatment combinations ranged from 1314 to 4486 kg ha^{-1} (Figs. 3a - c). Yields in 2008 were generally lower than in the other two years due to less rainfall and pest infestation. The interaction between water regime and sowing date on all yield components and grain yield was not significant (P=0.05) in 2006 and 2008, but was significant in 2007. In 2006 and 2008, grain yield was significantly affected by sowing date, but not by irrigation treatment. The response to irrigation treatment and sowing date was variable depending on the incidence and amount of rainfall each year, and of flooding. Under favourable conditions (adequate water, no submergence or water stagnation, no severe disease or pest infestation), yield was similar for all sowing dates and around 4500 kg ha^{-1}.

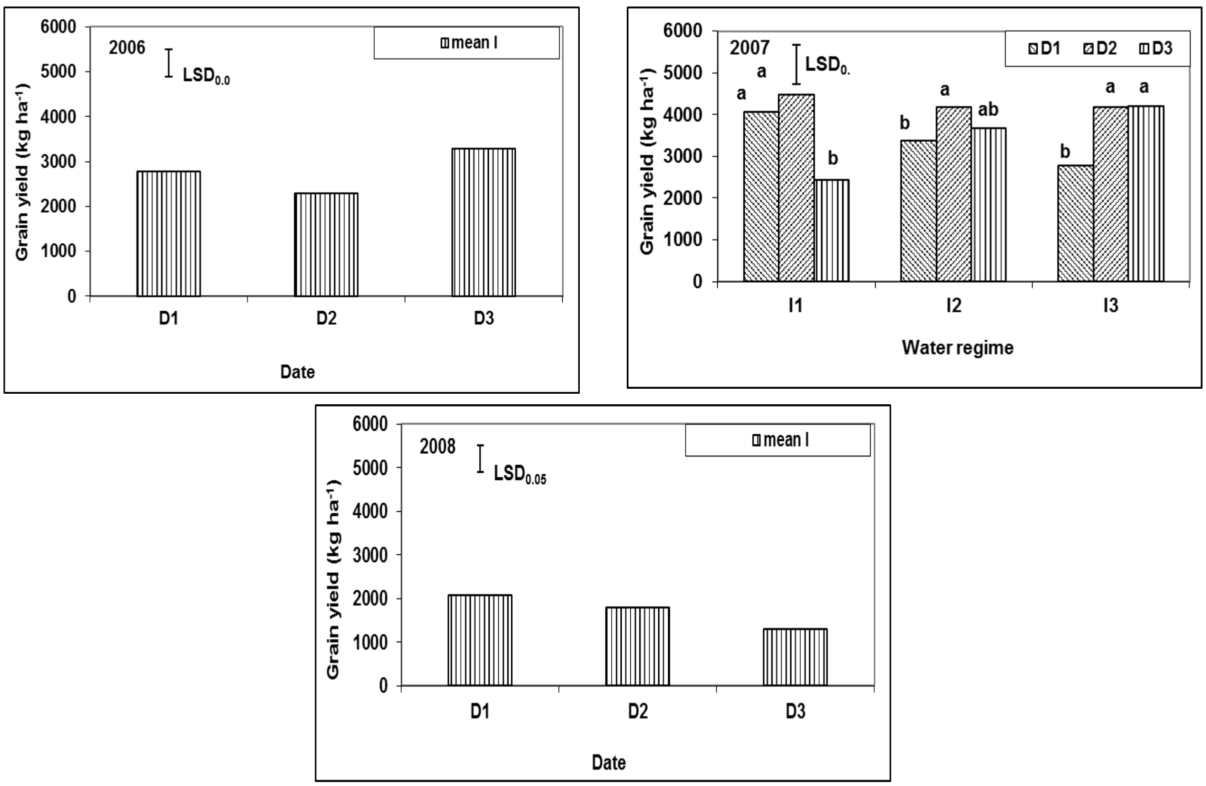


Fig. 3. Grain yield of *aus* rice in 2006, 2007 and 2008 as affected by sowing dates (D_1 = early-April, D_2 = mid-April and D_3 = late-April) and irrigation (I_1 = rainfed, I_2 = supplementary irrigation, I_3 = full irrigation). Vertical bars are the LSD (P=0.05) for seeding dates in 2006 and 2008, and for the interaction between seeding date and irrigation treatment in 2007.

There was a consistent trend for the irrigated treatments to have higher yields than rainfed treatments in years when the rice was seeded during dry spells, with significant differences in 2007. This was due to low panicle density (Table 3) of the rainfed treatments in the absence of adequate rainfall.

Higher plant density resulted in higher yield, except when submergence occurred due to high rainfall in July 2006 (Figure 1) at critical stages (in I_2 D_2 and I_3 D_2 of 2006) and when pest damage occurred (all irrigation treatments of $D_1$2007 and D_1 2008).

Submergence of the second sowing of both irrigated treatments in 2006 tended to reduce panicle density and/or the number of spikelets panicle^{-1}.

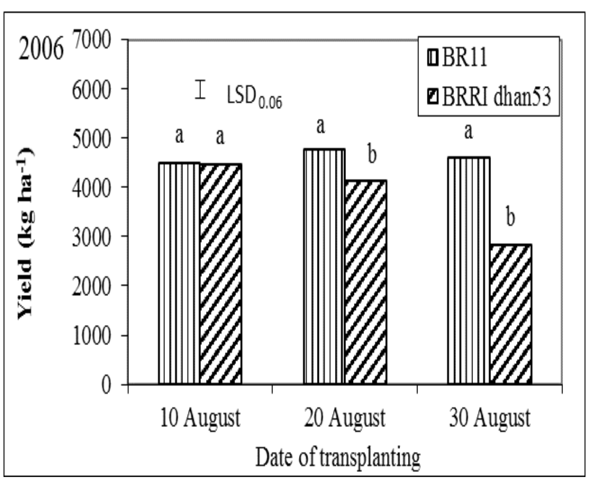
Table 3. Effect of sowing date and water regime on panicle density, number of spikelets per panicle, percent filled grain and thousand grain of *aus* rice (2006 - 2008).

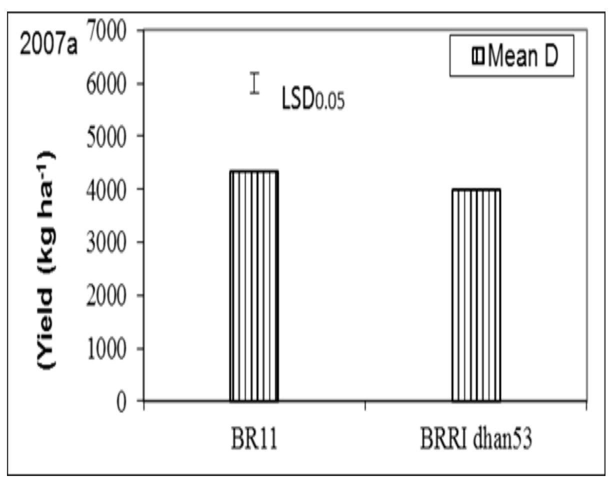
	2006 cropping season					2007 cropping season				2008 cropping season			
	I_1[3]	I_2	I3	Mean D		I1	I2	I3		I1	I2	I3	Mean D
Productive panicles (m^{-2})													
$_1^1$	138 b[4]	212 b	224 a		D_1	357 a	323 ab	274 b	D_1	165	205	184	
D_2	140 b	180 ab	198 a		D_2	318 a	308 a	309 a	D_2	112	129	147	
D_3	279a	248 b	253 b		D_3	131 b	212 a	233 a	D_3	46b	126a	146a	
$LSD_{.05}$ [2]	48.3					$LSD_{.05}$= 48.7				$LSD_{.05}$ =56.0			
Spikelets $panicle^{-1}$ (no)													
D_1	78 a	76 a	64 b		D_1	55 ab	60 a	52 b	D_1	62 a	52 b	57 ab	
D_2	65 ab	73 a	53 b		D_2	73 a	62 b	59 b	D_2	59 b	69 a	60 b	
D_3	63 a	66 a	71 a		D_3	79 a	70 b	65 b	D_3	59 b	71 a	67 ab	
$LSD_{.05}$ = 12.0						$LSD_{.05}$ = 6.8				$LSD_{.05}$ = 9.7			
Percent filled spikelet (%)													
D_1	76	73	69	73 y	D_1	79 a	77 ab	64 b	D_1	82	87	87	85 x
D_2	72	73	77	74 y	D_2	83 a	86 a	85 a	D_2	87	88	87	87 x
D_3	84	81	84	72 x	D_3	84 b	88 a	89 a	D_3	79	86	84	83 y
Mean I	78	76	77			$LSD_{.05}$ = 5.4			Mean I	82	87	86	
Thousand grain weight (gm)													
D_1	21.6 a	21.2 a	20.9 b		D_1	21.5 a	21.0 ab	20.8 b	D_1	20.9	20.8	21.2	20.9 x
D_2	21.2 a	21.5 a	21.0 a		D_2	21.6 a	21.4 a	21.3 a	D_2	20.6	21.3	21.3	21.1 x
D_3	21.5 a	21.6 a	21.4 a		D_3	21.2 b	21.9 a	21.8 a	D_3	20.9	21.5	21.7	21.4 x
$LSD_{.05}$ = 0.42						$LSD_{.05}$ = 5.5			Mean I	20.8 a	21.2 a	21.4	

[1]D_1 = Sowing on 5 - 10 April, D_2 = Sowing on 15 - 20April, D_3 = Sowing on 25 - 30 April; [2]$LSD_{.05}$ = LSD values for comparing three seeding dates under the same water regimes at 5% level of significance; [3]I_1 = Rainfed, I_2 = supplementary irrigation, I_3 = full irrigation; in each season and in each row mean values followed by the same letter were not significantly different at 5% level by LSD. Mean values were averaged over 4 replications; [4] In each season and in each column mean values followed by the same letter are not significantly different at 5% level by LSD. Mean values were averaged over 4 replications.

Effect of transplanting date and variety on performance of *aman* rice

Yields of BR11 ranged from 3515 to 4947 kg ha^{-1}, and of BRRI dhan53 from 2824 to 4478 kg ha^{-1}, across the three sowing dates and three years 2006 - 2008 (Figs. 4a-c).





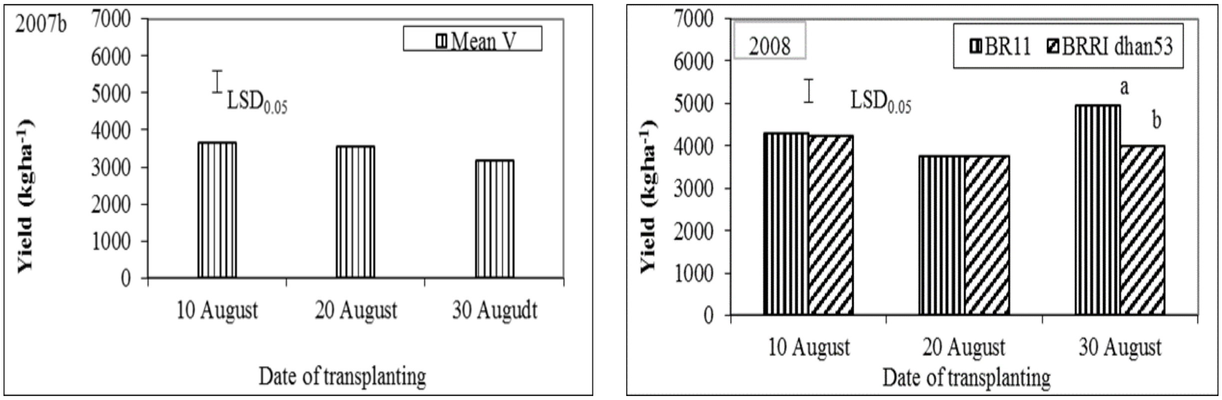


Fig. 4. Grain yield of *aman* as affected by sowing date and variety. Vertical bars are LSD (P=0.05) for the interaction between seeding date and variety in 2006 and 2008, and for the mean of variety (a) and date of sowing(b) in 2007.

Table 4. Effect of variety on panicle density, number of spikelets panicle^{-1}, percent filled grain, and thousand-grain-weight during different establishment dates of aman rrice in 2006 – 2008.

Transplanting date[1]	2006 cropping season			2007 cropping season			2008 cropping season		
	Variety[2]			Variety			Variety		
	V1	V2	Mean D	V1	V2	Mean D	V1	V2	Mean D
				Panicle density (no. m^{-2})					
D1	210	210	210	202	171	186	239	218	229
D2	217	199	208	167	174	171	223	201	212
D3	234	198	216	194	180	187	244	188	216
Mean V	220	202		188	175		235 a	202b	
$LSD_{.05}$[3]							$LSD_{.05}$ for v=17.8		
Interaction	N/S			N/S			N/S		
				Spikelets panicle^{-1} (no.)					
D1	115	117 a	116 a[4]	131	107	119 x[5]	92 a	106 a	
D2	107	97 b	102 b	115	103	109 y	93 a	102 a	
D3	102	91 b	97 c	122	113	117 x	98 b	112 a	
Mean V	108	102		123a	108b				
$LSD_{.05}$ for D	7.42						14.9		
Interaction	N/S			N/S					
				Filled spikelets (%)					
D1	67	66	67 y[5]	71b	79a		76 a	74 a	
D2	77	72	74 x	73a	70a		75 a	75 a	
D3	76	69	73 x	68a	65a		75 a	81 b	
Mean V	73	69							
$LSD_{.05}$ for D =7.26				LSD.05 = 5.6			LSD.05 = 3.6		
Interaction		N/S							
				Thousand-grain weight (g)					
D1	22.0 a	22.1 a		22.3	23.0	22.6 a	20.8	21.7	21.2 x
D2	22.2 a	21.8 a		22.3	22.3	22.3 a	21.0	21.5	21.3 x
D3	22.2 a	20.2 b		20.7	20.7	20.7b	20.4	20.3	20.4 y
Mean V				21.8	22.0		20.7a	21.2b	
$LSD_{.05}$	0.42			1.06					
Interaction							N/S		

[1] D = transplanting date, D_1 = 10 August, D_2 = 20 August, D_3 = 30 August; [2] V= rice varieties, V_1 = BR11, V_2 = BRRI dhan53; [3] LSD.05 = LSD values for comparing three seeding dates under the same variety at 5% level of significance; [4] In each season and in each row, mean values followed by the same letter (a, b) were not significantly different at the 5% level by LSD. Mean values were averaged over four replications; [5] In each season and in each column, mean values followed by the same letter (x, y) were not significantly different at the 5% level by LSD. Mean values were averaged over four replications

Annual *aus–aman* cropping system yield: Total system yield ranged from 5552 kg ha^{-1} to 7599 kg ha^{-1} over the three years from 2006 to 2008. The effects of *aus* sowing date and *aman* variety on annual system yield were inconsistent over the three years 2006 - 2008. The interaction between *aman* variety and *aus* seeding date was significant (P<0.05) in 2006 and 2008, but not in 2007. With BR11, there was no consistent effect of seeding date, but with BRRI dhan53, total system yield declined with delay in sowing in both 2006 (Figs. 5a) and 2008 (Figs. 5c). In 2007, system yield was significantly lower with the earliest sowing (6634 kg ha^{-1}) (Fig. 5b). Yields of this system were lower (5552 to 6851 kg ha^{-1}) in 2008 because of lower *aus* yield caused by drought and insect infestation.

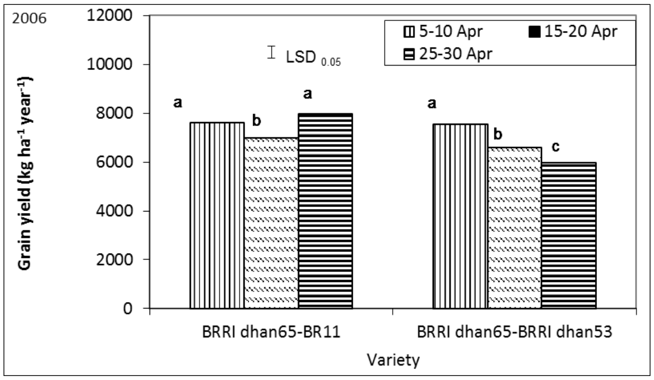
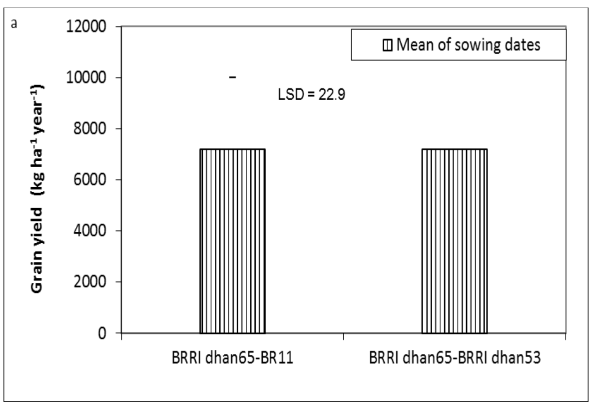


Fig. 5a. Total grain yield of the *aus*-*aman* cropping system as affected by *aus* seeding date and *aman* variety and *aman* variety during 2006. Vertical bars are the LSD (P = 0.05) for comparing all treatment combinations in 2006.



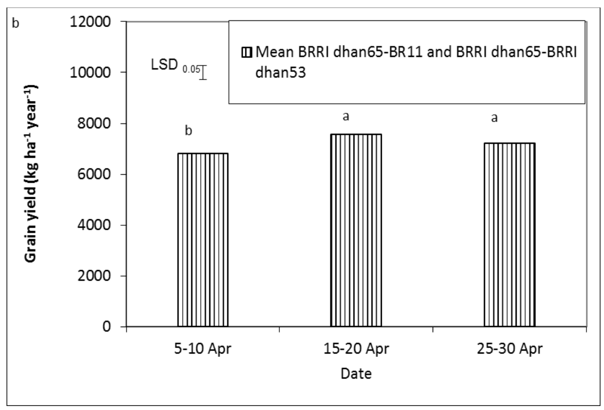


Fig. 5b. Total grain yield of the *aus*-*aman* cropping system as affected by *aus* seeding date and *aman* variety and *aman* variety during 2007. Vertical bars are the LSD (P = 0.05) for comparing all treatment combinations for comparing seeding date (a) and variety means (b) in 2007.

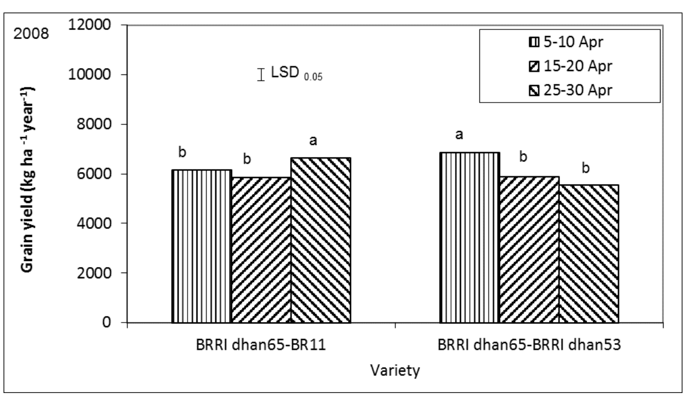


Fig. 5c. Total grain yield of the *aus*-*aman* cropping system as affected by *aus* seeding date and *aman* variety and *aman* variety during 2008. Vertical bars are the LSD (P = 0.05) for comparing all treatment combinations in 2008.

Effect of seeding date and irrigation management on irrigation input to *aus:* During the three *aus* seasons 2006 - 2008, rainfall intercepted by each treatment combination varied from 664 to 1043 mm (Table 5). Irrigation input to I_2 ranged from 94 to 188 mm, and to I_3 from 87 to 300 mm. There was a significant interaction between sowing date and irrigation treatment (supplementary vs full) on irrigation input to the *aus* crops in all three years (2006 - 2008). Each year, irrigation input to the fully irrigated treatment declined as sowing was delayed, while the effect of sowing date on irrigation input to the supplementary-irrigated treatment was variable. Total water input (rainfall plus irrigation) to *aus* ranged from about 900 mm in 2008 to about 1300 mm in 2006.

Incremental water productivity: Incremental water productivity of both irrigation treatments was higher when the crop faced drought which hampered rainfed rice establishment (e.g. D_3 of 2007). On the other hand, there were times when rainfed rice had a higher yield than irrigated rice because the latter suffered from pest infestation or submergence. The computation of incremental water productivity is not meaningful for the third sowing date in 2006 and for the first two sowing dates in 2007 as irrigated yield was lower than or equal to rainfed yield. Rainfed D_1 and D_2 of the 2008 cropping season had low yield due to drought during crop establishment, which caused high incremental water productivity of I_2 and I_3 in D_1 and D_2 of 2008. But incremental water productivity was low in D_2 of 2006 compared with that in D_1 under both irrigated water regimes because of low yield in D_2 due to crop submergence.

Table 5. Total water input from rainfall and irrigation in *aus* growing season (2006-2008), Basurabad village, Batiaghata, Khulna, Bangladesh.

	2006			2007			2008		
	I_1	I_2	I_3	I_1	I_2	I_3	I_1	I_2	I_3
Rainfall (mm)									
D_1	1068	996	996	800	897	922	664	773	767
D_2	1068	996	996	851	913	957	664	715	738
D_3	1043	1043	1043	842	875	923	659	745	747
Irrigation (mm)									
D_1	0	116	300	0	108	251	0	188	183
D_2	0	101	279	0	100	195	0	140	159
D_3	0	161	262	0	94	142	0	86	87
LSD		87			63			56	
Total water applied (mm)									
D_1	1068	1113	1297	800	1005	1173	664	961	950
D_2	1068	1098	1276	851	1014	1152	664	855	897
D_3	1043	1204	1305	842	968	1065	659	831	834
LSD		76			95			86	

Table 6. Incremental water productivity (kg rice m^{-3} water) in the *aus* season of 2006 - 2008 as affected by sowing date and irrigation treatment.

	2006		2007		2008	
	I_2[2]	I_3	I_2	I_3	I_2	I_3
D_1	0.77	0.31	Na	Na	0.43	0.04
D_2	0.27	0.008	Na	Na	0.63	0.54
D_3	na[3]	0.009	1.34	1.26	1.03	1.16

[1]D_1 = seeding on 5 - 10 April, D_2 = seeding on 15 - 20April, D_3 = seeding on 25 - 30 April.; [2]I_2 = supplementary irrigation, I_3 = full irrigation; [3]na = not applicable; when yield without irrigation is equal to or higher than that with irrigation, indicating no increment in yield with irrigation compared to without irrigation.

This study was aimed to develop technical packages for an *aus–aman* cropping system with stable and high yields in areas of the coastal zone with moderate salinity during the dry season. The interaction between *aus* seeding date and water management varied from year to year due to variation in rainfall at the beginning of the rainy season. With a short duration modern *aus* variety (BRRI dhan65, ~110 d) and supplementary irrigation of less than 100 mm, yields of 3.7 to 4.2 t ha^{-1} of dry seeded *aus* for sowing dates ranging from mid-April to late-April. Combining this with a modern, high yielding *aman* variety resulted in total system yields approaching 8 t $ha^{-1}yr^{-1}$, much higher than the 2.5 t $ha^{-1}yr^{-1}$ of rice commonly obtained by farmers who grow a single rice crop (*aman*) using local varieties.

The research also highlighted to problem of poor water management in the polders, leading to submergence and water stagnation at times in both the *aus* and *aman* crops. This points to the need for better water management at a regional scale, including the separation of lands of higher and lower elevation with small levees to prevent accumulation of water in lower lying lands, and for the ability to drain. It also points to the need for better submergence and water stagnation tolerance in modern *aus* and *aman* varieties. The combinations of BRRI dhan65 (*aus*) + BR11 (*aman*) gave the best yields under favourable conditions.

Acknowledgements

The authors are grateful to CGIAR Challenge Program on Water and Food (CPWF) for financial support to carry out research work and fellowship for PhD of the first author. The authors are thankful to the Field Assistant Mr Amal Krisna Roy for his continuous support during the work and the farmers for provision of land for field experiments.

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