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Towards development of early *rabi* crop establishment techniques: Performance of *wheat* under different tillage and irrigation conditions in the coastal region of Bangladesh

M Khairul Islam[1], Khalid Mahmud[1]*, Nefaur Rahman[1] and Manoranjan K Mondal[2]

[1]Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh, Bangladesh
[2]International Rice Research Institute (IRRI), Dhaka, Bangladesh

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ABSTRACT

Late crop establishment is a major problem for successful harvest of *rabi* crops in saline coastal zone of Bangladesh. Identification of appropriate crop establishment techniques is also important to overcome the problem. Because selection of proper crop establishment method is the first step towards earlier establishment of *rabi* crops. An experiment was conducted during December 2013 to May 2014 at Kismat Fultola village in Khulna district to identify appropriate crop establishment techniques for early establishment of wheat. Crop establishment methods tested were- C_1: seeds sown after row-spading at soil moisture in between saturation and field capacity, C_2: seeds sown in furrows at soil moisture in between saturation and field capacity, and C_3: seeds sown on the surface of saturated soil with straw mulch. There were three irrigation regimes- I_1 = No irrigation (rainfed), I_2 = One irrigation at 15–20 days after emergence (DAE), I_3 = Two irrigations at soil suction values of 50 kPa and 70–90 kPa, respectively at 37.5 cm soil depth. Early planting of wheat was 9 December 2013. The establishment techniques and planting dates showed different degrees of influence on the crops. The highest grain yield was obtained in C_3 (1.44 t ha^{-1}) and the lowest was found in C_1 (1.15 t ha^{-1}). In case of irrigation treatments, the grain yield in I_3 (1.49 t ha^{-1}) and I_2 (1.35 t ha^{-1}) was significantly higher than that in I_1 (1.04 t ha^{-1}). The highest yield (1.49 t ha^{-1}) was obtained from the two irrigations and straw mulch treated plot, even though the yield was less compared to standard wheat yield in that region (2.0–3.0 t ha^{-1}). This is because of less plant density due to uneven germination, damage/death of plants after germination and possibly leaching of the top-dressed nitrogen fertilizer out of root zone through cracks. The results demonstrate that early establishment of *rabi* crops in the coastal region is possible, which is highly desirable for improving food security and livelihoods of the climate-vulnerable coastal communities of Bangladesh.

INTRODUCTION

The coastal region of Bangladesh covers 47201 km² land area which is 32 percent of the total geographical area of the country (Mishu 2013). Agriculture sector in the coastal region is vulnerable to different kinds of climatic hazards like salinity, excessive flooding during the rainy season, severe cyclonic storms, and tidal surges throughout the year (Mondal et al. 2013). Salinity in river water increases steadily from December through February and reaches maximum in late March and early April (EGIS 2001). Out of 2.86 million ha of the coastal and offshore arable land areas, about 1.06 million ha of arable lands are affected by varying degrees of salinity (SRDI 2012). Impact of salinity on agriculture has already been recognized (Karim et al. 1990; SRDI 2012). Furthermore, other problems like poor drainage (Tuong et al. 2014), unavailability of quality irrigation water in the dry season (Rahman and Ahsan 2011) have detrimental impacts on agricultural productivity in the coastal region. Ultimate effects of these stressors have resulted in decreasing agricultural land use in the coastal zone. Agricultural land use in these areas is very poor, which is roughly 50% of the country's average (Ahmed et al. 2013).

*Corresponding author: khalid.iwm@bau.edu.bd

Poor agricultural land use can be easily indicated by looking into the cropping patterns. The existing cropping patterns in the study area-Khulna district (medium saline area in the south-west Bangladesh) are *aman-fallow and aman–rabi* (Rahman 2013). The predominant cropping practice in the study area (Batiaghata upazila) is traditional *aman* rice followed by sesame (rabi crop) planted delayed in the early *kharif* season (on about 80% of the land area). Late sowing of rabi crops increases the chance of crop damage due to the on-set of monsoon and cyclonic season prior to its harvest. In most cases late-grown sesame and *rabi* crops in Batiaghata upazila often get damaged by rainfall and tidal surge prior to its harvest (Mondal 1997; Mondal et al. 2004). *Rabi* crop is often damaged and sometimes completely destroyed by early rainfall in March–April and by cyclonic events in May (Tuong et al. 2014) due to its late sowing.

Two main causes associated with the late sowing of *rabi* crops have been identified. Firstly, most of the agricultural land is flooded during monsoon. Floodwater generally starts receding from October and continued up to late December. High tide often inundates the fields even in December (Haque 2006). Thus the drainage from the agricultural lands in the tidal ecosystem has to be delayed and even after the harvest of T. *aman* rice. Such late drainage results in delaying *rabi* crop cultivation. Secondly, after receding flood water the soils still remain too wet until mid–February to early March and hence become unsuitable for tillage prior to this (Ritu and Mondal 2006). This is because water drains very slowly from the silty clay soils that predominate in the region (Rahman 2015). Eventually, the farmers cannot plough their lands at optimum time for sowing seeds due to excess soil moisture, thus establishment of *rabi* crops is delayed.

The keys to solve this problem as well as increasing productivity of *rabi* crops in the coastal region of Bangladesh are improved water management and early establishment strategies of *rabi* crops. As suggested by (Mondal et al. 2013), these strategies may include (i) draining the fields rapidly at the end of the rainy season to allow timely establishment of *rabi* crops, (ii) developing appropriate crop establishment techniques for judicious utilization of residual soil moisture, and (ii) maximizing the availability of freshwater for irrigation during the dry season for *rabi* crops cultivation. Several recent studies have shown that, given the ability to drain excess water, HYV can be successfully grown during the rainy season with yields of 4 to 5 t ha^{-1} (Bhattacharya et al. 2015; Mondal et al. 2015; Saha et al. 2015). Furthermore, Mondal et al. (2015) also showed the possibility to manipulate the sluice gate in a sub-polder to enable effective drainage, and to harvest HYV before the end of November. The early harvest of *aman* then creates the opportunity to grow high yielding and high value crops such as maize and sunflower. A study conducted by Rahman (2015) has demonstrated the high potential for increasing crop production in the coastal zone by early establishment of *rabi* crops such as maize and sunflower. Different tillage management practices were used as treatments to evaluate the early crop establishment techniques for maize and sunflower. However, there is still ample scope to strengthen early establishment technology by testing different crop establishment methods for other different crops. Therefore, the present study was undertaken to investigate the possibilities of early establishment of wheat crop through combining irrigation and tillage treatments in the *rabi* season. The specific objective of this study was to test the impacts of different tillage management practices and different irrigation scheduling towards early establishing of wheat cultivation in the coastal saline soils.

MATERIALS AND METHODS

Experimental Site

The study was conducted during December 2013 to May 2014 in Polder 30 at Kismat-fultola village (22.7263°N, 89.5163°E) in Batiaghata upazila under Khulna district of the south-west coastal zone of Bangladesh. Most agricultural lands in polder 30 have an elevation of 1–2 m above mean sea level. The climate is subtropical, with average annual rainfall of 1,850 mm, two dominant seasons–a cool winter from December to February with mean monthly minimum temperatures of 12–15°C, and a hot summer in April to June with mean monthly maximum temperatures of 37–38°C.The soil was a slightly alkaline (pH about 8) silty clay with a bulk density of 1.45 g cm^{-3} at 15 cm (Mondal et al. 2006). Salinity of the topsoil (0–15 cm) ranges from 4.0 to 12.5 dS m^{-1} (electrical conductivity of the saturation extract) in the dry season and remains below 4.0 dS m^{-1} in the wet season (Mondal et al. 2006). River water salinity remains below 1 dS m^{-1} from July to December and gradually increases from January and reaches a peak of around 20 dS m^{-1} in April or May (Mondal et al. 2006). The salinity of the groundwater at 40 m depth at the study site is about 4 dS m^{-1} throughout the year.

Experimental Treatments

An experiment was conducted in split plot design to test the performance of wheat under different management practices in coastal saline soil having a total experimental area of 50m × 60 m. The experiment was conducted to test the performance of wheat under three crop establishment and three irrigation methods in a split plot design, with six replications.

<u>Main plots: Crop establishment method</u>

C_1 = Seeds sown after tillage of the seed row using a spade (5 cm wide strips)

C_2 = Seeds sown in furrows made using a hand *kota* (local name)

C_3 = Seeds sown on the saturated soil surface with 2.5 t ha^{-1} (5 cm) straw mulch (zero tillage)

<u>Sub–plots: Irrigation scheduling</u>

I_1 = No irrigation (rainfed)

I_2 = One irrigation at 15–20 days after emergence (DAE)

I_3 = First irrigation when soil tension increased to 50 kPa and second irrigation when soil tension was 70–90 kPa at 37.5 cm soil depth,

Experiment Conduction

Crop management

The salt and heat tolerant wheat variety BARI gom25 (growth duration of 110 d) was sown in rows (20 cm spacing, 3–4 cm depth) on 9 December 2013 and harvested on 2 April 2014. Seed rate was 125 kg ha^{-1}. According to BARI recommendations, the doses of N–P–K–S–B fertilizers were 250, 150, 100, 110 and 7.5 kg ha^{-1}, respectively (Hossain et al. 2006). All the fertilizers except urea were applied prior to sowing when soil remained at saturated condition. Half of urea was applied 5–10 days after crop emergence and the rest half was top-dressed during first irrigation (Hossain et al. 2006). Hand weeding was done two times at 20 and 40 days after emergence (DAE) synchronizing with the topdressing of urea and soil earthing up (where applicable). In order to control insect pest (rats) rodenticide was used and in addition protective plastic sheet was used to protect field from rat.

Crop monitoring

Five randomly selected plants in each plot were tagged and monitored for crop development until harvest. Plants were selected leaving 50 cm space from all corners to avoid border effects. The booting (BT), shooting, heading, flowering (FL) emergence and physiological maturity (PM) dates of wheat were recorded. Separate records of each plot from all replications were kept in the notebook. The date of 50% emergence (date when first leaf appears) was determined in 5 rows × 1 m at two locations diagonally. For BT monitoring, the main stem was dissected for observation. The stem was considered to have reached BT when the spike is visible to naked eyes (*i.e.* about 1 mm long). The crop was considered to have reached BT when 10 stems out of 12 main stems had visible spikes. The date of 50% anthesis was determined by counting the number of spikes in which anthesis commenced from selected 10 plants at 4 corners of the harvested area at the designated sampling area. PM date was determined when 80% of the spikes in 10 rows at the designated harvested area (in the middle) have turned yellow. The yield attributes and selected agronomic parameters of wheat, such as plant height, total and productive tillers, spike length, filled and unfilled grains per spike, 1000 grain weight and straw yield, were taken from five1 m^2 area of each plot, four from four corners and one from the middle of the plot. Grain yield was calculated in t/ha considering the harvest of whole plot (30 m^2). Plant height of wheat was measured at fifteen days interval in every subplot.

Irrigation water monitoring

Source of irrigation water was nearby canal (locally called Khal). Irrigation water salinity was more than 4 dS m^{-1} in both I_2 and first irrigation of I_3 treatments. As canal water was highly saline (EC = 10 dS m^{-1}) in case of second irrigation of treatment I_3. Canal water was mixed with pond (re-excavated by farmers) water with EC of 3 dS m^{-1} to irrigate wheat. Irrigation was provided by using a low lift pump (LLP) connected with hose pipe. Discharge of the LLP was measured by volumetric method by using a 20 L bucket and stop watch. Salinity of the irrigation water was measured using a portable EC Meter.

Soil moisture monitoring

Gravimetric soil moisture content was determined for soil samples collected from 0–15, 15–30, 30–45, 45–60, and 60–80 cm layers using a soil auger. Sampling was done at 15 days intervals from seed sowing until harvest. Soil water tension was measured using tensiometers installed at 37.5 cm depth in each plot of wheat. Tensiometer reading (kPa) was recorded at 9 am daily.

Rainfall and evaporation monitoring

A standard rain gauge and a USWB class A evaporation pan previously installed about 200 m from the experimental field were used to monitor rainfall and pan evaporation at 9 am daily. Daily maximum and minimum temperatures were also collected from the Khulna meteorological station, about 8 km north of the experimental site.

Statistical Analysis

The data were analyzed for significance of difference among the means with 5% level of significance using the Statistical Tool for Agricultural Research (STAR) software (STAR 2014).

RESULTS AND DISCUSSION

Weather Condition during Growing Period of Wheat

Rainfall was low throughout the growth period of wheat (9 December–2 April 2014). Only three rainfall events, 23, 13 and 245 mm, were recorded in February, March and May, respectively (Figure 1).There was 23 mm rainfall on 16–17 February at flowering stage of wheat and 13 mm on 23–25 March at ripening stage of wheat. No other rain was received during the growth period of wheat. Evaporation gradually increased from January (mean monthly total 64 mm) to April (total 191 mm). Mean monthly maximum temperature varied from 26°C in January to 36°C in April, while mean monthly minimum temperature varied from 15°C in January to 26°C in May. Daily sunshine hours was lowest in January (5.4 h) and the highest in April (8.8 h) (Figure 1). Early established wheat was harvested on 2 April 2014 whereas previous studies showed that the harvesting of *rabi* crops in coastal region is not possible before mid–May. Figure 1 shows that there was a heavy rainfall (245 mm) on 14 May 2014, which indicated that there was a possibility of crop damage if crops were not early established. Therefore, early establishment of *rabi* crops is important for safe harvest of *rabi* crops.

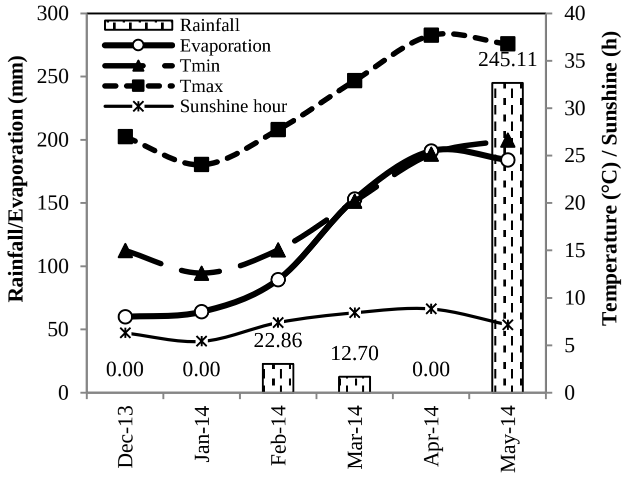

Figure 1. Monthly total rainfall and evaporation at the study site; sunshine hours and monthly mean maximum (T_{max}) and minimum (T_{min}) temperatures of Khulna during December 2013 to May 2014

Variation of Soil Moisture with Irrigation

Trend of soil moisture contents at different layers is shown in Fig. 2. Initially soil moisture content was about 38%–40% in first two layers, but it was higher in deeper layers (45%–48%). It has gradually decreased until mid-January. After first irrigation on 25 January 2014, soil moisture started to increase. After second irrigation (13 February 2014) and two rain events (16 February and 17 February 2014) there was an increasing trend of moisture content (Figure 2).

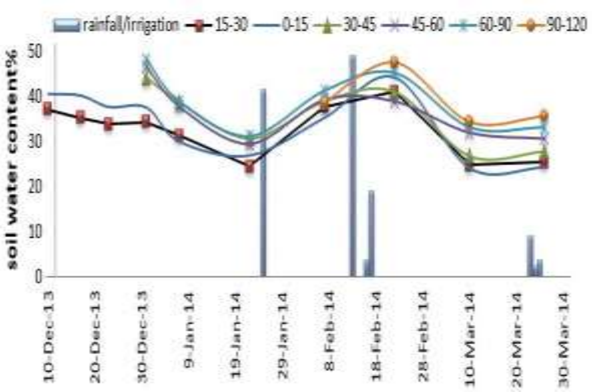

Figure 2. Trend of soil moisture at different layers of soil with rainfall and irrigation water during study period

Variation of Soil Water Tension with Crop Establishment Methods

The level of soil water tension in different crop establishment methods varied considerably (Figure 3). Soil water tension was much higher in C_1 and C_2 than C_3, as C_3 was a mulched plot that conserved more water in the soil profile. Furthermore, lower value of soil water tension in C_3 indicates slower soil drying in the mulched treatment which was probably due to reduced soil evaporation. This finding is in agreement with that of Bond and Willis (1969), who concluded that mulch can reduce soil evaporation especially when the plant canopy is small. Initially the soil water tension was within 45 kPa, the lowest in the mulched establishment, C_3 (about 18 kPa). The soil water tension gradually increased as the soil dries out and reached to about 90 kPa in C_1 and C_2, but remained within 70 kPa in C_3. The rapid increase in soil suction values for the first two months even in the mulched treatment indicate more water uptake by wheat during its vegetative stage.

Irrigation Water Requirement

Two irrigations were given in treatment I_3 based on the tensiometer reading. One irrigation was supplied in I_2 according to the set criteria for wheat (Table 1). Among the crop establishment methods C3 required the lowest irrigation (Table 1). Results indicate that mulching can be very effective in conserving soil water in the coastal area.

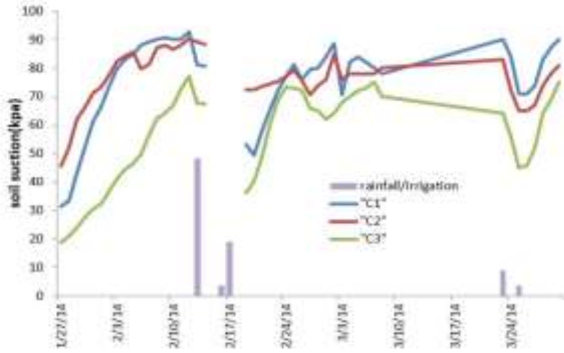

Figure 3. Variation of soil water tension at 37.5 cm with different crop establishment methods

Table 1. Water applied for wheat cultivation in the *rabi* season of 2013–14

Crop establishment	Irrigation methods								
	I_1= rainfed			I_2= one irrigation			I_3= two irrigation (based on soil water tention)		
	R (mm)	IR (mm)	Total (mm)	R (mm)	IR (mm)	Total (mm)	R (mm)	IR (mm)	Total (mm)
C_1	35.5	0	35.5	35.5	47.3	82.8	35.5	50.9	86.4
C_2	35.5	0	35.5	35.5	50.9	86.4	35.5	56.4	91.9
C_3	35.5	0	35.5	35.5	27.0	62.5	35.5	28.0	63.5

(R=Rainfall, IR=Irrigation)

Variation of Phenology Dates of Wheat

Different crop establishment methods did not have much influence on the phenology dates of wheat (Table 2). In mulched plot (C_3) all phenology dates were slightly delayed possibly because of higher soil moisture compared with other treatments. However, this crop establishment method (C_3) produced maximum yield. The result is similar to that of Khanh (2005) who observed that inhibition germination and seedling growth became more pronounced with increasing rate of wheat straw mulching that may be explained by increased concentration of individual allelochemicals or their compound effect of Phytotoxic compounds namely phenolics, cyclic hydroxamic acids (alkaloids).

Table 2. Phenology date of wheat in different treatments

Treatment	Maximum tillering (DAS)	Spike initiation (DAS)	Booting (DAS)	Shooting (DAS)	50% Flowering (DAS)	Physical Maturity (DAS)
C_1	19	39	56	62	72	94
C_2	19	41	57	63	74	95
C_3	21	42	60	65	76	97

*DAS is for days after sowing

Effects of Crop Establishment Treatments on Performance of Wheat

The crop establishment methods have significantly influenced the spike length of wheat (Table 3). The highest spike length (10.83 cm) was found in C_3, and the lowest was obtained in C_2 (9.23 cm). The results are supportive with that of Chang et al. (1991) who reported that mulched establishment method had significantly higher spike population and grains/spike than un-mulched plot. The number of filled grains spike^{-1} differed significantly among the crop establishment methods. The highest filled grain spike^{-1} was produced in C_3 (41.97 spike^{-1}), which was significantly higher than C_1 and C_2. There was no significant difference in 1000-grain weight under different crop establishment methods (Table 3). Among the crop establishment methods, C_3 produced the highest straw yield (2.18 t ha^{-1}), which was significantly different than that produced in C_1 and C_2 (Table 3). But grain yield was not significantly affected by the crop establishment methods. However, the highest grain yield was obtained in C_3 (1.44 t ha^{-1}) and the lowest was found in C_1 (1.15 t ha^{-1}). The results can be explained by the findings of Li et al. (1991) reported that mulched materials have the ability to increase water holding capacity of the soil, retard soil evaporation (Schillinger and Bolton, 1993) and control weeds to the acceptable level (Davis 1994) resulting in higher economic and biological yields. Yield of wheat at no-mulch plots were much lower than that of mulched plot because of crack formation in no-mulch plots. The result shows that mulching can reduce soil cracking considerably and that can be an important option for successful early establishment of *rabi* crops.

Table 3. Yield and yield attributes of wheat for different crop establishment methods

Crop establishment methods	Spike length (cm)	Filled grain (%)	Grain no. spike^{-1}	1000 grain wt (g)	Straw Yield (t ha^{-1})	Grain yield (t ha^{-1})
C_1	9.91b	94.28	36.01b	44.78	1.10b	1.15
C_2	9.23c	93.74	32.32c	45.15	1.17b	1.29
C_3	10.83a	94.54	41.97a	44.81	2.18a	1.44
$LSD_{0.05}$	0.238	NS	2.39	NS	0.76	NS

*NS= Non significant

* Common letter(s) within the same column do not differ significantly at 5% level of significance analyzed by Least Significant Difference Test

Effects of Irrigation Treatments on Performance of Wheat

Irrigation water was not evenly distributed in all crop establishment methods in wheat due to formation of cracks, which affected plant density and maybe one of the major reasons of low yields. However, irrigation regimes had significant effect on grain yield (Table 4). Irrigation method I_2 produced the longest spike (10.23 cm), which was significantly higher than that observed in I_1 and I_3 (Table 4). Among all three irrigation regimes, I_2 produced the highest straw yield (1.95 t ha^{-1}) and I_1 produced the lowest straw yield (0.99 t ha^{-1}) (Table 4). The grain yield in I_3 (1.49 t ha^{-1}) and I_2 (1.35 t ha^{-1}) was statistically similar but was significantly higher than that harvested in I_1 (1.04 t ha^{-1}). Two irrigations (I_3) (based on tensiometer reading) produced highest yield of wheat (1.49 t ha^{-1}), which indicates that more irrigation is required to get optimum yield of wheat. Irrigation water in coastal region is highly saline, so conservation of available soil moisture would be more preferable solution in this regard.

Table 4. Effect of irrigation on yield and yield attributes of wheat

Irrigation methods	Total tiller m^{-2}	Spike length (cm)	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})
I_1	116.30b	9.89b	0.99b	1.04 b
I_2	140.70a	10.23a	1.95a	1.35 a
I_3	133.82ab	9.86b	1.51ab	1.49 a
$LSD_{0.05}$	19.32	0.324	0.65	0.236

*NS= Non significant
*Common letter(s) within the same column do not differ significantly at 5% level of significance analyzed by Least Significant Difference Test.

CONCLUSION

Along with the early sowing date combination of mulching and two or more irrigation seem to be the best combination for obtaining good yield and safe harvest of wheat in the coastal saline soil. This study concludes that early establishment of *rabi* crops in coastal region is possible which can easily save crops from the natural calamities that is a great problem for existing cultivation practices. Furthermore, high yielding and high value crops (wheat, mungbean, and sunflower) may be a good option instead of low yielding traditional *rabi* crops which is highly desirable for improving food security and livelihoods of the climate-vulnerable coastal communities of Bangladesh. Further study needs to be conducted for evaluating the appropriate sowing dates of *rabi* crops in the coastal regions of Bangladesh. Cost-benefit analysis needs to be performed, and social acceptance of these changes needs to be further studied. In addition to this, study is needed to be designed on different mulching including living mulch not only to reduce soil cracking and soil salinity, but also to conserve soil moisture for better growth and development of *rabi* crops in the coastal zone of Bangladesh.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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