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Impact of *Boro* Rice Establishment Methods on Soil Salinity, Crop Growth and Yield in South-West Salt-Affected Coastal Region of Bangladesh

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***Boro* rice (irrigated rice) cultivation in the saline area of the coastal region of Bangladesh is limited because of increased soil and water salinity, lack of freshwater for irrigation and proper agronomic practices. An on-farm field trial was conducted in the farmer's field at Dacope upazila in Khulna district of Bangladesh during the dry season (*Boro*) in 2022-23 to evaluate the growth and yield of *Boro* rice with different establishment methods and soil salinity dynamics with each type of establishment. The tested establishment methods were: (i) conventional tillage wet direct seeding (CTWDS), (ii) no-tillage wet direct seeding (NTWDS), (iii) conventional tillage transplanting rice (CTTP) and (iv) conventional tillage dry direct seeding (CTDDS). Grain yield was significantly higher (13-63%) in CTTP treatment than the other treatments. The direct seeding methods saved irrigation water but had a lower panicle-bearing tiller and grain per panicle which was related to lower yield. The direct seeding methods had also higher soil salinity. In conclusion, *Boro* rice cultivation with conventional transplanting (CTTP) method in the saline area maintained a higher yield and lower soil salinity than the direct seeding method.**

(***Key words:*** *Boro rice, Direct seeding, Salinity, Transplanting*)

In the south-west coastal region of Bangladesh, dry season rice cultivation (*Boro* rice) is limited due to elevated soil and water salinity, freshwater scarcity, and lack of improved agronomic management. In this area, farmers mainly grow long-duration low-yielding local varieties of transplanted (T) *Aman* rice during wet season which is usually established in August/September and harvested in December/January (Mondal *et al.,* 2015a; Paul *et al.,* 2020b; Paul *et al.,* 2021d). The late harvest of T. *Aman* rice delays the planting of non-rice (*Rabi*) crops and *Boro* rice during the dry season. This delay crop establishment suppresses the crop growth and yield due to later high soil salinity and the scarcity of fresh irrigation water (Paul, 2020). Therefore, most of the land remains uncultivated which results in low cropping intensity (Bell *et al.,* 2019; Kabir *et al.,* 2019; Mondal *et al.,* 2020). The salinity of river and canal water increases with the progress of the dry season (ECw is higher than 2 dS m^{-1} after mid-February) because of decreased upstream freshwater flow. There is, therefore, a crisis in the supply of irrigation water in the later part of the growing season (Mila *et al.,* 2021). In addition, *Rabi* crops such as sunflower, maize, and watermelon are often completely damaged because of seasonal heavy rainfall and natural disasters during the dry season (Islam *et al.,* 2022; Paul *et al.,* 2020a; Paul *et al.,* 2021c; Paul *et al.,* 2022). Hence, in some areas, growing irrigated *Boro* rice can be an option to avoid waterlogging risk while increasing cropping intensity in the coastal region (Mondal *et al.,* 2015b).

Some farmers grow *Boro* rice where they prepare the seed bed in December/January and transplant the seedlings in the main field during last week of January

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**Corresponding author:* E-mail: plcpauliwm@yahoo.com or first week of February. The common practice of *Boro* rice cultivation is transplanting seedlings into soil in puddled conditions. *Boro* rice needs (145-155 days growth duration) about 1200-1500 mm (farmer's practice) of water for seedbed preparation, puddling of soil for transplanting and to meet water requirement throughout the growing season (Acharjee *et al.,* 2022; Paul *et al.,* 2013; Yesmin *et al.,* 2019). However, irrigation water at permissible level of salinity is very scarce in the coastal area. The lack of fresh irrigation water often reduces the rice yield or damages the crop. Some strategies to increase fresh/less saline irrigation water availability are conserving rainwater in the pond or blocked canal or stored water in the river/canal through temporary construction of an earthen cross dam or closing the sluice gate (Hossain *et al.,* 2019; Paul *et al.,* 2020a). *Boro* rice cultivation can be increased in the saline area through maximum utilization of this stored water. *Boro* rice already plays a vital role in national food security, contributing about 60% of Bangladesh's rice production (Rahman *et al.,* 2019). The Bangladesh government aims to increase rice production from the coastal region as the northern part of the country is fully intensified (where most *Boro* rice is grown with overexploited groundwater resources).

The key challenges of increasing *Boro* rice production in the saline area are managing soil salinity and increasing the availability of freshwater (Mainuddin *et al.,* 2020; Mondal *et al,* 2020; Paul *et al.,* 2021a). The soil and water salinity start to increase in December and typically climbed to a peak in March and April (Paul *et al.,* 2021b). The timing of salinity stress has a significant impact on rice growth and yield. Some studies showed that the young seedlings were the most sensitive to salinity (Flowers and Yeo, 1981; Heenan *et al.,* 1988). Other studies indicated flowering stage of rice is very sensitive to salinity (Zeng and Shannon, 2020). Key yield components affected by salinity are the grain formation, the number of spikelets per panicle and seed weight at the flowering stage (Khatun *et al.,* 1995; Sajjad, 1984). One conclusion that can be drawn from timing of salinity studies is that yields may be increased if the freshwater availability can be increased during the flowering stage and the root zone salinity can be minimized. In many areas of the world, direct seeding of rice is expanding to advance the establishment time, reducing labour costs, and save irrigation water (Cabangon *et al.,* 2002; Kumar and Ladha, 2011; Tabbal *et al.,* 2002). Huang *et al.* (2011) showed that no tillage direct seeding is effective for reducing production cost and conservation of soil in Hunan province in China. Balasubramanian and Hill (2002) summarized the benefits of direct seeding as higher water productivity, higher tolerance of water deficit and higher profit. Rashid *et al.* (2009) conducted research in the north-west region of Bangladesh on the direct seeded and transplanted rice for productivity and resources assessment. They found that there was no difference in grain yield between direct seeding and transplanting in puddled conditions, but productivity was lower with direct seeding (45 kg grain ha^{-1} day^{-1}) than with transplanted rice (55 kg grain ha^{-1} day^{-1}).

In the salt-affected coastal region of Bangladesh, the impacts of direct seeded *Boro* rice establishment on soil salinity, soil physical structure, grain yield and yield components need a greater understanding. The present study was therefore undertaken to evaluate the growth and yield of *Boro* rice with different establishment methods and to quantify the water productivity and soil salinity dynamics with each type of establishment.

MATERIALS AND METHODS

Study area

A field experiment was conducted at Dacope upazila in Khulna district during the *Boro* 2022-23 season with different establishment methods for *Boro* rice cultivation. The experimental field is located on the Ganges Tidal Flood plain in agro-ecological zone 13 (AEZ13) at 24.75° N latitude and 90.50° E longitude at an elevation of 3-5 m above sea level (Paul *et al.,* 2021c). The land is low lying where farmers usually grow long - duration local varieties of T. *Aman* rice in the wet season. During the dry season, the area adjacent to river channels are regularly inundated by saline water due to the high tidal range in the Bay of Bengal. In this area, the sub - tropical climate is characterized by an average annual rainfall of 1800 mm (Paul *et al.,* 2020a), a cool dry winter from November to February, and a hot and humid summer from March to June. The rainfall and temperature vary during the growing season areas as shown in Fig. 1. Before starting the field trial, initial soil samples were collected from 0 -15 cm soil depth to measure soil physico-chemical properties. The soil had a silty clay texture, a bulk density of 1.31 Mg m^{-3}, a pH of 7.6, an $EC_{1:5}$ of 0.44 dS m^{-1}, organic carbon content of 13 g kg^{-1}, a total nitrogen content of 1.4 g kg^{-1}, while exchangeable sodium was 0.91 cmol kg^{-1}, exchangeable potassium was 0.65 cmol kg^{-1}, exchangeable calcium was 11.7 cmol kg^{-1}, exchangeable magnesium was 16.3 cmol kg^{-1}. After the harvesting of T. *Aman* rice (*Kharif*), the land was fully saturated, which saved irrigation water for the land preparation for *Boro* rice.

Experimental details

The experiment was carried out to test four establishment methods namely: (i) conventional tillage wet direct seeding - CTWDS (sprouted rice seeds sown in lines on puddled soil), (ii) no tillage wet direct seeding-NTWDS (sprouted rice seeds sown in lines on non-puddled soil after zero tillage), (iii) conventional tillage transplanting rice - CTTP (a 30 - day - old seedlings transplanted in puddled soil) and (iv) conventional tillage dry direct seeding - CTDDS (sprouted rice seeds drilled in lines after conventional tillage). The field was laid out in a randomized complete block (RCBD) design with three replications in individual plots of 3 m × 3 m. Each plot was separated by an earthen levee (15 cm height and 30 cm width) with 1.0 m buffer zone between the plots. During CTWDS and NTWDS establishments after T. *Aman* rice harvest (*Kharif*), the soil was fully saturated (wet soil). For the first establishment (CTWDS), the land was puddled manually with a spade after adding 40 mm of water. For non-puddled rice sowing in saturated soil (NTWDS), a hand-held tine was used to make a furrow (zero tillage). Sprouted rice seeds were sown in lines on puddle and non-puddled soil on 28 December 2022. In the treatment CTTP, 30 - day - old seedlings were transplanted into puddled soil at 3 seedlings per hill on 28 January 2023 and in treatment CTDDS, sprouted rice seeds were drilled in lines after dry tillage on 29 January 2023. The seed rate for CTWDS, NTWDS and CTDDS treatments was 40 kg ha^{-1} and in treatment CTTP, the spacing was 20 cm × 20 cm in between rows and hills (Fig. 2). For puddled soil, fertilizer (urea, triple super phosphate, muriate of potash, gypsum, and zinc) was applied at 260 - 90 - 150 - 60 - 8 kg ha^{-1} during land preparation. Fertilizer except urea was applied as surface banding (placed at 2 - 3 cm depth) along the line at the above rate. Urea fertilizer was broadcast in three splits at 15 DAS (days after sowing), 35 DAS, and just before panicle initiation (56 DAS). For CTWDS, NTWDS and CTDDS treatments, five hand weedings were done throughout the season; whereas, three hand weeding was needed for CTP treatment. For controlling stem borer attacks, insecticide (Cartap Hydrochloride) was sprayed three times at 1.4 kg per hectare, and to control blast disease, Tricyclazole was used two times in all treatments at 1.2 kg per hectare. The crops were harvested on 30 April, 2023 for treatments CTWDS and NTWDS, 09 May, 2023 for treatment of CTTP and 20 May, 2023 for treatment CTDDS. In each plot, a 1 m^2 area was selected to measure plant height, number of tillers, and panicle-bearing tillers at the vegetative, flowering, and maturity stages. Panicle bearing tiller rate

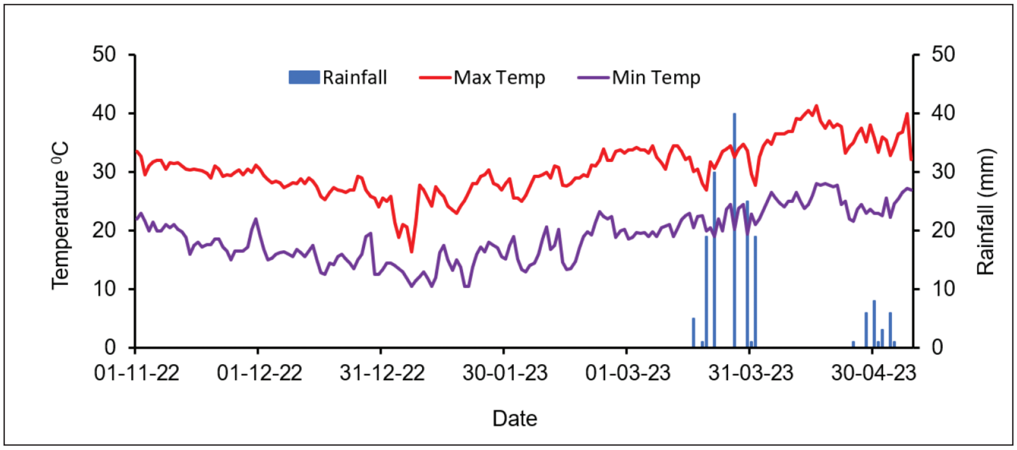

Fig. 1. *Seasonal rainfall and temperature during the Boro season of 2022-23 at Dacope, Khulna*

was estimated as the ratio of panicle number at maturity to maximum tiller number. At harvest, the plants were hand-threshed to separate grains and straw. From each panicle, filled and unfilled grains were separated and then the filled grain percentage was calculated. Grain weight (t ha^{-1}) was calculated from 6 m^2 and the yield was adjusted at 14% moisture content. The dry weight of filled and unfilled grains and straw was determined by oven drying at 70°C to constant weight. The harvest index was determined as the ratio of total aboveground biomass (total dry matter of straw with filled and unfilled grains) to the dry weight of filled grain. The biological yield was calculated as the sum of grain yield and straw yield.

Wet direct seeding in puddled soil

Wet direct seeding in non-puddled soil

Transplanting in puddled soil

Dry direct seeding in wet (but not saturated) soil

Fig. 2. *Field view of Boro rice under different establishment methods (Photos were taken on 17 February 2023)*

Irrigation water management

In the experimental site, river water salinity increased with the progress of the dry season. Therefore, less saline water (1.5 dS m^{-1}) was trapped in the canal before it became too saline. For preparing soil puddling to sow seed under treatment CTWDS, around 40 mm of water was needed but there was no water added for treatment NTWDS. In treatment CTTP, around 180 mm of water was applied for land preparation, whereas 30 mm of water was used to wet the soil surface before seed sowing in treatment CTDDS. Throughout the growing season, continuous standing water around 3-5 cm above the soil surface was maintained in treatment CTTP. However, for direct seeding, water was applied up to saturation for the first 30 days as the seedlings were short. After that, water was applied to maintain the water level at 3 - 5 cm above the ground surface and water was applied up to maturity. Irrigation was stopped at 15 days before harvesting. The total amount of irrigation water required was 1029, 980, 1200, and 840 mm in treatments CTWDS, NTWDS, CTTP and CTDDS, respectively.

Measuring plot water salinity

A perforated PVC pipe was installed in each plot to monitor the field water salinity. The stored canal water salinity varied from 1.5 dS m^{-1} to 3.2 dS m^{-1}. After applying the irrigation water in all treatments, a hand-held electrical conductivity meter (Model: Lutron-CD4301) was used to measure the water salinity inside the PVC pipe.

Measuring soil salinity ($EC_{1:5}$)

Soil samples were collected from each plot at 0-15 cm depth before establishment, panicle initiation, flowering, and after harvesting. Around 250 g soil was collected each time using a handheld auger and these samples were immediately sealed in polythene bags. Gravimetric soil water content (weight basis) was measured after oven drying (maintained 105°C at 72 hr) as the difference between soil wet weight and dry weight. The electrical conductivity of 1:5 soil: water extracts was measured with an electrical conductivity meter (Model: Lutron-CD4301) from the same soil samples.

Statistical analysis

One-way analysis of variance (ANOVA) was performed to test the effects of different establishment methods on grain yield and yield components of *Boro* rice by using R statistical software (version 4.3.0). The comparison of means was tested using the least significant difference (LSD) at the 95% confidence level.

RESULTS AND DISCUSSION

Variation of irrigation water salinity and perched water salinity

Both irrigation water and perched water salinity in the soil increased with the progress of dry season. At the beginning of *Boro* season, irrigation water salinity was around 1.5 dS m^{-1} whereas perched water salinity (after applying irrigation water) was 0.5-0.7 dS m^{-1} (Fig. 3). Irrigation water salinity increased to 4.0 dS m^{-1} in 3rd week of March and then decreased to 2 dS m^{-1} because of rainfall. On the other hand, perched water salinity was much higher from the first week of February (3.0-3.5 dS m^{-1}) to 3rd week of March (6.8-8.8 dS m^{-1}). Among the treatments, perched water salinity was lower in treatment CTTP than in other treatments (direct seeding in puddled and non - puddled condition) (Fig. 3). It appears that perched water salinity was affected by soil

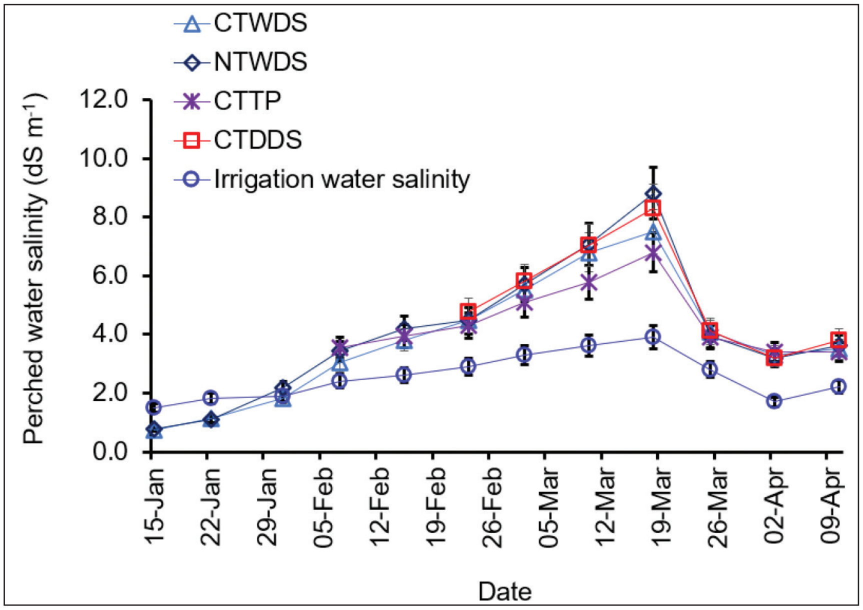

Fig. 3. *Variation of irrigation water and perched water salinity in the soil under different rice establishment methods in 2022-23 Boro season. Each vertical bars indicate the standard errors of mean*

salinity and it was increased over time.

Variation of soil salinity ($EC_{1:5}$)

Soil salinity ($EC_{1:5}$) at 0.15 cm depth varied throughout the growing season in all treatments (Fig. 4). Soil salinity was varied between 0.40 dS m^{-1} and 0.60 dS m^{-1} during establishment. Soil salinity increased to 0.80-0.90 dS m^{-1} before panicle initiation and reached 1.0-1.4 dS m^{-1} by flowering stage. At harvest, the soil salinity decreased to 0.78-0.84 because of rainfall. Among the treatments, soil salinity was significantly lower in CTTP than in other treatments (Fig. 4). In direct seeded treatments (CTWDS, NTWDS and CTDDS), the application of lower amount of irrigation water until 30 DAS (up to saturation) accelerated the soil drying and formation of tiny cracks (data not recorded) which can be contributed to salt build-up in the upper soil.

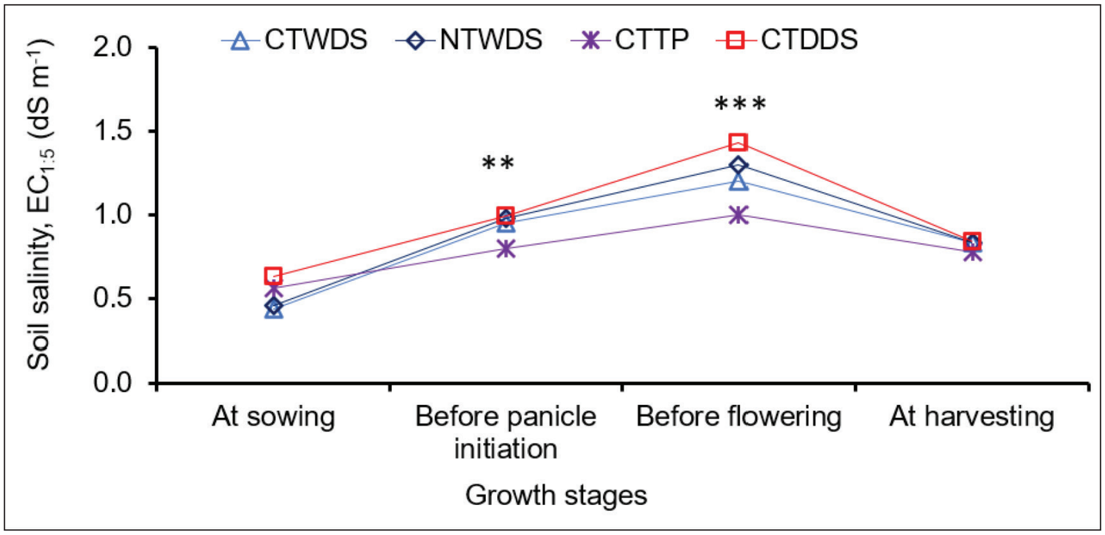

Fig. 4. *Variation of soil salinity (EC1:5) at 0-15 cm depth in different rice establishment methods in Dacope, Khulna, Bangladesh in 2023. ** and *** indicate the significant level of the treatments mean at 0.01 and 0.001 percent probability*

Yield and yield characteristics

Establishment methods significantly affected yield and yield components (Table 1). The highest yield (3.8 t ha^{-1}) was observed with the CTTP method and the lowest yield (1.4 t ha^{-1}) with the CTDDS method. The yield was 13% and 24% lower with the CTWDS and NTWDS methods, respectively than that with CTTP. Rice establishment methods had significant effects in grain per panicle, seed weight, straw yield, and biological yield. The number of filled grains was substantially higher in treatment CTTP than in other treatments. By contrast, the number of unfilled grains in treatment CTDDS were almost double compared to treatment CTTP. The weight of 1000-seeds were almost similar in CTWDS and NTWDS, but it was significantly lower in CTDDS than in CTTP. Although CTTP produced a higher grain yield, the straw yield was significantly lower in CTTP than that in CTWDS. The biological yield was almost identical in CTWDS, NTDDS and CTTP treatments, but significantly lower in CTDDS. Overall, CTTP increased panicle bearing tiller rate, number of filled grains, and seed weight which were related to higher yield than other treatments. Some studies also reported a significant yield penalty under wet or dry direct seeded rice compared to transplanted rice (Kumar *et al.,* 2008; Rao *et al.,* 2007; Rickman *et al.,* 2001; Singh *et al.,* 2005).

Boro rice establishment methods influenced the tillers per square meter, panicle-bearing tiller rate and harvest index (Table 1). The maximum tillers per square meter (1133) was much higher in the CTWDS treatment than in CTTP (598), whereas the panicle-bearing tiller rate was significantly higher in CTTP (57%) relative to other treatments (22-46%). In all treatments, the

Table 1. *Yield and yield attributes of rice under different establishment methods at Dacope, Khulna, Bangladesh in 2022-23 Boro season*

Treatment	Straw yield (t ha^{-1})	Number of filled grains per panicle	Number of unfilled grains per panicle	1000-seed weight (g)	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Tillers per meter square	Panicle bearing tiller rate (%)	Harvest index (%)
CTWDS	4.3	86	23	20	4.3	7.7	1133	46.5	43.5
NTWDS	3.8	80	26	19	3.8	6.7	902	42	42.2
CTTP	3.7	105	16	22	3.7	7.5	598	57	50.7
CTDDS	2.2	37	33	13	2.2	3.6	440	22	38.5
p-value	0.001	0.001	0.06	0.001	0.001	0.001	0.001	0.01	0.01
LSD value	0.4	11	12	1.99	0.4	0.75	126	10.4	4.4
CV	5.8	7.15	25	5.3	5.8	5.9	7.6	12.4	5.1

CTWDS - conventional tillage wet direct seeding, NTWDS - no tillage wet direct seeding, CTTP - conventional tillage transplanting rice, CTDDS - conventional tillage dry direct seeding, LSD - least significance difference, CV - Coefficient of Variation higher harvest index was in CTTP but there were little differences in other treatments. A similar result was found by Huang *et al.* (2011). The compensation for panicle bearing tiller rate resulted in low spikelet per panicle under wet and dry direct-seeded rice.

Plant height pattern

Plant height increased with time in all treatments (Fig. 5). At 35 and 55 days after sowing (DAS), there was no difference in plant height between the treatments. However, at harvest, plant height was significantly higher in the CTTP treatment than in other treatments (Fig. 5). Among the treatments, the treatment CTDDS had a lower plant height (72 cm) than other treatments (95 cm in CTTP and 87 cm in CTWDS treatments). Our result is in line with the report by Badshah *et al.* (2014) where they recorded the highest plant height in transplanted rice than in direct - seeded rice.

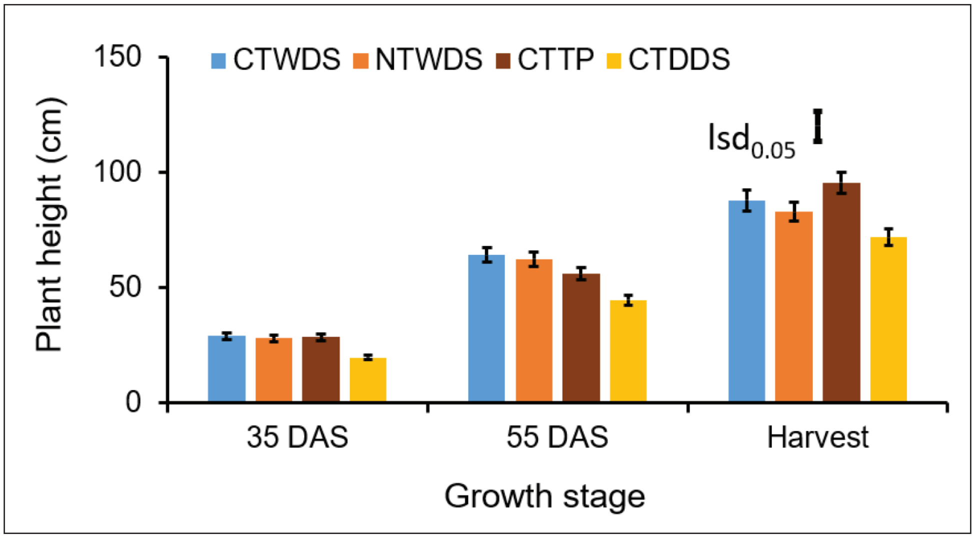

Fig. 5. *Boro rice plant height dynamics at different growth stages. Bars represent the standard error of means. lsd is the least significant difference in treatment*

Relationship between rice yield and yield parameters

Rice grain yield was positively correlated with grain per panicle, panicle per square meter, thousand seed weight and harvest index (Fig. 6). Grain per panicle explained the most variation in yield ($R^2 = 0.95$) and harvest index explained the least in yield (63%). The panicles per square meter and 1000-seed weight explained about 88% variation of yield. In the present study, it is indicated that the higher yield in CTTP treatment was determined by higher grain per panicle, panicle per meter square and seed weight but not by harvest index.

Rice growth response to soil salinity

Across all treatments, rice yield was negatively correlated with increasing soil salinity (Fig. 7). The salinity impact was not significant at the early stage (at sowing time), but the impact increased with the progress of dry season. The most significant impact of salinity was at the flowering (Fig. 7B) ($R^2 = 0.71$) and at panicle initiation (Fig. 7A) ($R^2 = 0.53$). The present study provided evidence that higher soil salinity at maturity and panicle initiation ($EC_{1:5}$ varied from 0.8-1.4 dS m^{-1}; EC_e = 6.8-12.7 dS m^{-1}) did affect the yield parameters and grain yield because the grain per panicle was determined to be more important in estimating the grain yield. In the present study, the confounding effects of higher salinity under direct seeding methods were associated with lower yield (Fig. 7). These results were dare consistent with those previously reports (Khatun *et al.*, 1995 and Zeng and Shannon, 2000) which mentioned that increasing salinity level significantly affected yield the yield and yield components.

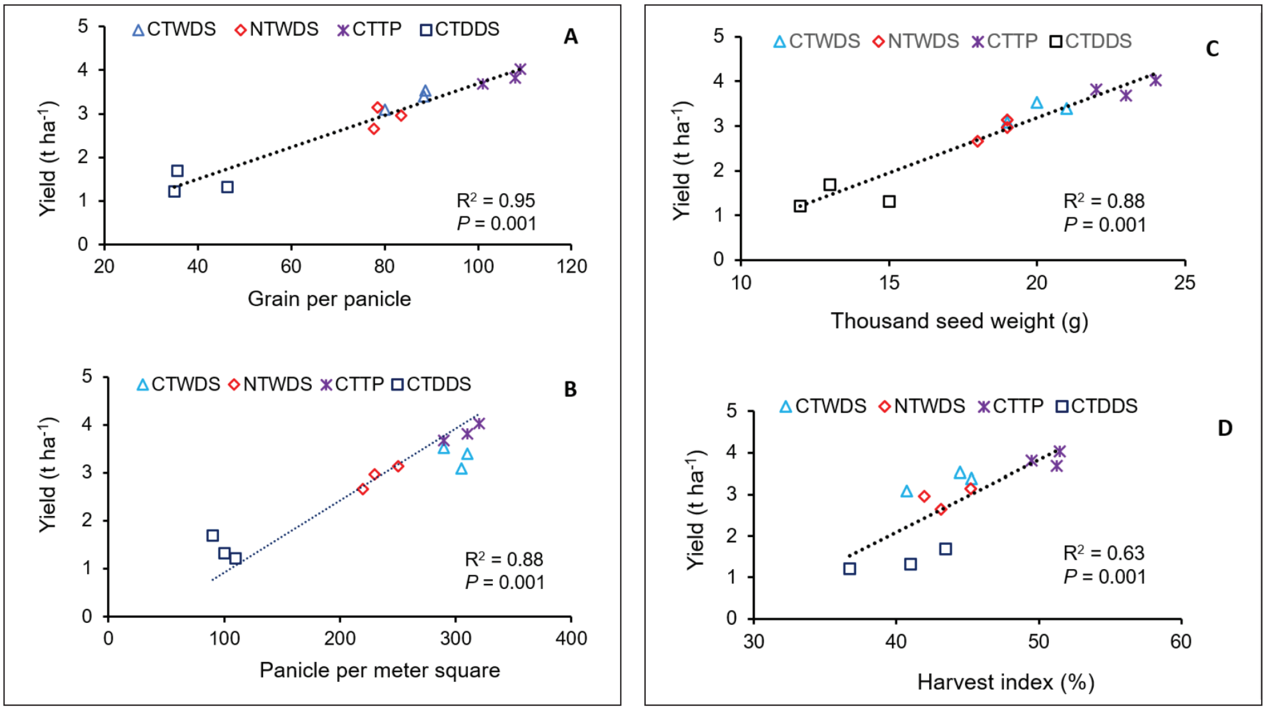

Fig. 6. *Relationship between rice yield and yield parameters (A) grain per panicle, (B) panicle per meter square, (C) 1000-seed weight and (D) harvest index in Dacope, Khulna in 2022-23 Boro season*

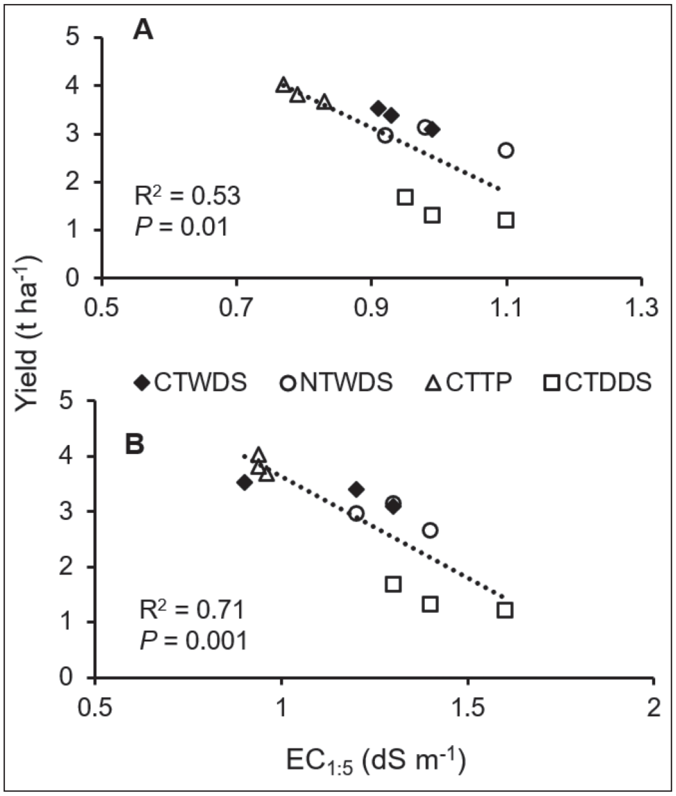

Fig. 7. *Relationship between rice yield and salinity (EC$_{1:5}$) (A) at sowing and (B) at panicle initiation stage at Dacope, Khulna in 2022 - 23 Boro season*

CONCLUSION

In the salt-affected coastal region of Bangladesh, wet direct seeding of *Boro* rice advances the establishment time and saves irrigation water but decreases yield due to lower panicle bearing tiller and grain per panicle. In case of direct seeding, higher soil salinity was also occurred. The *Boro* transplanting in puddled soil had less weed infestation, lower soil salinity, and higher grain per panicle and hence, increased yield. Further research can be carried out in this saline area with early establishment of *Boro* rice for maximum utilization of soil residual water and avoiding the high salinity stress during the flowering stage to achieve maximum yield.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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