Reducing irrigation water requirement of dry season rice (boro) in coastal areas using timely seeding and short duration varieties

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Abstract

Irrigated dry season rice (boro) can help to bridge the gap between production and consumption in eastern India. Due to scarcity of fresh surface water during the dry season, farmers resort to pumping ground water for irrigation. However this leads to the lowering of groundwater piezometric levels, increased pumping costs and saline water intrusion. Conservative use of irrigation water (IW) is essential to enable boro cultivation while sustaining the productivity of this fragile ecosystem. Therefore, research was conducted to test the hypotheses that early seeding and the use of short duration varieties would reduce IW requirements and increase the IW productivity (IWp) of boro rice. The experiment was conducted in the 2012–2013 and 2013–2014 boro seasons at Canning Town in West Bengal, India. Eight rice varieties including four from Bangladesh were sown during the first week (early seeding) and the last week (late seeding) of November. Each season, yields of early sown Binadhan-8, BRRI dhan47 and CSR 22 were similar (about 6 t ha^{-1}) and significantly higher than yields of the other varieties. With late seeding, Binadhan-8 produced significantly higher grain yield (5.9 t ha^{-1}) than all other varieties. Late seeding reduced grain yield of most varieties, more so in the case of longer duration varieties - by up to 24%. Irrigation water input increased with variety growth duration and was lowest with BRRI dhan55, followed by IR 10206-29-2-1-1 and BRRI dhan47. Average IW input with early seeding was 17% less than with late seeding, mainly due to lower irrigation requirements for land preparation. Irrigation water productivity with early seeding (41-45 kg grain ha^{-1}cm^{-1}) was 30% higher than with late seeding (31-35 kg grain ha^{-1}cm^{-1}) each year. With early seeding BRRI dhan47 had the highest IWp, while with late seeding Binadhan-8 had the highest. Two of the three varieties with highest yield and highest IWp came from Bangladesh, signifying the importance of cross-country germplasm exchange. There was an indication that early seeding resulted in higher yields and IWp, but this needs further verification.

Key message: Irrigation water input to boro crops in the coastal zone of west Bengal can be reduced while achieving yields in excess of 5 t ha^{-1} through the use of high yielding, short duration varieties, and possibly through earlier seeding.

Keywords: cropping intensification, eastern India, water management, water productivity

1. Introduction

The importance of rice as a staple food crop is known worldwide and Asian countries depend on rice as the major source of daily dietary requirements. It is the staple food of half the world's population and is grown by more than half the world's farmers (Fairhurst and Dobermann 2002). Rice is the most widely grown crop in India, which makes the country the second highest rice producer (close to 100 Mt per year) in the world. India needs to produce 120 Mt per year by 2030 to feed what will be by then its population of over one and a half billion (Adhya 2011). To meet the requirement, innovations are needed for higher production and sustained productivity.

One of the important strategies for increasing production is cropping intensification. In India, rice is mostly grown during three seasons, locally known as aus or autumn or pre-kharif (pre-monsoon), aman or kharif (monsoon), and boro or rabi or summer (post-monsoon or dry season). Among these three growing seasons, rice yield is highest during the boro season due to ample sunshine, controlled water management (irrigation) and higher efficiency of inputs like fertilizer and crop protection chemicals (Sarangi et al. 2014). But the area planted during boro is the least—around 4 Mha, in comparison to 38 Mha during kharif—mainly due to limited availability of irrigation water and suitable varieties. These constraints are particularly true for eastern India where surface water is affected by salinity during the dry season (Kukal et al. 2010; Bouman and Tuong 2001).

The source of water for dry season rice irrigation in eastern India is mainly pumping of groundwater through tube wells. Indiscriminate pumping of groundwater lowers the groundwater table during the dry season by an alarming magnitude, which has caused many tube well systems to go dry or deliver pulsating discharges during summer months (Goswami 2006). This situation results in increased pumping costs, salinity intrusion to the aquifers below rice growing land and build up of soil salinity in the top soil. In the future, groundwater utilization is likely to increase with expansion of irrigated agriculture and efforts to achieve national food production targets. Climate change is also likely to affect groundwater availability in terms of both quantity and quality (in particular coastal aquifers) due to changes in precipitation and evapo-transpiration (Pathak et al. 2014). Therefore, judicious use of irrigation water is essential to sustain boro rice production and to optimize the boro rice cultivated area. To reduce the irrigation water requirement of boro rice effective use of residual soil moisture after the kharif crop, optimum time of seeding and transplanting, and salt tolerant rice varieties are needed. Shorter duration boro varieties are also needed as rice requirements for irrigation water decrease with duration.

There is great scope for increasing rice production in the eastern coastal plains of India through the development and adoption of suitable varieties with site-specific crop and natural resource management (Saha et al. 2008). Planting date plays a crucial role in irrigation requirement and yield. Usually, farmers sow the seeds of the boro crop in the nursery from late November to the first week of December, about three weeks after the harvest of wet season rice. This planting date fails to tap the residual soil moisture in the topsoil of the paddy fields, which dries rapidly due to evaporation and recession of the groundwater table. Furthermore, the late sown rice crop is exposed to higher temperature and evaporation demand during the latter part of the crop growing period, from March to April (Fig. 1). The flowering and grain filling periods are exposed to warmer weather (heat stress), which increases spikelet sterility and shortens the grain filling period leading to lower yield (Castillo et al. 2006). Modelling studies for two boro rice varieties (BR3 and BR14) in Bangladesh indicated significant reduction (23 to 41%) in rice yield for delayed planting (Basak et al. 2010). Sterility percentage increased from 24 to 45% due to delayed planting (Mannan et al. 2012). Soil salinity also increases as the dry season progresses. Salt tolerant varieties can be used to maintain economic yield under moderate soil salinity and may need less irrigation water for leaching of salt than susceptible varieties.

Keeping these facts in view, this study was conducted to test the hypotheses that early seeding and the use of short duration varieties would reduce irrigation water (IW) requirement and increase the IW productivity (IWp) of boro rice.

2. Materials and methods

2.1 The study site

The experiment was conducted during the boro seasons of 2012-13 and 2013-14 at the ICAR-CSSRI Regional Research Station, Canning Town (Latitude: 22°15′N, Longitude: 88°40′ E; Altitude 3.0 m above MSL), West Bengal. The climate is tropical monsoon with average annual rainfall of 1802 mm, of which 89% occurs during the monsoon season (June-October). Rainfall during the boro season is not enough to meet the crop water requirement. Both maximum and minimum air temperatures, as well as potential evaporation, increase from January to April (Fig. 1) and the sky is usually cloudless with sufficient bright sunshine (6–7 h d^{-1}) for photosynthesis.

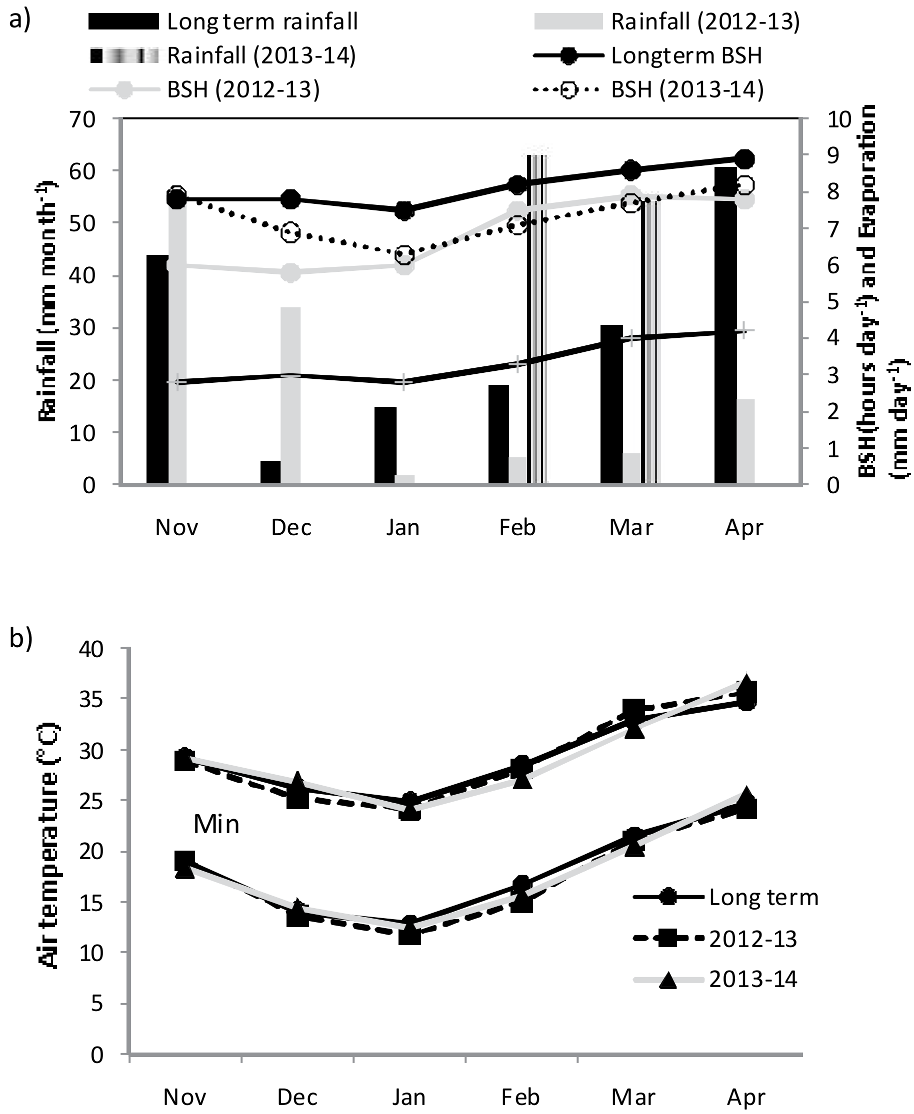

Fig. 1. Weather parameters during the crop growing months of the dry season: (a) rainfall, bright sunshine hours (BSH) and pan evaporation; and (b) maximum and minimum temperatures at ICAR-CSSRI RRS Canning Town. Long term data are for the period 1984-85 to 2013-14.

The experiment was conducted in two adjacent fields with very similar soil properties and groundwater table dynamics (Table 1, Fig. 2). The soil was a silty clay with a neutral pH, low organic carbon and available nitrogen, medium available phosphorus, and high available potassium (Table 1). Both fields were under paddy cultivation (one rainy season crop per year) for the three years prior to conducting this experiment.

Table 1. Initial physical and chemical properties of the topsoil (0-15 cm) at the experimental site. Area 1 and Area 2 refer to two fields (see section 2.2, experimental design).

Location	Clay	Sand	BD	N	P	K	Zn	pH	OC	ECe
	%		g cm-3		kg ha-1			ppm	%	dS m-1
Area 1	40	10	1.49	210	12.1	419	7.6	6.8	0.42	3.6
Area 2	44	10	1.52	227	11.1	378	7.8	7.1	0.46	4.2

The depth to the groundwater table (as observed in piezometers installed to a depth of 3 m) was similar in both experimental areas (Fig. 2). The water table was about 0.4 to 0.6 m below the soil surface in November each year, and the depth increased to about 1.2 m in April as the boro season progressed.

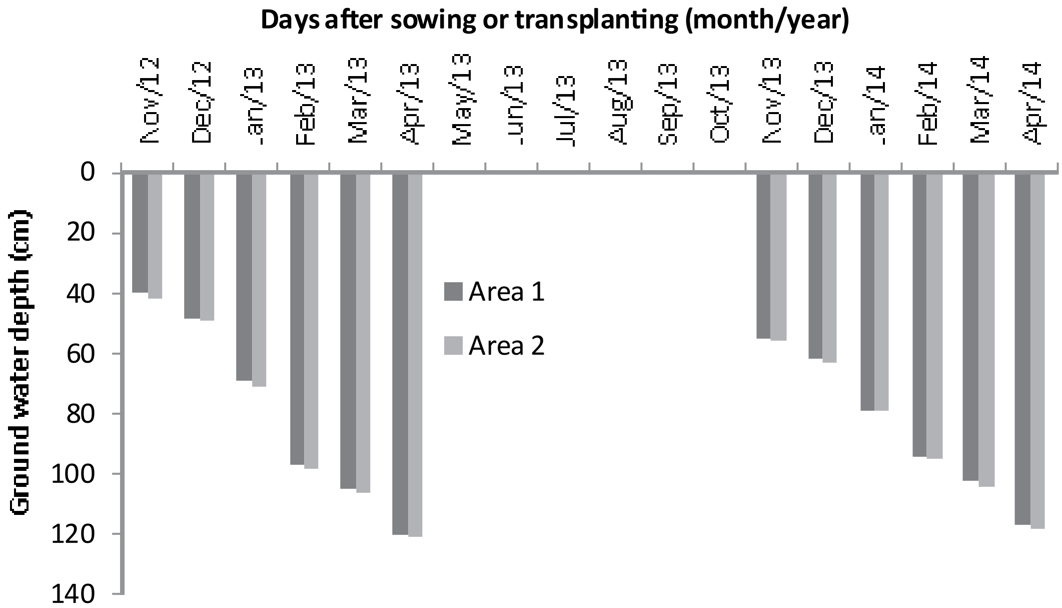

Fig. 2. Depth of groundwater in the study areas during the boro seasons of 2012-13 and 2013-14. Area 1 and Area 2 refer to two fields of the experiment (see section 2.2, experimental design). (For simplicity, data for May to October are not presented.)

2.2 Experimental design

The experiment was conducted in two adjacent fields with two seeding dates (early and late November), one seeding date per field. Eight varieties or lines were evaluated in each field.

Seeding dates:

Area 1: early November (6 Nov. 2012, 4 Nov 2013)
Area 2: late November (28 Nov. 2012, 24 Nov. 2013)

Varieties:
BRRI dhan47
BRRI dhan53
BRRI dhan55
Binadhan-8
CSR 34, CSR 22
IR 10206-29-2-1-1
CSRC (S) 50-2-1-1-4-B

All varieties tested were semi-dwarf high yielding salt tolerant varieties. Four varieties from Bangladesh were included, three of which are short duration (BRRI dhan47, BRRI dhan55 and Binadhan-8), with the other (BRRI dhan53) being medium short duration (www.knowledgebank-brri.org, www.bina.gov.bd). Three varieties/lines (CSR 22, CSR 34 and CSRC(S) 50-2-1-1-4-B) from India and one line from IRRI (IR 10206-29-2-1-1) were also included. These varieties were selected on the basis of previous evaluations done at CSSRI, RRS, Canning Town (Annual Report, CSSRI, 2011-12).

There were three replicates of each variety in a randomized block design within each field. Each variety plot measured 5 m x 19 m (gross area, including bunds). The plots were surrounded by 20 cm high x 50 cm wide bunds. The bunds were first built with dry soil, irrigation was applied for puddling, and the bunds were then plastered with mud to minimize lateral seepage. Irrigation for land soaking and puddling was applied 4 d before transplanting.

2.3 Management

Thirty day-old seedlings were transplanted at a spacing of 20 cm x 10 cm with one to two seedlings per hill. A fertilizer dose of 120:20:0 kg N:P2O5:K2O ha-1 was applied to each plot as urea, single super phosphate and muriate of potash, respectively. All of the P and K and 25% of the N were applied prior to leveling. Half of the N was broadcast 21 d after transplanting (DAT) and the remaining 25% was broadcast at 60 DAT. Hand weeding was done twice at 20 and 40 DAT to remove all weeds.

Chloropyriphos @ 2 ml l-1 water and tricyclazole @ 0.6 g l-1 water was used to control insects and diseases, respectively, as recommended. The plots were kept flooded (2.5-7.5 cm) throughout the season until about 20 d before harvest maturity.

2.4 Parameters monitored

2.4.1 Soil

Initial physico-chemical characteristics of the soil of the two fields were determined from top soil samples (0–15 cm) which were sun dried and sieved through a 2 mm sieve. Samples were then analyzed for texture, salinity, pH, organic carbon (Walkley and Black 1934), available nitrogen (Subbiah and Asija 1956), available phosphorus (Olsen et al. 1954) and available potassium (Hanway and Heidel 1952). Bulk density at 5-10 cm soil depth was determined on samples collected using a core sampler.

2.4.2 Water

The volume of irrigation water applied to each plot for puddling was measured from the discharge rate of the pump and the time of pumping. The depth of applied water was calculated by dividing volume by the plot area; the calculation assumes that lateral seepage was negligible as all plots were irrigated and puddled at the same time.

Water depth sticks with cm scales were installed in the middle and four corners of each plot after puddling. Irrigation was applied when water depth (as indicated by 3 out of the 5 water sticks) in the plot fell below 2.5 cm, to bring the water depth to 7.5 cm.

2.4.3 Crop duration

Crop duration was determined as the number of days from seeding to harvest. Harvesting was done when 80% of the grains turned straw colour.

2.4.4 Yield and yield components and irrigation water productivity

At harvest, grain yield was detemined on an area of 5 m x2 m in the middle of each plot. The grain was sun dried, weighed, moisture content was determined using a moisture meter, and grain yield was adjusted to a moisture content of 14%. Yield components (panicle density (no. m-2), number of spikelets panicle-1, spikelet fertility (%), 1000-grain weight) were also determined. The number of panicles was counted in three randomly selected areas of 1 m2 in each plot, and the average of three was used for statistical analysis. Ten panicles were randomly selected from each plot to count spikelets. These panicles were hand-threshed, filled (grains) and empty spikelets (chaff) were separated by submerging in water (floating spikelets considered empty), then the number of grains and empty spikelets was counted. Grain samples were adjusted to 14% moisture content to determine 1000-grain weight.

Irrigation water productivity (IWP) of each treatment was calculated by using the following formula:

IW_P (kg $ha^{-1}cm^{-1}$) = grain yield (kg ha^{-1})/volume of irrigation water applied (ha.cm)

All irrigation water, from land soaking and pudlling to the end of irrigation period, was included in the determination of IWP.

2.5 Statistical analysis

The results for each seeding date were analyzed separately. The effects of variety and year were determined by analysis of variance using the Statistical Tool for Agricultural Research (STAR) software developed by the International Rice Research Institute (http://bbi.irri.org). Treatment means were compared using the least significant difference (LSD) test and compared at P=0.05 level of significance (Gomez and Gomez 1984). When the interaction between variety and year was not significant, means were averaged across the two years. Lack of randomization of seeding date did not allow statistical analysis to be carried on the effects of seeding date.

3. Results and discussion

3.1. Crop duration, yield and yield components

There were no significant interactions between year and variety for either seeding date on duration, all yield components, and yield (Table 2). However, there were significant effects of variety and year on all these parameters for both seeding dates.

Table 2. Level of significance of the effects of year and variety and their interaction on crop duration and yield parameters for early and late sown boro

	Duration	Panicle m^{-2}	Spikelet $panicle^{-1}$	% fertility	1000-grain weight	Grain yield (t ha^{-1})
Effects	P>F	P>F	P>F	P>F	P>F	P>F
Early seeding (D1)						
Variety (V)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Year (Y)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
V x Y interaction	0.712	0.199	0.094	0.499	0.162	0.665
Late seeding (D2)						
Variety (V)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Year (Y)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
V x Y interaction	0.999	0.081	0.099	0.739	0.759	0.351

The duration of the varieties varied from 125 to 143 d with early seeding, and from 120 to 142 d with late seeding. The duration of each variety with late seeding was consistently 3 to 5 d shorter than that of the same variety with early seeding. In both sowing dates, BRRI dhan55, IR 10206-29-2-1-1, and Binadhan-8 had the shortest duration, while CSR 34 and CSR 22 had the longest duration.

Yields of CSR 22 and BRRI dhan47 did not differ significantly from that of Binadhan-8 in the first seeding, but were significantly lower than that of Binadhan-8 in the second seeding. On average, grain yield was 11% more with early seeding (mean 5.5 t ha-1) than late seeding (4.9 t ha-1). There was a general trend for delayed seeding to reduce grain yield of the longer duration varieties by more than the shorter duration varieties. Yield of BRRI dhan55 (duration 120-125 d) was not affected by seeding date, while the effect of seeding date on yield of Binadhan-8 (130-134 d) was small. Variety duration accounted for 56% of the effect of seeding date on yield (data not presented). The reduction in grain yield with late seeding was associated with reduced spikelet fertility, and to a very small degree with reduced panicle density (by 1%, but consistent across varieties) (Table 3). On average, spikelet fertility decreased from 84% in D1 to 77% in D2. This was probably due to higher temperature at flowering with late seeding each season. Flowering of the early seeding occurred in February while flowering of the late seeding occurred in March. The greater effect of late seeding on yield reduction with longer duration varieties is also probably due to flowering at higher temperatures.

The higher yield of Binadhan-8, CSR 22 and IR 10206-29-2-1-1 was associated with higher panicle density than most or all other varieties and more spikelets per panicle than some varieties. Bindhan-8 also had much higher grain weight than all other varieties except BRRI dhan47. BRRI dhan47 also had relatively high panicle density and significantly more spikelets per panicle than all other varieties.

The higher yield in 2013-14 was associated with unusually high rainfall in February and March 2014 (total about 120 mm, Fig. 1a) which probably reduced the salinity experienced by both the early and late sown crops.

3.2 Irrigation water (IW)

The interaction between variety and year was not significant for all IW parameters except IWP at late seeding. Therefore, mean data of the two years are presented for all parameters except the latter. There was a significant effect of variety on all parameters except the amount of irrigation water for land soaking and puddling (IWL) in both years, and a significant effect of year on all parameters except irrigation number.

The depth of irrigation water required for land preparation for the early seeding (22 cm) was much less than that for late seeding (38 cm) (Table 4). This is attributed to the higher water table depth (Fig. 2) and higher water content of the soil profile at the time of seeding. The amount of irrigation water for land preparation in 2012 was about 20 mm less than in 2013 for both crops. In 2012 there were 34 and 36 mm of rain between the times of harvest and transplanting of the early and late seeded crops, respectively, compared with no rain during this period in 2013, hence the higher irrigation input for land preparation in 2012. The irrigation input during the cropped period was 30 to 40 mm lower in 2013-14 than in 2012-13, and this was associated with the unusually high rainfall in February and March 2014 (Fig. 1a).

Table 3. Crop duration, yield and yield components of early and late sown boro varieties. Means are the average of three replicates over two years

	Duration	Panicle m^{-2}	Spikelet $panicle^{-1}$	% fertility	1000-grain weight	Grain yield (t ha^{-1})
Early seeding (D1)						
Variety Binadhan-8	134[b]	490[a]	121[bc]	89.1[a]	26.7[b]	6.04[a]
CSR 22	143[a]	485[a]	118[c]	84.7[c]	22.9[f]	5.95[a]
BRRI dhan47	135[b]	455[b]	139[a]	83.9[c]	27.5[a]	5.89[a]
IR 10206-29-2-1-1	134[b]	483[a]	126[b]	81.4[d]	23.9[d]	5.57[b]
BRRI dhan53	141[a]	387[c]	112[d]	80.6[de]	22.3[g]	5.51[b]
CSR 34	143[a]	325[e]	97[f]	85.0[bc]	23.1[e]	5.25[c]
BRRI dhan55	125[c]	357[d]	107[e]	86.6[b]	25.5[c]	4.97[d]
CSRC(S) 50-2-1-1-4-B	135[b]	286[f]	97[f]	79.6[e]	22.3[g]	4.56[e]
LSD (P=0.05)	1.49	5.3	3.1	1.08	0.07	0.12
Year						
2012-13	138[a]	415[a]	115[a]	84.8[a]	24.2[b]	5.75[a]
2013-14	134[b]	401[b]	114[b]	83.0[b]	24.3[a]	5.19[b]
LSD (P=0.05)	0.73	2.65	1.53	0.54	0.04	0.06
Mean	*136*	*408*	*115*	*83.9*	*24.24*	*5.47*
Late seeding (D2)						
Variety Binadhan-8	130[d]	485[a]	122[c]	81.6[a]	26.5[b]	5.86[a]
CSR 22	141[a]	479[ab]	119[c]	73.9[cd]	22.7[f]	5.21[c]
BRRI dhan47	132[c]	451[c]	140[a]	79.0[ab]	27.3[a]	5.34[b]
IR 10206-29-2-1-1	131[cd]	477[b]	126[b]	76.3[bc]	23.8[d]	5.46[b]
BRRI dhan53	137[b]	383[d]	113[d]	73.7[cd]	22.1[g]	4.57[e]
CSR 34	142[a]	320[f]	99[f]	75.3[c]	22.9[e]	4.24[f]
BRRI dhan55	120[e]	352[e]	107[e]	81.7[a]	25.3[c]	4.92[d]
CSRC(S) 50-2-1-1-4-B	132[c]	282[g]	98[f]	71.5[d]	22.1[g]	3.79[g]
LSD (P=0.05)	1.73	7.1	3.8	3.15	0.13	0.18
Year						
2012-13	134[a]	410[a]	116[a]	77.31[a]	24.0[b]	5.22[a]
2013-14	133[b]	396[b]	115[b]	75.96[b]	24.2[a]	4.63[b]
LSD (P=0.05)	0.62	2.51	1.35	1.10	0.05	0.06
Mean	*134*	*403*	*116*	*76.6*	*24.1*	*4.92*

Note: In the same seeding date, means with the same letter in a column are not significantly different at the 5% level by LSD. The interaction between year and variety was not significant for any parameters.

Table 4. Level of significance of the effects of year and variety and their interaction on number of irrigations (In), depth of irrigation for land soaking and puddling (IWL), depth of irrigation during crop period (IWC), total irrigation water (Total IW) and irrigation water productivity (IWP), for early and late sown boro

	I_n	IWL (cm)	IWC (cm)	Total IW (cm)	IW_P (kg $ha^{-1}cm^{-1}$)
Effects	P>F	P>F	P>F	P>F	P>F
Early seeding (D1)					
Variety (V)	<0.05	0.788	<0.05	<0.05	<0.05
Year (Y)	1.000	<0.05	<0.05	<0.05	<0.05
V and Y interaction	1.000	0.999	1.000	1.000	0.878
Late seeding (D2)					
Variety (V)	<0.05	0.708	<0.05	<0.05	<0.05
Year (Y)	1.000	<0.05	<0.05	<0.05	<0.05
V and Y interaction	1.939	0.944	0.941	0.998	<0.05

The number of irrigations increased with crop duration. About 17 irrigations were required for early sown CSR 22 and 34 (duration 141-143 d), whereas early sown IR 10206-29-2-1-1 and BRRI dhan47 (duration 131-135 d) needed only 13 irrigations. The number of irrigations under late seeding increased to 23 in the case of CSR 22 and CSR 34, and to 18 in the case of IR 10206-29-2-1-1and BRRI dhan47.

The amount of irrigation water applied between transplanting and harvest of the early seeding (107 cm) was approximately five times that needed for land preparation. The amount of irrigation water applied between transplanting and maturity (IWC) was similar for early (107 cm) and late (114 cm) seedings. There were small but significant differences in the amount of water applied during the cropped period to each variety , with differences of up to about 20 cm between varieties within both early and late seedings. Both IWC and total IW increased with crop duration, and were highest for CSR 22 (early seeding total 138 cm), followed by BRRI dhan53. Irrigation requirement was lowest in BRRI dhan55 followed by BRRI dhan47. BRRI dhan55 needed about 20 and 13 cm less irrigation water than CSR 22 under early and late seeding, respectively. On average, early seeding needed 17% less irrigation water than late seeding.

3.3 Irrigation water productivity (kg ha-1cm-1)

There was a consistent trend across years and seeding dates for highest IWP in Binadhan-8, BRRI dhan47 and IR 10206-29-2-1-1. This was due to both higher grain yield and lower irrigation water requirement during the crop growing period. The low IWP of BRRI dhan55 was due to lower grain yield which more than offset its lower irrigation water requirement.

Within variety, there was a consistent trend for higher IWP with early seeding (41-45 kg ha-1cm-1) than late seeding (31-35 kg ha-1cm-1) each year. This was mainly due to the larger amount of irrigation water required for land soaking and puddling and lower yield of the late seeding. Sarangi and Lenka (2000) observed that IWP in summer rice (variety: Lalat) in coastal areas of Odisha (India) could be increased from 38 kg grain ha-1 cm-1 with flooding throughout the growing period to 50 kg grainha-1cm-1of irrigation water by maintaining saturation from one week after transplanting to maturity in comparison with a ponded water depth of 3-5 cm.

Table 5. Number of irrigations from TP to maturity (In), depth of irrigation for land soaking and puddling (IWL), depth of irrigation during crop period (IWC)and total irrigation water (Total IW) used for boro rice crop at Canning Town, West Bengal, India (mean of 2012-13 and 2013-14)

Treatment	I_n	IWL (cm)	IWC (cm)	Total IW (cm)
Early seeding (D1)				
Variety Binadhan-8	14^{b}	21.1	111^{ab}	132^{bc}
CSR 22	17^{a}	21.9	116^{a}	138^{a}
BRRI dhan47	13^{b}	21.4	102^{c}	123^{c}
IR 10206-29-2-1-1	13^{b}	21.5	101^{c}	123^{d}
BRRI dhan53	16^{a}	21.7	113^{ab}	135^{ab}
CSR 34	17^{a}	22.3	112^{ab}	134^{bc}
BRRI dhan55	13^{b}	20.9	97^{c}	118^{d}
CSRC(S) 50-2-1-1-4-B	16^{a}	22.1	109^{b}	131^{c}
LSD (P=0.05)	1	NS[1]	4	3
Year				
2012-13	15	20.7^{b}	109^{a}	130^{a}
2013-14	15	22.5^{a}	106^{b}	128^{b}
LSD (P=0.05)	NS	0.9	2	1
Mean	*15*	*21.6*	*107*	*129*
Late seeding (D2)				
Variety Binadhan-8	19^{c}	37.7	109^{d}	147^{d}
CSR 22	23^{a}	38.1	120^{b}	158^{b}
BRRI dhan47	18^{c}	37.4	107^{d}	144^{e}
IR 10206-29-2-1-1	18^{c}	37.5	109^{d}	146^{de}
BRRI dhan53	21^{b}	37.8	117^{c}	155^{c}
CSR 34	23^{a}	38.0	124^{a}	162^{a}
BRRI dhan55	18^{c}	36.7	107^{d}	144^{e}
CSRC(S) 50-2-1-1-4-B	21^{b}	38.0	120^{b}	158^{b}
LSD (P=0.05)	1	NS	2	2
Year				
2012-13	20	36.4^{b}	116^{a}	153^{a}
2013-14	20	38.9^{a}	112^{b}	151^{b}
LSD (P=0.05)	NS	0.8	1	0.8
Mean	*20*	*37.7*	*114*	*152*

[1]NS= not significant

Note: In the same seeding date, means with the same letter in a column are not significantly different at the 5% level by LSD.

Table 6. Water productivity of rice varieties for early and late seeding (the interaction between year and variety was not significant for early seeding)

Variety	Early seeding (D1)	Late seeding (D2)	
	Mean	2012-13	2013-14
Binadhan-8	45.8[b]	41.7[a]	37.9[a]
BRRI dhan47	47.6[a]	38.9[b]	35.1[b]
BRRI dhan53	40.8[d]	33.1[d]	27.8[d]
BRRI dhan55	42.1[c]	35.9[c]	32.3[c]
CSR 22	43.1[c]	38.0[b]	31.2[c]
CSR 34	39.2[e]	31.1[d]	24.4[e]
CSRC(S) 50-2-1-1-4-B	34.9[f]	26.0[e]	22.9[f]
IR 10206-29-2-1-1	45.3[b]	39.2[b]	35.3[b]
Mean	*42.4*	*35.5*	*30.9*
LSD (P=0.05)	1.1		
LSD (P=0.05) for variety and year interaction 1.2			

Note: Means with the same letter in a column are not significantly different at the 5% level by LSD.

4. Conclusions and recommendations

The present study identified promising boro varieties for the coastal salt affected areas of West Bengal. The best varieties were Binadhan-8, BRRI dhan47 and CSR 22, which yielded > 5 t ha-1. Because of their short duration, Binadhan-8 and BRRI dhan47 used less irrigation water and had higher irrigation water productivity than CSR 22. Thus, two of the three varieties with highest yield and highest irrigation water productivity came from Bangladesh, signifying the importance of cross-country germplasm exchange.

The two season, non-replicated comparison between early seeding (during the first week of November) and late seeding (during the last week of November, farmers' practice) suggested that early seeding produced higher grain yield, required less irrigation water and thus had higher irrigation water productivity. The effects of seeding date, however, need to be confirmed by further research with adequate replication of date of seeding.

As availability of irrigation water is a constraint during the boro season, combining varieties with high yield and high irrigation water productivity with optimum seeding time can contribute to increasing rice production in coastal salt-affected areas.

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