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Optimum Sowing Date and Salt Tolerant Variety Boost Rice (*Oryza sativa* L.) Yield and Water Productivity during Boro Season in the Ganges Delta

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Abstract: Rice-fallow and rice-rice are major cropping systems in the salt affected region of the Ganges Delta covering West Bengal, India and Bangladesh. The dry season rice (Boro) is grown mostly by irrigation from ground water in this water scarce region. Boro encounters soil and water salinity, air temperature fluctuations and intense evaporative demand. We studied six sowing dates (1 October, 15 October, 1 November, 15 November, 1 December and 15 December) and three varieties (WGL 20471, Bidhan 2 and IET 4786) of rice to find an interacting effect on yield and water productivity. Soil and water salinity varied during the growing period with lower soil salinity during the month of November (2.20–2.53 dS m^{-1}) and higher soil salinity towards the end of the growing season (4.30–5.23 dS m^{-1}). The mean field water salinity was higher (1.78 dS m^{-1}) during the Boro 2017–18 compared to that (1.65 dS m^{-1}) during 2016–17, as about 49 mm rainfall was received in the month of March 2017. Sowing dates significantly affected the yield of Boro rice. Earliest sowing on 1 October is not feasible as it significantly reduced the grain and straw yields. Sowing of nursery up to 1 of November was found to be the best possible option, and it should not be delayed up to 15 December. The rice variety IET 4786 was found to be susceptible to salinity with the lowest grain yield 2.65–2.98 t ha^{-1}, compared to Bidhan 2 (3.41–5.95 t ha^{-1}) and WGL 20471 (3.40–5.81 t ha^{-1}). Both irrigation and economic water productivity of Boro were affected by sowing dates and variety. Rice variety IET 4786 required less irrigation water (1320 mm) than the other two varieties (1350 mm). Higher (>0.5 kg m^{-3}) irrigation water productivity of Boro can be achieved by selecting salt tolerant varieties (WGL 20471 and Bidhan 2) and optimum sowing window of 1–15 November.

Keywords: disease score; irrigation; water productivity; salt tolerance; temperature; variety

1. Introduction

Rice (*Oryza sativa* L.) is the predominant field crop in the coastal areas of India and Bangladesh during the major cropping seasons of monsoon (Kharif/Aman) and post monsoon/dry season (Boro). During the Kharif (July–November) season, rice is grown as rainfed and during Boro (November–May) it is mainly an irrigated crop. Cultivation of non-rice crops during the dry season is difficult, due to the soil wetness just after harvest of previous season rice, occasional waterlogging of the heavy soils and plant damage due to rising soil salt concentration [1]. Boro rice is one of the cropping options for the dry season, provided sufficient irrigations are assured. However, this is a cost-intensive crop, requiring specific management strategies to tackle soil and water salinity. Sowing date is a major responsible factor for realizing the potential yield of rice by utilizing the resources effectively and saving the crop from abiotic stresses [2,3]. Sowing time indirectly determines soil temperature and weather conditions (temperature, precipitation, humidity, sunshine hours) to which young rice seedlings and plants are exposed during different development stages [4,5]. The optimum sowing date is important for three major reasons [6]. Firstly, it ensures that vegetative growth occurs during a period of satisfactory temperatures and high levels of solar radiation/sunshine hours. Secondly, the cold sensitive phase of the rice crop occurs when the minimum night temperature is historically the warmest and thirdly, it guarantees that grain filling occurs when milder spring temperatures are more likely, hence good grain quality is achieved. The transplanting date also has a direct impact on the rate of establishment of rice seedling, and transplanting rice in the optimum period of time is critical to achieve high grain yield [7]. Rice seeded before the window of optimum dates usually has a slow germination and emergence, poor stand establishment, soil borne seedling diseases under cold condition, as well as being prone to damage by birds (parrots, pigeon, sparrow, munia etc.) during sowing time and damage by rodents and birds upon earliest maturity, when adjacent fields have not flowered. Delayed transplanting exposes the crop to higher temperature, increased damages from insect pests, salinity, tropical storm-related lodging, and possible damage by heavy rain/hailstorms during the heading and grain filling periods [8]. Therefore, finding an optimum sowing window for Boro in coastal region is the foremost important requirement.

The source of water for Boro rice cultivation is mainly by pumping the groundwater through shallow tube wells. With indiscriminate pumping of groundwater, there is an alarming reduction of the groundwater table during the dry season. This situation results in an increased cost of pumping, salinity intrusion to the aquifers in the rice growing ecosystem, and build-up of soil salinity in the top soil, resulting in abandonment of paddy growing land [9]. Therefore, judicious use of irrigation water is essential to sustain Boro rice production and to optimize the cultivated area. To reduce the irrigation water requirement of Boro rice, the effective use of residual soil moisture after the Kharif crop, an optimum time of seeding and transplanting, and salt tolerant rice varieties are needed. Irrigation water input to Boro crops can be reduced through the use of high yielding (>5 t ha^{-1}), short duration varieties, and possibly through earlier seeding [8]. With increase in salinity due to saltwater intrusion, cultivars with greater tolerance to salinity and shorter duration are needed for the saline coastal region of the Ganges Delta [10].

It is reported that 15 November–15 December is the best sowing window of Boro rice in Bangladesh irrespective of varieties [2]. Studies on rice varietal adjustment for salt affected areas showed that short duration varieties could escape salinity at the end of season, while long-duration varieties could benefit from an irrigated desalinization treatment [11]. The selection of stress-tolerant rice varieties for coastal region is also an important strategy to achieve sustainable yield under worsening abiotic stresses (high temperature, drought, flooding and salinity) as the consequences of climate change [12]. Rice varieties of different degrees of salt tolerance are available for Boro season in coastal regions [13,14]. However, the interaction of sowing dates and Boro rice varieties with different characteristics (flowering and maturity duration, salt tolerance) were not studied in depth. Though modelling [15] and field studies [16] highlight the importance of sowing/planting dates significantly influencing the yield and sustainability of Boro rice, this factor has not been taken into consideration in the yield/knowledge gap analysis [17]. Farmers are cultivating some of these varieties based on their usual practice, irrespective of the varietal characteristic to fit to an optimum sowing date. Keeping these facts in view, a field experiment was conducted to find out optimum sowing date and tolerant rice variety for Boro in coastal region. We hypothesize that the optimum sowing date increases yield and water productivity of Boro rice, and it is dependent on the rice varietal characteristics.

2. Materials and Methods

2.1. Study Site and Experimental Details

The experiment was conducted during the Boro seasons of 2016–17 and 2017–18 at the Indian Council of Agricultural Research (ICAR)-Central Soil Salinity Research Institute (CSSRI), Regional Research Station, Canning Town (Latitude: 22°15′ N, Longitude: 88°40′ E; Altitude 3.0 m above MSL), West Bengal, India. It is located in the Sundarbans region of the Ganges Delta. The top soil (0–15 cm depth) of the experimental site is silty clay in texture (42% clay), low in soil organic carbon (0.43%), low in available nitrogen (247 kg ha^{-1}), medium in available phosphorus (19.1 kg ha^{-1}) and high (423.5 kg ha^{-1}) in available potassium (Supplementary Table S1). The climate is tropical monsoon with average annual rainfall of 1802 mm, of which 89% occurs during the monsoon season (July-November). Rainfall during the Boro season was not enough to meet the crop water requirement. Therefore, irrigation from groundwater resource was used to grow Boro rice crop. Both maximum and minimum air temperatures, as well as wind velocity, increased from January to April (Table 1), and the sky was cloudless with sufficient bright sunshine (6–7 h day^{-1}) for photosynthesis during this period.

Table 1. Weather data during the crop growing period of 2016–17 and 2017–18 recorded at Canning Town, West Bengal.

Month	Temperature (°C)			RH * (%)	Rainfall (mm)	Rainy Days	Av. Wind (km h^{-1})	BSSH # (h Day^{-1})
	Max.	Min.	Mean					
2016–17								
Oct.	31.9	24.8	28.3	61.0	27.5	3	0.3	5.8
Nov.	29.2	18.6	23.9	47.3	48.2	3	0.2	6.6
Dec.	26.3	14.6	20.5	50.1	0.0	0	0.3	5.9
Jan.	25.7	12.7	19.2	77.9	0.0	0	0.6	7.6
Feb.	29.4	17.0	23.2	81.0	0.0	0	1.2	7.1
Mar.	31.4	21.5	26.4	81.9	49.0	4	3.4	6.9
Apr.	34.2	26.0	30.1	76.8	12.6	2	6.8	5.0
May	36.6	26.9	31.7	72.5	66.6	5	7.5	8.4
2017–18								
Oct.	31.4	24.9	28.2	88.2	420.8	11	4.1	5.5
Nov.	29.3	19.1	24.2	76.8	34.6	5	2.0	6.9
Dec.	25.7	15.6	20.7	86.7	28.8	2	2.0	5.9
Jan.	24.3	11.2	17.8	81.0	0.0	0	1.9	7.4
Feb.	30.6	17.8	24.2	79.0	0.0	0	2.7	7.0
Mar.	33.9	22.8	28.4	78.0	2.4	0	4.2	7.2
Apr.	34.4	23.9	29.1	75.0	67.4	7	6.5	8.0
May	34.9	26.3	30.6	74.5	141.0	7	7.7	7.9

* RH: Relative Humidity; # BSSH: Bright sunshine hours.

This experiment consisted of six dates of sowing (D1: 1 October, D2: 15 October, D3: 1 November, D4: 15 November, D5: 1 December and D6: 15 December) in main-plot and three varieties (V1: WGL 20471, V2: Bidhan 2 and V3: IET 4786) of rice in sub-plot in split-plot design with three replications. The rice variety WGL 20471 locally called "Lal-minikit", developed in India, can tolerate salinity of EC 6.0–8.0 dS m^{-1} with plant height of 95–105 cm, and grain yield potential of 5.0–5.5 t ha^{-1} with long slender grains. This variety is highly resistant to gall midge. The variety Bidhan 2 developed in India, is also salt tolerant (ECe 6.0 dS m^{-1}), having plant height of 105–110 cm, and grain yield potential of 4.0–5.0 t ha^{-1} with long slender grains [13]. IET 4786 "Sada-minikit" has comparatively less salinity tolerance limit of 4–6 dS m^{-1}, plant height of 80–95 cm, grain yield level of 3.5–5.6 t ha^{-1} with long slender grains [18].

2.2. Crop Management

Nursery sowing of three rice varieties was done in staggered manner as per the main-plot treatments of different dates of sowing. Thirty-day-old seedlings were transplanted at a spacing of 20 cm × 10 cm with 1–2 seedlings per hill. A fertilizer dose of 120–20–10 kg N-P_2O_5-K_2O ha^{-1} was applied to each plot as urea (46% N), single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O), respectively. All of the P and K and 25% of the N were applied prior to leveling. Half of the N was broadcast 21 days 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. Chlorpyrifos @ 2 mL L^{-1} water and tricyclazole @ 0.6 g L^{-1} water were 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 days before harvest.

2.3. Observations

Soil and water salinity was observed from each plot at monthly intervals using a digital electrical conductivity meter (Systronics India Ltd., Ahmedabad, Gujarat, India). Soil salinity was determined as the electrical conductivity of the soil saturation extract (ECe) and water salinity as electrical conductivity (EC) in deci Siemens per meter (dS m^{-1}). Disease severity of treatments were evaluated at flowering stage following the modified Standard Evaluation Scores (SES) system developed by International Rice Research Institute [19]. Disease score of 1: corresponds to no incidence, 2: less than 1%, 3: 1–3%, 4: 4–5%, 5: 11–15%, 6: 16–25%, 7: 26–50%, 8: 51–75% and 9: 76–100% disease incidence. The volume of irrigation water applied to each plot 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. Water depth sticks with centimeter (cm) scales were installed in the middle of each plot after puddling. Irrigation was applied when water depth in the plot fell below 2.5 cm, to bring the water depth to 7.5 cm. Irrigation water productivity (IWP) was estimated as a ratio of the grain yield (kg) to the irrigation water applied (m^3) during the crop growth period. Thus, IWP was expressed as kg m^{-3}. Economic water productivity (EWP) was calculated as the ratio of prevailing price in Indian rupees (₹) of rice grain in the local market to the amount of irrigation water applied (m^3) and expressed as ₹ m^{-3}. The prices per kg of rice grains of WGL 20471, Bidhan 2 and IET 4786 during 2016–17 were ₹ 15.0, 13.4 and 16.0 and during 2017–18 were ₹ 17.5, 15.0 and 18.5, respectively. The value of one US dollar ($) during 2016–17 and 2017–18 was ₹ 65 and ₹ 68, respectively.

At harvest, grain yield was determined on an area of 5 m × 2 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 (number 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 m^2 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.

2.4. Statistical Analyses

The data were analyzed using a split-split plot design with sowing dates as the main plot, varieties as the sub-plot, and year as the sub-sub plot. Year was taken as a sub-sub plot in the analyses as the experimental layout was the same for both years of study (repeated measures). The effects of sowing date, 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, Los Banos, Philippines [20]. The level of significance of the effects of treatments, year and their interaction for different parameters studied is given in Supplementary Table S2. Standard error of means (SEm±) was calculated by using mean sum of squares of error a (main-plot) and b (sub-plot), number of replication and level of treatments. Two-way tables of sowing dates and varieties are given separately for both years where the interaction is significant and revealed important information. Pooled mean data of sowing dates, varieties and years are presented where there was no significant interaction. Treatment means were compared using the least significance difference (LSD) values at $p = 0.05$ level of significance [21]. When interaction was significant, treatment means were compared for four different types of pair comparisons, viz., C1: comparison between two main-plot treatment means averaged over all sub-plot treatments; C2: comparison between two sub-plot treatment means averaged over all main-plot treatments; C3: comparison between two sub-plot treatment means at the same main-plot treatment and C4: comparison between two main-plot treatment means at the same or different sub-plot treatments (i.e., means of any two treatment combinations). Where interaction was not significant, treatment means were compared by using C1 and C2 for main-plot and sub-plot treatment means, respectively. Pearson's product-moment correlations between different parameters were estimated by using STAR software and significance level was tested at $p < 0.001$, 0.005 and 0.05 (Supplementary Table S3).

3. Results

3.1. Effect of Sowing Dates on Phenology and Irrigation Water Requirement of Boro Rice

The Boro rice crop was exposed to different air temperature regimes during vegetative and reproductive stages due to the different sowing dates. As a result, it affected the growth duration of rice and ultimately the yield. Disease incidence on the rice crop was severe when sowing was done on 1 October (Table 2). Spikelets panicle^{-1} (r = −0.49 ***) and fertility (r = −0.35 ***) were the most significantly affected yield attributes of Boro rice due to disease severity (Supplementary Table S3). Out of the three varieties, the disease incidence was higher in IET 4786 (11–15%) compared to other two varieties (4–5%). Earliest sowing date of 1 October resulted in exposure of rice crop to lowest temperature regime in the month of January (Table 3), and as a result, the maturity duration of the crop was delayed (170–177 days) compared to other sowing dates. The bright sunshine hours (BSSH) per day during the month of October (Table 1) was also the lowest (5.5–5.8 h day^{-1}), hence the growth of the earliest sown crop was slow and further, due to the low temperature regime during the flowering stage, the rice crop development was affected. During the subsequent four sowing dates, mild temperature regimes prevailed, while the extreme late sowing date of 15 December exposed the rice crop to highest temperature regimes of the growing period prevailing in the month of May (Max. temp. 34.9–36.6 °C). Further, the increase in soil salinity towards late in the growing period exposes the rice crop to salinity hazards.

Table 2. Effect of different sowing dates and varieties of Boro rice on disease score and irrigation water requirement observed at Canning Town, West Bengal, India (Pooled mean data of main effects).

Treatments	Disease Score	Irrigation Water Requirement (mm)
Sowing dates		
D1	6.61 ^{a}	1391 ^{b}
D2	3.83 ^{bc}	1210 ^{e}
D3	3.50 ^{c}	1285 ^{d}
D4	3.33 ^{c}	1334 ^{c}
D5	3.72 ^{c}	1384 ^{b}
D6	4.61 ^{b}	1444 ^{a}
SEm±	0.17	9.8
$LSD_{0.05}$	0.52	31.2

Table 2. *Cont.*

Treatments	Disease Score	Irrigation Water Requirement (mm)
Varieties		
V1	3.97 [b]	1357 [a]
V2	3.94 [b]	1341 [b]
V3	4.89 [a]	1326 [c]
SEm±	0.11	4.7
$LSD_{0.05}$	0.33	13.8
Years		
2016–17	4.17 [b]	1308 [b]
2017–18	4.37 [a]	1374 [a]
SEm±	0.04	3.03
$LSD_{0.05}$	0.12	9.15
Interaction	ns	ns

D1, 1 October, D2, 15 October, D3, 1 November, D4,15 November, D5, 1 December and D6, 15 December; V1, WGL 20471, V2, Bidhan 2 and V3, IET 4786; SEm±, Standard error of means; ns, not significant; Means with the same letter in a column are not significantly different.

Table 3. Flowering and maturity (mean over varieties) period and the air temperature regimes corresponding to different sowing dates of Boro rice observed at Canning Town, West Bengal, India during 2016–17 and 2017–18.

Dates of Sowing	Mean Air Temperature (°C) during Flowering	Flowering Period	Harvesting Period	Mean Air Temperature (°C) at Harvesting	Maturity Duration (Days)
1 Oct.	17.8–19.2	Late Jan.	Late Mar.	26.4–28.4	170–177
15 Oct.	23.2–24.2	Early Feb.	Late Mar.	26.4–28.4	155–162
1 Nov.	26.4–28.4	Early Mar.	Early Apr.–Mid Apr.	29.1–30.1	160–167
15 Nov.	26.4–28.4	Mid Mar.	Late Apr.	29.1–30.1	155–162
1 Dec.	29.1–30.1	Late Mar.–Mid Apr.	Early May	29.1–30.1	155–162
15 Dec.	30.6–31.7	Late Apr.–Early May	Mid May–Late May	30.6–31.7	155–162

There was a significant effect of sowing dates on irrigation water requirement of Boro rice crop. The earliest and delayed sowing required 50–103 mm more irrigation water than the average irrigation requirement of Boro rice (Table 2). The rice variety IET 4786 required 15–31 mm less irrigation water than the other two varieties. During 2017–18, about 5% higher irrigation water was consumed compared to 2016–17.

3.2. Effect on Yield Attributes

Sowing dates and varieties had significant effects on yield attributes (panicles m^{-2}, spikelets $panicle^{-1}$, spikelet fertility % and 1000-grain weight) of Boro rice (Table 4). In both the years, yield attributes were lower with earliest sowing on 1 October and with subsequent sowing date it increased significantly. The panicles m^{-2} decreased by 19.6, 22.4, 14.9 and 26.6% due to sowing on D3, D4, D5 and D6 respectively compared to D2 sowing. In D1 sowing there was 48 numbers less spikelets $panicle^{-1}$ than D2 sowing. Delaying sowing beyond D2 resulted in lesser numbers of spikelets $panicle^{-1}$ by 4.5, 6.4, 16.0 and 24.4% in D3, D4, D5 and D6 respectively. Spikelet fertility was at par (86.5–88.8%) for D2, D3 and D4. It decreased by 3–6% when sown beyond the above dates. There was varietal difference with respect to yield attributes. Averaged over the sowing dates and years, the variety WGL 20471 had 25 and 47 more number of panicles m^{-2} than Bidhan 2 and IET 4786, respectively. Highest mean spikelets $panicle^{-1}$ was observed in Bidhan 2 (157 spikelets $panicle^{-1}$) followed by WGL 20471 (125 spikelets $panicle^{-1}$) and IET 4786 (122 spikelets $panicle^{-1}$). The average fertility of spikelets was 86.4–87.0% for WGL 20471 and Bidhan 2, whereas it was the lowest (81.6%) in case of IET 4786. The mean 1000-grain weight was 19.1–19.3 g for WGL 20471 and IET 4786, whereas it was 20.6 g for Bidhan 2.

The varieties WGL 20471 and IET 4786 are having finer grains compared to Bidhan 2. Therefore, the market price of WGL 20471 and IET 4786 was higher compared to Bidhan 2.

Table 4. Effect of different sowing dates and varieties of Boro rice on yield attributes (panicles m^{-2}, spikelets $panicle^{-1}$, spikelet fertility and 1000 grain weight) observed at Canning Town, West Bengal, India (Pooled mean data of main effects).

Treatments	Yield Attributes			
	Panicles m^{-2}	**Spikelets $Panicle^{-1}$**	**Spikelet Fertility (%)**	**1000 Grain wt (g)**
Sowing dates				
D1	345 ^{bc}	108 ^{e}	82.2 ^{bc}	19.43
D2	429 ^{a}	156 ^{a}	88.8 ^{a}	19.99
D3	345 ^{bc}	149 ^{ab}	86.5 ^{ab}	19.81
D4	333 ^{bc}	146 ^{b}	86.6 ^{ab}	20.24
D5	365 ^{b}	131 ^{c}	84.5 ^{b}	19.60
D6	315 ^{c}	118 ^{d}	81.4 ^{c}	18.98
SEm±	13	3	0.9	0.25
$LSD_{0.05}$	42	9	2.7	ns
Varieties				
V1	379 ^{a}	125 ^{b}	86.4 ^{a}	19.12 ^{b}
V2	354 ^{ab}	157 ^{a}	87.0 ^{a}	20.58 ^{a}
V3	332 ^{b}	122 ^{b}	81.6 ^{b}	19.33 ^{b}
SEm±	11	2	0.5	0.17
$LSD_{0.05}$	32	7	1.5	0.49
Years				
2016–17	310 ^{b}	133	83.6 ^{b}	19.65
2017–18	400 ^{a}	136	86.4 ^{a}	19.70
SEm±	10	1	0.4	0.12
$LSD_{0.05}$	27	ns	1.2	ns
Interaction	ns	ns	ns	ns

D1, 1 October, D2, 15 October, D3, 1 November, D4,15 November, D5, 1 December and D6, 15 December; V1, WGL 20471, V2, Bidhan 2 and V3, IET 4786; SEm±, Standard error of means; ns, not significant; Means with the same letter in a column are not significantly different.

3.3. Effect on Grain and Straw Yields

The mean grain yield was reduced by 41.5% when Boro rice was sown the earliest, on 1 October, compared to 15 October sowing. This was mainly due to the incidence of diseases and low temperature regime during the reproductive stage when sown on 1 October. Highest grain yield range (4.11–5.51 t ha^{-1}) was observed in the sowing on 15 October (Tables 5 and 6); however, during the second year, grain yield was greater than 5.5 t ha^{-1} in the mid-four sowing dates from 15 October to 1 November. On average, yield penalty was 13% due to delay in sowing to 15 December (Tables 5 and 6). Bidhan 2 and WGL 20471 produced additional 1.8 t ha^{-1} grain yield over IET 4786. Overall, 56% higher yield was observed during 2017–18 compared to 2016–17. This may be due to less soil salinity in the former year than the later year.

There was a significant interaction between sowing dates and varieties with respect to grain and straw yields. The highest grain yield of IET 4786 was observed in second sowing date (D2), and beyond that the grain yield of this variety drastically reduced during both the years (Tables 5 and 6). This indicates that in case of salinity-susceptible varieties, the sowing date should be early, and in case of tolerant varieties (WGL 20471 and Bidhan 2 are not affected by increase in soil and water salinity with time) sowing can be delayed. The straw yield in the first date of sowing during 2016–17 was 67% higher compared to 2017–18, this might have been due to the effect of lower minimum temperature regimes during the months of Nov–Dec 2016 compared to Nov–Dec 2017 (Table 1). The mean straw yield declined by about 13.6% when sowing was delayed beyond 1 November. However, this was more conspicuous in the case of rice variety IET 4786 (23.4% decline) compared to Bidhan 2 and WGL 20471.

Table 5. Grain and straw yields (t ha^{-1}) of Boro rice varieties under different sowing dates at Canning Town, West Bengal, India during 2016–17.

Dates of Sowing	Grain Yield (t ha^{-1})				Straw Yield (t ha^{-1})			
	V1	V2	V3	Mean	V1	V2	V3	Mean
D1	3.06 ^{bc}	2.48 ^{d}	3.23 ^{b}	2.92 ^{bc}	8.04 ^{a}	7.89 ^{a}	6.57 ^{a}	7.50 ^{a}
D2	3.40 ^{b}	3.98 ^{b}	4.96 ^{a}	4.11 ^{a}	4.93 ^{b}	5.91 ^{b}	5.67 ^{b}	5.51 ^{b}
D3	4.06 ^{a}	5.10 ^{a}	1.40 ^{d}	3.52 ^{ab}	4.45 ^{c}	5.62 ^{bc}	4.85 ^{c}	4.97 ^{b}
D4	2.67 ^{c}	3.18 ^{c}	1.32 ^{d}	2.39 ^{c}	4.28 ^{c}	3.93 ^{d}	2.11 ^{d}	3.44 ^{c}
D5	4.25 ^{a}	2.95 ^{cd}	2.49 ^{c}	3.23 ^{b}	4.36 ^{c}	3.18 ^{e}	4.48 ^{c}	4.01 ^{c}
D6	2.98 ^{c}	2.76 ^{d}	2.52 ^{c}	2.75 ^{bc}	4.99 ^{b}	5.35 ^{c}	5.79 ^{b}	5.38 ^{b}
Mean	3.40	3.41	2.65	-	5.17	5.31	4.91	-
Comparisons	C1	C2	C3	C4	C1	C2	C3	C4
SEm±	0.23	0.16	0.40	0.13	0.29	0.17	0.43	0.15
$LSD_{0.05}$	0.71	0.48	1.17	0.40	0.92	ns	1.25	0.46

D1: 1 October, D2: 15 October, D3: 1 November, D4:15 November, D5: 1 December and D6: 15 December; V1: WGL 20471, V2: Bidhan 2 and V3: IET 4786; C1: comparison between two main-plot treatment means averaged over all sub-plot treatments; C2: comparison between two sub-plot treatment means averaged over all main-plot treatments; C3: comparison between two sub-plot treatment means at the same main-plot treatment and C4: comparison between two main-plot treatment means at the same or different sub-plot treatments (i.e., means of any two treatment combinations).Means with the same letter in a column are not significantly different.

Table 6. Grain and straw yields (t ha^{-1}) of Boro rice varieties under different sowing dates at Canning Town, West Bengal, India during 2017–18.

Dates of Sowing	Grain Yield (t ha^{-1})				Straw Yield (t ha^{-1})			
	V1	V2	V3	Mean	V1	V2	V3	Mean
D1	2.74 ^{d}	2.66 ^{d}	2.73 ^{b}	2.71 ^{c}	4.83 ^{d}	4.36 ^{e}	4.27 ^{b}	4.49 ^{c}
D2	5.95 ^{b}	6.32 ^{b}	4.25 ^{a}	5.51 ^{a}	6.64 ^{b}	6.59 ^{c}	4.85 ^{a}	6.03 ^{a}
D3	6.69 ^{a}	6.95 ^{a}	3.05 ^{b}	5.57 ^{a}	7.07 ^{a}	7.64 ^{a}	3.32 ^{c}	6.01 ^{a}
D4	7.08 ^{a}	7.19 ^{a}	2.95 ^{b}	5.74 ^{a}	7.11 ^{a}	7.32 ^{ab}	3.30 ^{c}	5.91 ^{a}
D5	6.85 ^{a}	6.85 ^{a}	2.84 ^{b}	5.51 ^{a}	7.00 ^{a}	7.05 ^{b}	3.47 ^{c}	5.84 ^{a}
D6	5.53 ^{c}	5.76 ^{c}	2.08 ^{c}	4.45 ^{b}	6.03 ^{c}	6.06 ^{d}	3.48 ^{c}	5.19 ^{b}
Mean	5.81	5.95	2.98	-	6.45	6.50	3.78	-
Comparisons	C1	C2	C3	C4	C1	C2	C3	C4
SEm±	0.16	0.17	0.42	0.13	0.19	0.14	0.34	0.12
$LSD_{0.05}$	0.52	0.53	1.29	0.40	0.58	0.43	1.04	0.35

D1: 1 October, D2: 15 October, D3: 1 November, D4:15 November, D5: 1 December and D6: 15 December; V1: WGL 20471, V2: Bidhan 2 and V3: IET 4786; C1: comparison between two main-plot treatment means averaged over all sub-plot treatments; C2: comparison between two sub-plot treatment means averaged over all main-plot treatments; C3: comparison between two sub-plot treatment means at the same main-plot treatment and C4: comparison between two main-plot treatment means at the same or different sub-plot treatments (i.e., means of any two treatment combinations). Means with the same letter in a column are not significantly different.

3.4. Irrigation Water Productivity (IWP) and Economic Water Productivity (EWP)

Lowest IWP was observed with earliest and delayed sowing dates during both the years (about 0.2 kg m^{-3} in 2016–17 and 0.2–0.3 kg m^{-3} in 2017–18) irrespective of variety (Figure 1). Though highest IWP was observed in the second sowing date (D2) in 2016–17, it did not vary significantly up to fourth sowing date (D4) during 2017–18. IWP of the fifth sowing date (D5) was 0.39 kg m^{-3} in 2017–18, remained at par with third (D3) and fourth (D4) sowing dates (0.42 kg m^{-3}). Both the rice varieties WGL 20471 and Bidhan 2 were significantly superior in terms of IWP compared to IET 4786 during both the years. The mean IWP for WGL 20471, Bidhan 2 and IET 4786 was 0.34, 0.35 and 0.22 kg m^{-3}, respectively. Sowing dates and varieties had significant interaction effect on EWP. Variety WGL 20,471 was not affected in terms of EWP due to varying sowing dates during the first year. For the variety Bidhan 2, EWP was lower in the earliest (15 Oct.) and most delayed (15 Dec.) sowing dates. The variety IET 4786, recorded higher values of EWP (₹ 6.56–6.95 m^{-3}) for D2, which was at par with D1 during the first year and with D1, D3, D4 and D5 during the second year. However, during 2017–18, the EWP of all the three varieties was at par for D2, D3 and D4. Similarly, the EWP of all the three varieties for D5 was at par with D3 and D4 during 2017–18 (Figure 2). The EWP was ₹ 2.7–5.2 m^{-3} in 2016–17 and ₹ 3.2–7.5 m^{-3} in 2017–18. Delay in sowing for WGL 20471 and Bidhan 2 could be affordable but not for IET 4786 to get higher EWP. The variation in mean EWP of varieties during 2016–17 were ₹ 3.9, 3.5 and 3.3 m^{-3} for WGL 20471, Bidhan 2 and IET 4786, respectively. During 2017–18, EWP was significantly higher for WGL 20471 (₹ 7.4 m^{-3}) and Bidhan 2 (₹ 6.6 m^{-3}) compared to IET 4786 (₹ 4.1 m^{-3}).

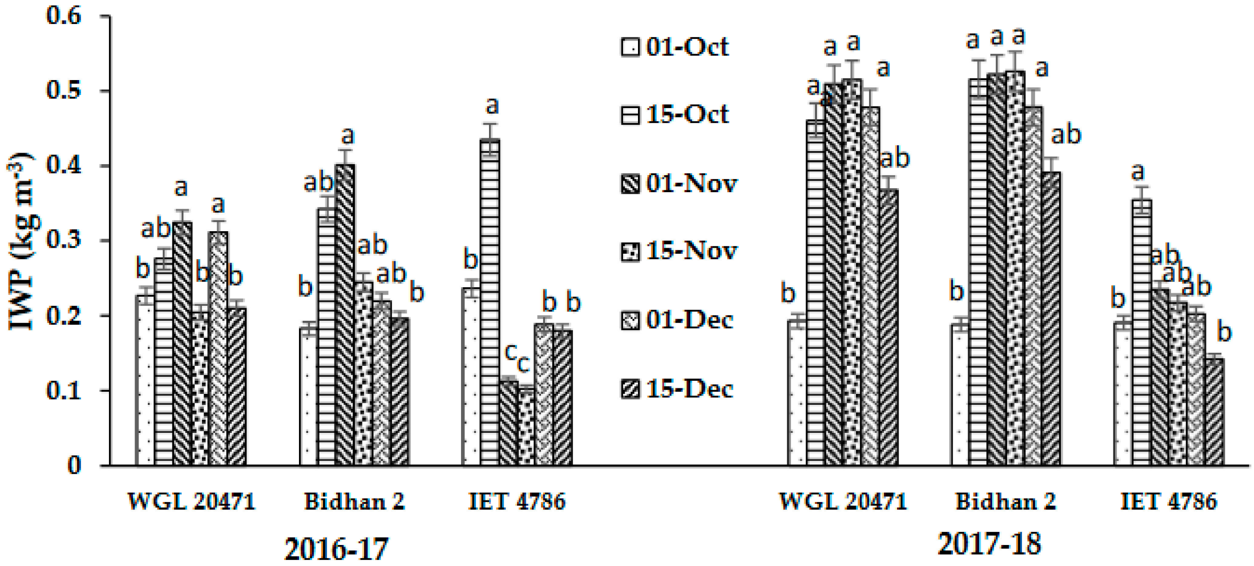

Figure 1. Irrigation water productivity (IWP) of Boro rice as affected by sowing dates and varieties during 2016–17 and 2017–18 at Canning Town, West Bengal, India. Vertical error bars indicate ±SE. Means depicted in bars with the same letter within a variety are not significantly different.

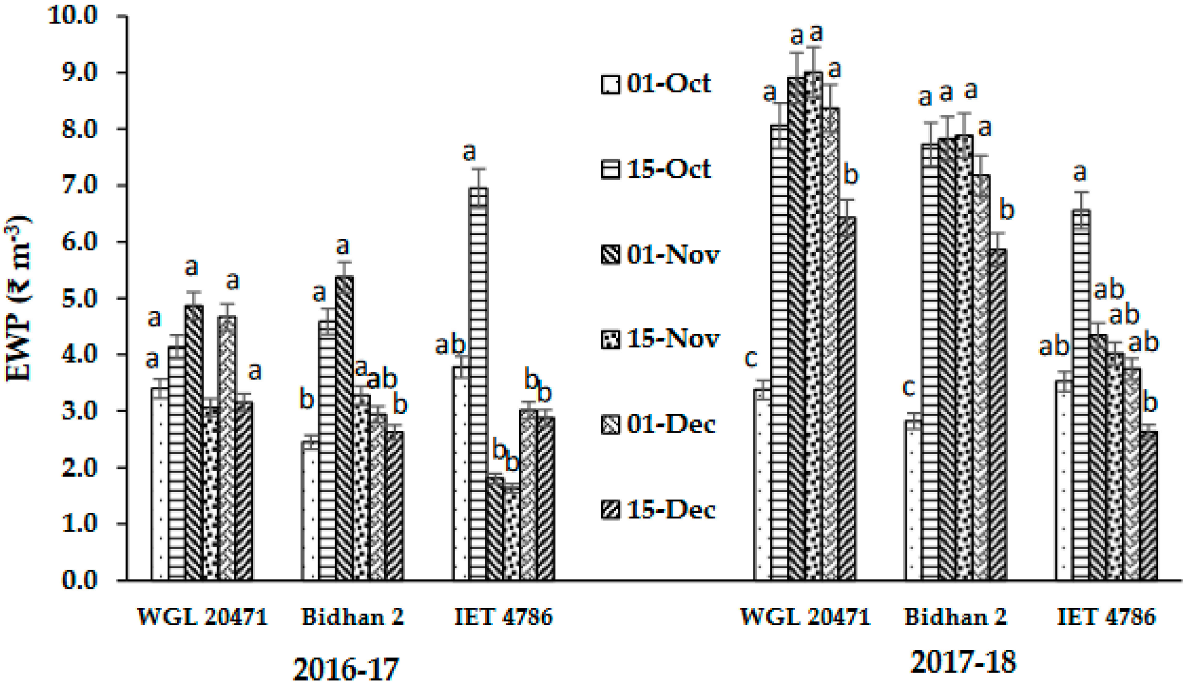

Figure 2. Economic water productivity (EWP) of Boro rice as affected by sowing dates and varieties during 2016–17 and 2017–18 at Canning Town, West Bengal, India. The value of one US dollar ($) during 2016–17 and 2017–18 was ₹ 65 and ₹ 68, respectively. Vertical error bars indicate ±SE. Means depicted in bars with the same letter within a variety are not significantly different.

3.5. Changes in Soil and Water Salinity

The soil salinity increased over time during both the years with lowest salinity at the beginning of the season (November) and highest during the month of April (Table 7). The mean soil salinity (ECe) during 2016–17 was 4.03 dS m^{-1}, whereas during 2017–18, it was 3.16 dS m^{-1}. The irrigation water salinity varied from 1.15–1.76 dS m^{-1} during 2016–17 and it was in the range of 1.42–1.77 dS m^{-1} during 2017–18. The field water salinity increased up to February 2017 during 2016–17 and up to April 2018 during 2017–18. The decrease in field water salinity beyond February 2017 was mainly due to the rainfall of 49 mm (Table 1) received during the month of March 2017. There was no or scanty rainfall from January–March 2018, and as a result the mean field water salinity was higher (1.78 dS m^{-1}) during the Boro season of 2017–18 compared to that (1.65 dS m^{-1}) during 2016–17.

Table 7. Mean (±standard error) soil and water salinity (dS m^{-1}) during the Boro seasons of 2016–17 and 2017–18 at Canning Town, West Bengal, India.

Months	2016–17			2017–18		
	Soil Salinity (ECe)	IW * Salinity (EC)	# Field Water Salinity (EC)	Soil Salinity (ECe)	IW Salinity (EC)	Field Water Salinity (EC)
Nov.	2.53 ± 0.37	1.28 ± 0.05	1.37 ± 0.07	2.20 ± 0.61	1.42 ± 0.03	1.51 ± 0.04
Dec.	3.26 ± 0.25	1.76 ± 0.04	2.04 ± 0.05	2.35 ± 0.46	1.52 ± 0.02	1.77 ± 0.05
Jan.	3.96 ± 0.32	1.57 ± 0.03	1.72 ± 0.06	2.93 ± 0.61	1.58 ± 0.04	1.79 ± 0.06
Feb.	4.18 ± 0.26	1.15 ± 0.04	1.84 ± 0.07	3.30 ± 0.59	1.77 ± 0.06	1.85 ± 0.08
Mar.	4.99 ± 0.25	1.39 ± 0.02	1.51 ± 0.06	3.90 ± 0.48	1.72 ± 0.03	1.87 ± 0.05
Apr.	5.23 ± 0.27	1.32 ± 0.07	1.42 ± 0.08	4.30 ± 0.53	1.72 ± 0.04	1.89 ± 0.07

* IW = Irrigation water; # Paddy field water salinity; ECe = Electrical conductivity of saturation extract; EC = Electrical conductivity.

4. Discussion

Boro rice is a major dry season crop in the coastal region of the Ganges Delta, which is fully dependent on ground water irrigation [22]. In the present study, our hypotheses that sowing dates and varieties have significant interactions with respect to yield and water productivity of Boro rice was accepted. Sowing dates had a significant effect on yield attributes and finally on yield. Early sowing had been advocated as a better water management strategy for rice [23]. However, in our study the earliest sowing was not congenial, as the yield and water productivity was the lowest. Similar results were observed for the most delayed sowing on 15 of December.

Low temperature stress (12 °C) of 6–9 days at the flowering stage severely decreased yield per plant and yield attributes, but increased time to 50% grain filling and maturity by 5–12 days [24]. Due to this high temperature and the evaporation rates, the irrigation water demand of the crop increases, and as a result the crop water requirement is higher due to very late sowing [8]. Significant effect of sowing date was observed on panicle number m^{-2}, spikelets $panicle^{-1}$ and 1000-grain weight [25]. Delayed sowing resulted in a lower grain yield because of the decreased 1000-grain weight and an increase in sterile spikelets $panicle^{-1}$. Low temperature (15–19 °C) during the reproductive stage of rice resulted in yield penalty of 19–29%, depending upon the variety, as it impairs microspore development and causes the production of sterile pollen grains, resulting in poor grain filling and spikelet fertility [26]. Rice plants are considered sensitive to heat stress, especially during reproductive growth phase. On average, a 12% and 9% reduction in paddy yield was obtained in sowing dates where heat stress coincided with reproductive and seedling growth, respectively [27]. Delayed sowing exposes the rice crop to higher air temperatures during May. Therefore, adjustment in sowing dates is a simple yet powerful tool for adapting to the effects of potential global warming [28].

The results of this study revealed that water productivity of Boro rice is not only a function of the amount of irrigation water use but also dependent on sowing dates and variety used. Recent studies [4] showed that there is limited scope for improving farmers' water management practices in Boro rice. Both IWP and EWP of rice in West Bengal is not encouraging (IWP: 0.24 kg m^{-3}; EWP: ₹ 3.46 m^{-3}) compared to other eastern Indian states such as Odisha (IWP: 0.35 kg m^{-3}; EWP: ₹ 4.77 m^{-3}), Assam (IWP: 0.38 kg m^{-3}; EWP: ₹ 4.73 m^{-3}) and Chhattisgarh (IWP: 0.68 kg m^{-3}; EWP: ₹ 11.66 m^{-3}) [29]. Therefore, findings of this research have relevance in boosting the irrigation water productivity in the coastal salt affected region of West Bengal, India. Pearson's correlation between IWP and Boro rice yield attributes, particularly panicles m^{-2}, spikelets panicle^{-1} and spikelet fertility (%) was found to be significant (r = 0.48–0.70 ***). Similarly, the correlation between IWP and grain yield (r = 0.96 ***) was significantly higher (Supplementary Table S3). If rice is the crop choice, increasing water productivity should be the focus, or else diversification options to other low water-requiring crops during Boro season should be contemplated. Diversification to legume crops may be an alternative as there is a deficit of production to meet the demand of pulses (production: 23.15 mt; demand: 26.64 mt) [30]. However, in the salt affected areas, where high salinity development does not allow growing of pulse crops, comparatively low water requiring crops such as maize, potato and mustard may be grown to boost economic water productivity [31–33].

Varietal selection in the context of Boro rice production in the Asian continent is one of the major options to increase IWP [34]. The differential yield response of varieties to various sowing dates was found to be due to their differential tolerance against high temperature stress at vegetative and reproductive growth phases. In case of the varieties WGL 20471 and Bidhan 2, sowing can be delayed up to 15 December. However, in case of variety IET 4786, early sowing within 15 October is beneficial and any delay in sowing resulted in a significant loss in yield. Differential response of rice cultivars was observed when the cultivars were given different periods of low temperature exposure [24]. Sowing window of Boro rice is also dependent on the previous Kharif season rice variety used, land type and method of crop establishment. When shorter duration rice allows earlier harvest of Kharif rice, low-lying waterlogged situation does not allow selection of such varieties; therefore, there is delay in the harvest of Kharif rice crop. In such situations, where the Kharif rice harvest is delayed, the sowing window of 1 November to 1 December may be selected. Wherever possible, alternative rice crop establishment of drum seeding may be practiced to utilize the carryover soil moisture of the previous Kharif season [10]. Tolerance to abiotic stresses is one of the most significant criteria for selection of rice variety for the salt affected region of the Ganges Delta [35]. In this study the grain yield of the less tolerant (4–6 dS m^{-1}) variety was 2.65–2.98 t ha^{-1}, whereas when the tolerance level of rice variety increased to 6–8 dS m^{-1}, the yield jumped to 3.41–5.95 t ha^{-1}. Modelling investigations project a worsening situation of soil salinity in the Ganges-Brahmaputra-Meghna mega-delta [36]. Therefore, there is a need for breeding Boro rice varieties for higher salt tolerance (>12 dS m^{-1}) to sustain the yield level under changing climate.

Climate change effects on growing season weather conditions, soil and water salinity will be more intense and by the end of the 21st century, the dry season is expected to be 2–3 weeks longer, irrigation water is likely to be become more saline than what it was in 2014, and so salt accumulation becomes significant [37]. Rice is an obvious crop choice in saline soils, as standing water input flushes out the salts beyond the crop root zone. However, it needs a huge quantity of good quality water. In our study, the irrigation water salinity was in the range of 1.40–1.77 dS m^{-1}, which is considered as slightly saline [38]. This ground water was extracted from a deeper layer of the aquifer (~300 m below ground level), which was a cost intensive option. Farmers in this region mostly extract the ground water for irrigation by shallow tube wells from about 100 m depth with irrigation water salinity of 3.65–5.38 dS m^{-1} (moderate to high saline), resulting in soil salinity of 5.79–10.05 dS m^{-1} and low grain yield (1.87 t ha^{-1}) of Boro rice [39]. However, when irrigation water is slightly saline to good quality, Boro rice cultivation is profitable in the salt affected region (mean output: input ratio of 1.66) compared to Kharif rice cultivation with an output:input ratio of 1.40 (Supplementary Table S4). In the coming years, the Boro rice area in the coastal zone is expected to increase rapidly to meet the food demand of burgeoning population as well as to meet the livelihood under higher risk of Kharif rice due to climate change. Therefore, use of shallow ground water as irrigation for Boro rice will increase and large-scale extraction will push the sea water interface further inland [40]. Soil salinization is therefore expected to increase in the coastal zones of the Ganges Delta. In this situation, the harvesting of rainwater and its utilization in dry season cropping is the best option, and use of this fresh water for crop cultivation is one of the important strategies to remove salts due to higher crop evapotranspiration [41]. Selection of salt tolerant varieties is one of the important options under increasing soil and water salinity. In our study, out of the three varieties, growing of WGL 20471 was found to be profitable with higher net return and output:input ratio (Supplementary Table S5). Renovation of existing water harvesting structures and excavation of new ones, efficient water management, mulching, salt tolerant crops/varieties, in-situ use of field water and above all optimum sowing date of crops are some of the strategies that need to be adopted to sustain rice yields in these stress-prone regions.

5. Conclusions

Boro rice yield and irrigation water productivity were significantly affected by sowing dates and varieties. The selection of sowing window depends on the type of variety to be grown. Sowing date of varieties with higher salt tolerance may be delayed, but varieties with less salt tolerance should be sown around 15 October–1 November. Early sowing before 15 October and delayed sowing after 15 December are not suitable for Boro rice, irrespective of varieties chosen in the coastal region of the Ganges delta. The yield varies over years, due to variations in weather conditions, soil and water salinities. Higher rainfall during the active growing period (March) reduces the irrigation water requirement. Therefore, a strategy involving optimum sowing window, salt tolerant varieties and effective use of dry season rainfall favors the performance of Boro rice in the salt-affected coastal region.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/agronomy11122413/s1, Table S1: Level of significance (*p*-values) of the effects of treatments (sowing dates and varieties), years and their interaction for disease score, irrigation water requirement (mm), irrigation water productivity (kg m^{-3}), economic water productivity (₹ m^{-3}), yield attributes and yield of Boro rice during 2016–17 and 2017–18; Table S2: Initial soil properties of the experimental site at ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengal, India; Table S3: Pearson's product-moment correlations between different parameters of Boro rice studied during 2016–17 and 2017–18 in the coastal zone of West Bengal, India; Table S4: Economics of Kharif and Boro rice cultivation (₹ ha^{-1}) in the coastal zone of West Bengal, India during 2017–18; Table S5: Economics (₹ ha^{-1}) of Boro rice cultivation under different sowing dates and varieties during 2017–18 at Canning Town, West Bengal, India.

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