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Cropping System-Based Irrigation for Improving Crop and Water Productivity in the Coastal Zone of Bangladesh

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The cropping intensity in the coastal zone of Bangladesh is significantly lower than the country's average. The dominant crop grown in the saline areas is transplanted *aman* (T. *aman*) rice. The feasibility of intensified cropping patterns based more efficient water management and the production of two/three crops in a year has not been investigated in the salt-affected areas of Bangladesh. In this study, we tested five cropping patterns to understand their effects on grain yield, water use and water productivity, soil salinity and overall profitability. Field experiments were conducted in farmers' fields at Amtali, Barguna, Bangladesh, during 2016-2017 and 2017-2018. The cropping patterns were (i) CP_1: Mustard - T. *aus* - T. *aman*, (ii) CP_2: Sunflower - T. *aus* - T. *aman*, (iii) CP_3: Maize - T. *aus* - T. *aman*, (iv) CP_4: Wheat - Mungbean - T. *aman* and (v) CP_5: Fallow - Fallow - T. *aman*. Standard agronomic management practices for each crop were followed. The rice equivalent yield, production efficiency, total system productivity and profitability were all greater in CP_2 than other cropping patterns. The marginal benefit-cost ratios were 1.28, 1.60, 1.46, 0.83 and 1.50 for CP_1, CP_2, CP_3, CP_4 and CP_5, respectively. The soil water contents among the treatments in soil profiles decreased from sowing to harvest but the soil water content was found lower in treatment of CP_5 (Fallow - Fallow - T. *aman*) followed by other cropping patterns. Salt accumulated in soil during the growing season rising from 4 dS m^{-1} (November) to 9 dS m^{-1} (March) in 0-60 cm soil profile. The highest soil salinity and osmotic solute potential were recorded in CP_5 during February/March. Over the 2 years, the diversified cropping patterns incorporating mustard, sunflower and maize crops (CP_1, CP_2 and CP_3) enhanced the productivity and profitability of the system and represent superior options to one crop per year in the salt-affected areas of Bangladesh.

(***Key words:*** *Benefit cost ratio, Coastal zone, Rice equivalent yield, Soil salinity, Water productivity*)

Soil salinity is one of the serious abiotic stresses that reduce plant growth, development and productivity (Siringam *et al*., 2011). More than 800 Mha of land throughout the world are affected by varying degrees of salinity (FAO, 2008). The coastal areas of Bangladesh cover about 20% of the country and comprise more than 30% of the cultivable lands of the country. About 30% of the lands of the coastal areas of Bangladesh are affected by salinity. Agricultural land in these areas is underutilized and cropping intensity in coastal zone of Bangladesh (173%) is significantly below the country's average cropping intensity of 199% (Haque, 2006; BBS, 2011; Bhattacharya *et al*., 2015). The factors which contribute to the development of saline soil are tidal flooding during the wet season (June-October), direct inundation by saline water, daily tides and the upward capillary movement of saline ground water during the dry season (November to May) driven by soil evaporation, resulting in surface deposition. The severity of the salinity problem in Bangladesh increases with the desiccation of the soil. The effects of salinity depend on its magnitude at critical stages of crop growth, but in severe cases reduces yield to zero. The dominant crop grown in the saline areas is transplanted *aman* (T. *aman*) rice which is grown during the *kharif*-2 season (June-September) using traditional long-duration low-yielding varieties. The primary cropping pattern followed in the coastal areas is Fallow – Fallow - T. *aman*. Cropping intensity in the coastal zone of Bangladesh is low and large areas of agricultural land remains fallow during

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the dry season (Mondal *et al*., 2015). But recently, the cultivation of a wide range of crops such as maize, sunflower, watermelon, wheat, mustard and vegetables following T. *aman* harvest has been expanding around surface water sources and shallow wells with low salinity water (Akanda *et al*., 2015). Cropping intensity can be increased in slightly saline areas by adopting proper soil and water management practices and by the introduction of salt-tolerant crop varieties (Haque, 2006). Bhattacharya *et al*. (2015) reported that a rice - rice - *rabi* system produced around 18 t ha^{-1} yr^{-1} of rice equivalent yield (REY) in low salinity regions of the coastal zone of Bangladesh where drainage was possible during the rainy season. Triple rice cropping with a total system production of around 16 t ha^{-1} yr^{-1} is possible in the coastal zone of Bangladesh in areas where there is year-round fresh water availability, separation of lands of different elevation, and the ability to drain excess water (Saha *et al*., 2015). In the coastal saline zone, with its short winter season, timely sowing/planting of rabi (winter) crops is essential to avoid problems with drought and high salinity late in the season, but this is restricted by late harvest of T. *aman* rice. Prolonged water-logging due to inadequate drainage and faulty operation of sluice-gate facilities restricts potential land use for crop production within the polders. Besides, cropping systems depend on climate, soil type and water availability to achieve the desired optimum production through efficient use of available resources and the patterns of crops are decided upon through consideration of the interaction of farm resources, farm enterprises and the availability of technologies. The diversified rice-wheat cropping system in non-saline soils involving potato, vegetable peas, groundnut and clever water management practices increases production, economic return and water use efficiency. It may also ameliorate soil fertility and break the cycle of weeds and diseases common in continuous one crop cultivation practice (Singh *et al*., 2008). A diversified cropping system increases the production of various crops like as cereals, pulses, oilseeds and vegetables; enhances farm income, creates employment opportunity and reduces risk.

Crop diversification is an option to achieve paradigm change from the traditional one crop cultivation to two or more crops per year. The proper selection of crops and salt-tolerant cultivars, management of water supplies and maintenance of soil and a suitable soil environment can be ensured under low saline water irrigation (Gupta and Abrol, 1990). The introduction of maize, sunflower, wheat or mustard in rice systems is necessary to replace the fallow during the winter season. During the rainy season, if the canal/pond has stored excess water, it may provide irrigation to rabi crops. System-based crop cultivation is essential for efficient utilization of irrigation water, labor and other inputs required for improving the system productivity and profitability.

Two issues have been raised which require attention in minimizing water use and promoting increased economic returns to the farmers. These are (i) increased water productivity and (ii) crop diversification with high value crops, in the existing single-rice-dominated cropping pattern. The feasibility of different cropping patterns based on more efficient water management to produce two or three crops in a year has not been demonstrated in the salt affected areas of coastal region in Bangladesh. A hypothesis is that increased cropping intensity is possible using a combination of (i) earlier sowing/planting, (ii) high yielding, earlier maturing, salt-tolerant aman varieties, (iii) efficient techniques of utilizing residual soil moisture, and (iv), clever water management (especially drainage during rainy season and irrigation during the dry season). We also hypothesize that the relationship between salt dynamics in different soil layers, grain and stover yields, and water productivity of different crops defines the best cropping options and management strategies, through field evaluation and co-learning with farmers. Therefore, a field experiment was undertaken on diversified cropping patterns with different crops and water management practices, aiming to increase the production, water productivity, and economic returns for farmers. Implicit in this aim was evaluating the feasibility of growing two or three crops in a year instead of one in the salt affected areas of coastal zone in Bangladesh.

MATERIALS AND METHODS

Study site

The field experiments were conducted on farmers' fields in the village of Sikandorkhali, Amtali, Barguna, Bangladesh (latitude and longitude of 22° 07′ 45.842′′ N and 90° 13° 44.04′′ E) during *kharif*-1, *kharif*-2 and *rabi* seasons of 2016-2017 and 2017-2018. The experimental site belongs to the agro-ecological zone, Ganges Tidal Floodplain (AEZ-13). The land situation is medium-low land and the soil texture is clay loam (Table 1). Before crop sowing, soil samples were randomly collected from the desired depths (0-60 cm) of the experimental plots to determine the soil physical and chemical properties of the experimental field. The bulk density, field capacity and initial gravimetric soil water content were determined and shown in Table 1. The percentage of organic matter (OM), pH, total nitrogen (N), and extractable phosphorus (P), potassium (K), sulfur (S), zinc (Zn) and boron (B) were also determined (Table 1). The Ca, Mg, K, P, S, B and Fe were greater than critical limits (Table 1).

Experimental design and treatments

The field experiments were established in a randomized complete block design with five cropping patterns and three replications. The treatments were: (i) CP_1: Mustard - T. *aus* - T. *aman*, (ii) CP_2: Sunflower - T. *aus* - T. *aman*, (iii) CP_3: Maize - T. *aus* - T. *aman*, (iv) CP_4: Wheat - Mungbean - T. *aman*, (v) CP_5: Fallow - Fallow - T. *aman* (Farmers' practice, control). The total plot size was 1348 m^2.

Crop management

Standard crop management practices and irrigation scheduling of different crops were followed. Crops with different duration under different cropping patterns were considered over two years of 2016-2017 and 2017-2018 (Fig. 1). Mustard (BARI Sarisha-14), a low salt tolerant variety (optimum yield upto 3.5 - 4.5 dS m^{-1}) was sown with a row spacing of 30 cm. Seeds were planted in line at the rate of 7 kg ha^{-1} at a row-spacing of 30 cm. Fertilizers were applied (kg ha^{-1}) @ N_{75}, P_{20}, K_{45}, S_{15}, $Zn_{1.25}$, and $B_{0.5}$ in the form of urea, triple super phosphate, muriate of potash, gypsum, zinc sulphate and borax, respectively. Two-thirds of N and the all of other fertilizers were applied at the time of final land preparation and the remaining N was applied as a top dressing after the first irrigation. Irrigations were applied at vegetative/pre-flowering and pod formation. Sunflower (*cv*. Hisun-33) was sown with a row-spacing of 60 cm and plant to plant distance along the row was 40 cm. Fertilizers were applied (kg ha^{-1}) @ N_{129} P_{32} K_{60} S_{21} Mg_6 Zn_2 $B_{1.6}$. Half of nitrogen (N) and potassium (K) and all of phosphorus, sulfur, magnesium, zinc and boron was applied as basal dressings during the final land preparation. The remaining N and K was applied as top dressings in two equal splits: (i) at 20-25 days after

Table 1. *Initial soil physical and chemical properties of the soil profile at the experimental field at Amtali, Barguna*

Soil depth (cm)	Soil type	Bulk density (Mg m^{-3})	Field capacity (%) at 0.33 bar	Moisture content (%) at 0 bar	Organic matter (%)	Ca	Mg	K	Total N	P	S	B	Fe
						Meq 100 mL^{-1}			%	µg mL^{-1}			
0-15	Clay loam	1.46	31.8	43.8	0.83	7.30	2.07	0.41	0.282	14.4	72.1	0.20	6.9
15-30	Clay loam	1.43	31.4	43.0	1.02	7.37	2.30	0.59	0.054	18.6	69.9	0.21	9.8
30-45	Clay loam	1.46	32.0	46.0	0.95	6.87	2.03	0.58	0.050	12.2	88.6	0.23	8.8
45-60	Clay loam	1.45	31.9	46.3	0.59	6.93	2.03	0.62	0.031	13.23	83.6	0.24	9.1
		Critical limit				2	0.5	0.12	-	10	10	0.2	4

sowing (DAS) (early vegetative stage) and (ii) at 45-50 DAS (before flower initiation stage). Irrigations were applied at early vegetative, flowering and grain filling stages. Maize (Hybrid Maize cv. NK40) was sown with a row-spacing of 60 cm and plant to plant distance along the row of 20 cm. Fertilizers were applied (kg ha^{-1}) @ N_{255} P_{75} K_{120} S_{52} Mg_{15} Zn_{4}, $B_{1.4}$. One-third of N and K and all of the P, K, S, Mg, Zn and B was applied basally during final land preparation. The remaining two-thirds of N and K was applied in two equal splits as side dressings in the maize rows at 30-35 DAS and 50-60 DAS (tasseling stage). Irrigations were applied at early vegetative [30-35 days after emergence (DAE)], tasseling/silking (65-70 DAE) and grain development (100-110 DAE) stages. Wheat (*cv*. BARI gom-25), a moderately salt-tolerant variety (optimum yield upto 6-6.0 dS m^{-1}) was sown at 140 kg seed ha^{-1} with a row spacing of 60 cm and continuous seed sowing within rows. Fertilizers were applied (kg ha^{-1}) @ N_{120} P_{30} K_{90} S_{15} Mg_{6} $Zn_{2.6}$ B_{1}, with two-thirds of N and all the P, K, S, Mg, Zn and B applied basally. The remaining one-third of N was applied at 17-21 DAS after the first irrigation. Irrigations were applied at CRI (17-21 DAS), booting (55-60 DAS) and grain filling (75-80 DAS) stages. During *kharif*-1 season, the rice seedlings of T. *aus* were produced at the Regional Agricultural Research Station, BARI, Rahmatpur, Barishal. The germinated seeds were sown on a prepared seed bed. The experimental plots for T. *aus* were prepared before the seedlings were transplanted. The fields were usually flooded. The puddling was done mechanically by a two-wheeled tractor-operated power tiller. After ploughing, the leveling was done. Seedlings were uprooted on 10 May 2017 and transplanted in the main experimental field on 11 May 2017. 23-days old seedlings of BRRI dhan 48 were planted in the experimental plots under the supervision of scientists. BRRI dhan48 is a short duration and high yielding variety. Only healthy seedlings were transplanted in straight row to row 20 cm with 20 cm plant to plant spacing and three or four seedlings were transplanted per hill. The plots were fertilized with 127-52-82-60-10 kg ha^{-1} in the form of urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum and zinc sulphate, respectively. The whole amount of TSP, MoP, gypsum and zinc fertilizers were applied during final land preparation. One third of the urea was applied basally, with another one-third applied at four or five tillering stage and the final one-third at 5-7 days before panicle initiation (Islam *et al*., 2013). During the *kharif*-2 season, the short-duration high-yielding T. *aman* variety, BRRI dhan73, was selected to evaluate the feasibility of growing two/three crops in a year instead of one crop per year (in CP_1-CP_4). The experimental plots for T. *aman* were prepared about two days before the seedling were transplanted. The fields were usually flooded. One-third urea (80 kg ha^{-1}) and full doses of the other fertilizers (TSP (128 kg ha^{-1}), MoP (150 kg ha^{-1}), gypsum (90 kg ha^{-1}) and zinc-sulphate (11.25 kg ha^{-1}) were applied during final land preparation. The remaining two-thirds of urea was applied as a top-dressing at early vegetative growth stage. The puddling was done mechanically by a two-wheeled tractor-operated power-tiller. After ploughing, the leveling was done. 28-days old seedlings of BRRI dhan73 were planted in the experimental plots under scientist supervision. BRRI dhan73 is a short-duration (105-113 days) and high-yielding cultivar. Only healthy seedlings were transplanted in straight rows 20 cm apart

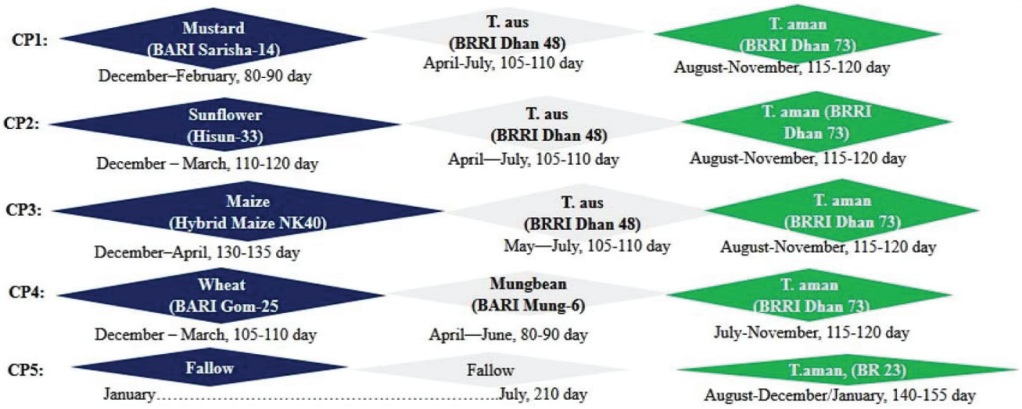

Fig. 1. Different cropping patterns evaluated over two years, 2016-2017 and 2017-2018

and at 15 cm plant to plant (the recommended spacing), and two or three seedlings were transplanted per hill. The traditional rice variety (BR 23, CP_5) was planted in August-September and harvested during mid-December to mid-January. The total crop duration of local Aman variety (BR 23) varied from 140 to 150 days. There were no pest/disease infestations in the experimental plots. Adequate plant protection measures were undertaken at vegetative stages. Different intercultural operations were performed as recommended for better yield performance. Weeding was performed as necessary throughout the growing season. One manual weeding was done for wheat, mustard, sunflower and maize at 30-33 days after sowing.

Crop yield

Crop yields were determined at harvest. The mean yield of each crop was taken from each plot within one square meter. Plants were harvested manually at the ground level from the corner avoiding the border effect. After manual threshing, the cleaned, dried filled grain yields were recorded at 12% moisture content. For sunflower and maize, five plants were randomly chosen to measure the yield from each treatment. All the treatment mean values were compared following randomized complete block design with three replications. The rice equivalent yield (REY) was considered to compare the performance of cropping patterns by converting the yield of individual non-rice crop into equivalent rice yield based on market price using the following equation (Mandal *et al*., 2014; Vandana *et al*., 2014):

$$\mathrm{REY}_{\mathrm{cx}} = \mathrm{Y}_{\mathrm{x}} \frac{P_x}{P_r} \quad \text{….. (1)}$$

where, $\mathrm{REY}_{\mathrm{cx}}$ is the rice equivalent yield, Y_{x} is the yield of individual non-rice crop (x) (kg ha^{-1}), P_{x} is the price of individual non-rice crop (x) (Tk kg^{-1}), and P_{r} is the market price of rice.

Production efficiency (PE) was calculated as the ratio of the total system productivity in terms of rice yield equivalent in kg ha^{-1} to total duration of the system in days (Tomar and Tiwari, 1990; Patil *et al*., 1995).

Soil water content

Gravimetric soil water content was determined at sowing and harvesting and before each irrigation. The soil samples were collected using a soil auger over a root zone depth of 60 cm with 15 cm increment. The samples were well-mixed, sub-sampled, weighed, dried at 105°C, and reweighed to determine moisture content.

Soil salinity and osmotic potential

Soil was collected for monitoring soil moisture content, soil salinity and osmotic potential at different growth stages and soil profiles. Soils were sampled from 0-15, 15-30, 30-45 and 45-60 soil depths at the time of sowing to harvest. The electrical conductivity in a 1:5 extract ($EC_{1:5}$) was determined and converted to actual salinity EC_e at saturated soil water content (dS m^{-1}) using the formula derived from Richards (1954), Slavich and Petterson (1993) and Rengasamy (2010). $EC_{1:5}$ was also converted to osmotic potential (kPa) of field soil solution using the formula derived from Rengasamy (2010). $EC_{1:5}$ was determined using portable instrument of water and soil conductivity meter with sensor probes using TRI-METER (model: pH/EC & TEMP-983) that can be inserted directly into the soil solution.

Irrigation water use and water productivity

Irrigation schedules followed BARI recommendations and irrigation water was applied based on the gravimetric soil moisture determination at different crop growth stages. Irrigation frequency was determined at certain intervals depending on the different growth stages (initial stage, vegetative stage, flowering and grain development stages (Reddi and Reddy, 2009; Sarker *et al*., 2016) from plant establishment to before final harvest. Irrigation in each crop plot was based on soil moisture and crop water requirements. The amount of irrigation water to replenish the soil moisture deficit was estimated using the standard formula suggested by Michael (1978) and Majumdar (2004):

$$\mathrm{I} = \sum_{n=i}^{n} \frac{\mathrm{P_{wi}\, A_{si}\, D_i}}{100} \quad \text{… (2)}$$

where, $\mathrm{P_{wi}} = \mathrm{FC} - \mathrm{RL}$, FC is the mean soil moisture content at field capacity (%); RL is residual soil moisture level before each irrigation in the i^th^ layer of soil profile (%); I is the depth of irrigation water to be applied within one irrigation cycle (mm); $\mathrm{A_{si}}$ is the apparent specific gravity of the ith layer of the soil; $\mathrm{D_i}$ is the depth of the ith layer of the soil within the root zone to be irrigated (mm); and n is the number of soil layers in the root zone depth. The calculated amount of irrigation water was measured by the volumetric method and supplied to the experimental plots using a polyethylene pipe. Each of the experiment plots were separated by a distance of 1.5 m to prevent the lateral movement of water from one to another. Total water use (TWU) was calculated as the sum of total irrigation water applied (I), effective rainfall (P_e) and soil water contribution (SWC) (changing soil moisture) between sowing and final harvest and expressed by the following equation. Effective rainfall was estimated by using the USDA Soil Conservation Method (Smith, 1992).

$$TWU = I + P_e \pm SWC \qquad \dots (3)$$

Water productivity (WP) was estimated as a ratio of total crops grain yield to water consumed, or total water input to the system, and expressed as kg m^{-3} which was calculated by the following equation,

$$WP = \frac{GY \ x\ 100}{TWU} \qquad \dots.. (4)$$

where, WP is the water productivity (kg m^{-3}), GY is the crops yield (kg ha^{-1}) and TWU is the amount of total input water use (mm).

Profitability analysis

The profitability analysis was done to evaluate the comparative advantages of the different cropping systems in a year. The profitability analysis was performed based on variable cost (VC). Variable cost was estimated based on the operating cost of land preparation using machinery, chemicals, human labour, fertilizers, and irrigation. In this study, fixed cost (rental value of land use in Bangladeshi Tk 33,000-38,000 ha^{-1}) was not considered in the production process. Gross return (GR) was calculated by simply multiplying the total marketable yield and it's per unit price in the harvesting period. Gross margin was calculated by the subtraction of total costs from gross return. Marginal benefit cost ratio (MBCR) was calculated as the gross return divided by the total variable cost of crops production per hectare. Primary and secondary data were collected and the profitability of the cropping system was evaluated.

RESULTS AND DISCUSSION

Yield and yield components

Table 2 shows the different crops with cultivar, mean yield and rice equivalent yield (REY), production efficiency (PE) and total system productivity (TSP) under the 5 different cropping patterns. In 2016-2017, *rabi* crop yields were highest in maize under the CP_3 (Maize - T. *aus* - T. *aman*) (Table 2). The grain yield of short duration T. *aman* rice was similar (2.39 kg ha^{-1}) in all treatments, and lower than traditional yield of T. *aman* (Local variety: 3.5 kg ha^{-1}) due to damage to the early-maturing crop by rats and birds. In the second year (2017-2018), the average grain yield of the modern rice variety was 3.89 t ha^{-1}, which was still lower than local varieties (4.63 kg ha^{-1}). The results indicated that the timely sowing of mustard, sunflower or maize (but not wheat) after T. *aman* harvest could be option for intensifying cropping system. The grain yields of sunflower (Hysun-33) and maize (Hybrid maize NK 40) were lower in 2017-2018 than in 2016-2017. The rice equivalent yield (REY), production efficiency (PE) and total system productivity (TSP) were better in CP_2 and CP_3 and followed by traditional cropping pattern of CP_1 (Table 2). The order of the cropping system based on PE and TSP in terms of REY was $CP_3 > CP_2 > CP_1 > CP_4 > CP_5$. The cropping system productivity can be increased in the coastal zone of Bangladesh by using improved varieties, available suitable water resources and standard irrigation schedules and crop management practices (Mondal *et al*., 2015).

From this experience, the participating farmers were not interested to cultivate the very short duration T. *aman* rice variety due to low tillering and damage by rats and birds. Other research indicates that alternative early maturing rice cultivar achieve comparable grain yield to farmers' varieties (Maniruzzaman *et al*., 2019), but are still harvested 15-30 days earlier, which is sufficient for early establishment of rabi crops. The average productivity of rice in the coastal region is lower (3 kg ha^{-1}) than the potential yield (5.5 kg ha^{-1}) of modern varieties (http://publications.iwmi.org). Although the high yielding BRRI variety BR23 is usually preferred in the coastal zone it is sometimes problematic due to its late maturing nature. While BR23 has good yield potential (5-6 kg ha^{-1}) under favorable conditions, it is photoperiod sensitive, only moderately salinity-tolerant,

Table 2. *Mean values of crop yields, rice equivalent yields, crop duration, production efficiency and total system productivity of different crops in the five cropping patterns at Amtali, Barguna, Bangladesh, over two years of 2016-2017 and 2017-2018*

Cropping pattern (CP)*	Growing season	Crop	Mean yield (kg ha^{-1})		REY (kg ha^{-1})		Crop duration (day)		PE (kg ha^{-1} day^{-1})		TSP (kg ha^{-1}) in terms of REY	
			2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
CP$_1$	*rabi*	Mustard	0.94	0.96	3.55	4.61	85	87	32.7	40.6	9.7	12.5
	kharif-1	T. *aus*	3.80	4.00	3.80	4.00	108	108				
	kharif-2	T. *aman*	2.39	3.89	2.39	3.89	105	113				
CP$_2$	*rabi*	Sunflower	2.10	1.86	5.68	5.03	108	115	36.9	38.5	11.9	12.9
	kharif-1	T. *aus*	3.80	4.00	3.80	4.00	108	108				
	kharif-2	T. *aman*	2.39	3.89	2.39	3.89	105	113				
CP$_3$	*rabi*	Maize	7.25	6.72	6.69	5.45	141	131	36.4	37.9	12.9	13.3
	kharif-1	T. *aus*	3.80	4.00	3.80	4.00	108	108				
	kharif-2	T. *aman*	2.39	3.89	2.39	3.89	105	113				
CP$_4$	*rabi*	Wheat	1.13	1.24	3.03	4.59	97	107	26.6	38.6	5.4	8.5
	kharif-1	Mungbean$^{£}$	-	-	-	-	-	-				
	kharif-2	T. *aman*	2.39	3.89	2.39	3.89	105	113				
CP$_5$	*rabi*	Fallow	-	-	-	-	-	-	24.1	31.9	3.5	4.6
	kharif-1	Fallow	-	-	-	-	-	-				
	kharif-2	T. *aman*	3.50	4.63	3.50	4.63	145	145				

Here, REY indicates the rice equivalent yield (t ha^{-1}). PE indicates the production efficiency. TSP indicates the total system productivity. Mustard economic seed yield @ Tk 55 kg^{-1}; Sunflower economic grain yield @ Tk 50 kg^{-1}, wheat grain yield @ Tk 25 kg^{-1}; maize grain yield @ Tk 15 kg^{-1} and T. *aman* grain yield @ Tk 18.5 kg^{-1}. *Cropping pattern (CP): CP$_1$: Mustard - T. *aus* (Optional) - T. *aman*; CP$_2$: Sunflower - T. *aus* (Optional) - T. *aman*; CP$_3$: Maize - T. *aus* (Optional) - T. *aman*; CP$_4$: Wheat - Mungbean (Optional) - T. *aman*; CP$_5$: Fallow – Fallow - T. *aman* (Farmers' practice, control). £Mungbean did not establish due to heavy rainfall sensitive to submergence, and has a long duration (145-150 days). The use of recently developed high yielding varieties with tolerance to salinity such as BRRI dhan73 and related variety of BRRI dhan76 may provide an opportunity to increase the productivity of *aman* crops grown in rotation with brackish water in coastal zones of Bangladesh (Rahman *et al*., 2015). The present experiments indicated that although rice yields were reduced, these early-maturing varieties facilitated the successful sowing of subsequent *rabi* crops, thereby increasing overall annual crop production and profit.

Water use and productivity

Seasonal crop water use (SCWU) of *rabi* crops during 2016-2017 (Table 3) and 2017-2018 (Table 3) followed the order: mustard (150, 146 mm) < wheat (177, 189 mm) < sunflower 201, 215 mm) < maize (229, 238 mm). The water productivity (WP) of mustard, wheat, sunflower, and maize was found 0.66, 0.70,0.93 and 2.93 kg m^{-3} under the cropping systems, CP$_1$, CP$_2$, CP$_3$ and CP4 (Table 3). In this study, the water productivity of T. *aus* and T. *aman* was 0.36 and 0.37 kg m^{-3}, respectively (Table 3) which was taken from a review report recently published by Rahman *et al*. (2016).

The total system WP was greater in CP$_3$ (4.2 kg m^{-3}) than other cropping patterns due to higher grain yield as well as crop yield response to better utilization of irrigation water and crop management practices in 2016-2017. In the second year (2017-2018), the highest total system water productivity (3.66 kg m^{-3}) was again found in CP$_3$. The results clearly revealed that the system water productivity of the improved cropping patterns of CP$_1$ (Mustard - T. *aus* - T. *aman*), CP$_2$ (Sunflower - T. *aus* - T. *aman*) and CP$_3$ (Maize - T. *aus* - T. *aman*) were better than the cropping pattern of CP$_4$ (Wheat - Mungbean - T. *aman*) and the traditional cropping pattern of CP$_5$ (Fallow - Fallow - T. *aman*) in the salt-affected areas of coastal zone.

Soil moisture contents

The variations of gravimetric soil water content in the soil profiles over 0-60 cm soil depth during the growing season of different crops for each cropping patterns are shown in Fig. 2. The effective precipitation of 152 mm which occurred during growing season of 2016-2017 at Amtali, affected the crop growth and increased crop yield. On average, variations of gravimetric soil water content of around 16 to 30% during the growing season

Table 3. *Mean values of total water use, water productivity and total system water productivity of different crops under different cropping systems at Amtali over two years of 2016-2017 and 2017-2018*

Cropping pattern (CP)	Growing season	Crop	TWU (mm)		*WP (kg m^{-3})		Total system WP (kg m^{-3})	
			2017	2018	2017	2018	2017	2018
CP$_1$	*rabi*	Mustard	150	146	0.62	0.66	1.35	1.39
	kharif-1	T. *aus*	*	*	0.36	0.36		
	kharif-2	T. *aman*	*	*	0.37	0.37		
CP$_2$	*rabi*	Sunflower	215	201	0.98	0.93	1.71	1.66
	kharif-1	T. *aus*	*	*	0.36	0.36		
	kharif-2	T. *aman*	*	*	0.37	0.37		
CP$_3$	*rabi*	Maize	238	229	3.47	2.93	4.2	3.66
	kharif-1	T. *aus*	*	*	0.36	0.36		
	kharif-2	T. *aman*	*	*	0.37	0.37		
CP$_4$	*rabi*	Wheat	189	177	0.60	0.70	0.97	1.07
	kharif-1	Mungbean	-	-	-	-		
	kharif-2	T. *aman*	*	*	0.37	0.37		
CP$_5$	*rabi*	Fallow	*	*	-	-	0.37	0.37
	kharif-1	Fallow	-	-	-	-		
	kharif-2	T. *aman*	*	*	0.37	0.37		

* WP indicates the water productivity. Reference water productivity of T. *aus* and T. *aman* were taken considering green water irrigation. Here, T. *aus* and T. *aman* were cultivated under rainfed conditions.

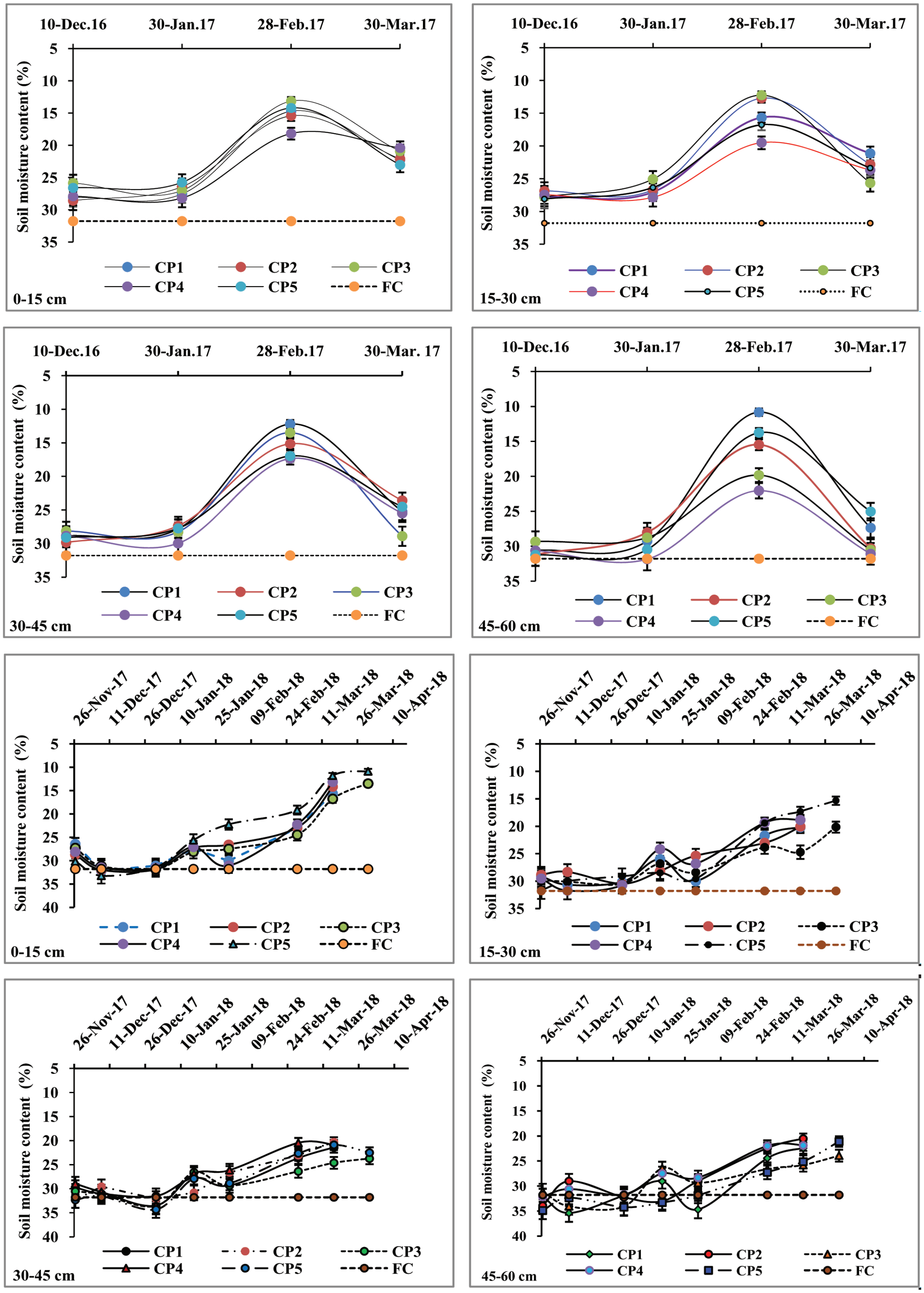

Fig. 2. Variations of gravimetric soil water content at different soil layers during crop growth seasons of 2016-2017 and 2017-2018 at salt affected coastal zone of Amtali, Barguna. Bars indicate the error percentage at 5%

of January to March was observed. In second year (2017-2018), soil water contents (SWC) decreased on average about 30 to 19 % from sowing (November) to harvesting (March 2018). At later growth stages of the crops, SWC of 12 % and 19% at top (0-15 cm) and lower (45-60) soil layers, respectively, were recorded, which affected the crop development and grain filling stages of crops (Fig. 2). The SWC was found always lower in profiles of CP_5 (Fallow - Fallow - T. *aman*) followed by other cropping patterns under irrigation management practices in 2018. Two or more crops cultivation per year with water management practices may option for utilizing the residual soil moisture in rice based cropping patterns which could improve the system productivity and increase the benefits of the system.

Salinity in field soil

Soil salinity profiles during the growing season for various treatments are shown in Fig. 3. On average, the soil salinity varied from 7 to 17 dS m^{-1} (January to March, 2017) in the 0-60 cm soil profiles (Fig. 3). The highest salt accumulation occurred from the middle to end of the February in all treatments in soil profiles during 2016-2017. The salinity in the field soil showed that slightly higher salt accumulation occurred among the treatments within the top soil layer in 0-15 cm depth than lower depth of soil profiles (45-60 cm) due to capillary rise from the saline water-table and increased deposition in the soil surface by evaporation. During the year of 2017-2018, the changes soil salinity varied from 4 to 9 dS m^{-1} from sowing (November 2017) to harvest (March 2018) as shown in Fig. 3. The changes in soil salinity exhibited a similar trend among the treatments within the soil layers from 0-60 cm. The EC_e in field soil was greater in treatment of CP_5 (Fallow - Fallow - T. *aman*) followed by other cropping patterns with two or three crops in a year. The soil salinity EC_e builds up mainly due to the addition of salts from saline water irrigation and upward movement of salts through capillary rise from shallow groundwater table and gradually increased during the dry season to reach a maximum EC_e at or close to harvesting stage. However, in this study, crops are irrigated, using fresh water, therefore soil salinity did not increase as in the Fallow - Fallow - T. *aman* pattern (Ashraf and Saeed, 2006).

Osmotic potential

Soil salinity profiles during the growing season for the various treatments are shown in Fig. 4. The osmotic potential among the treatments were similar in trend over the 15 cm increments of soil profiles during the year of 2016-2017. On average, the osmotic potential was -300 kPa to -680 kPa during the growing season from January to March 2017 and highest in February 2017. In 2017-2018, the osmotic potential ranged from -303 kPa (November 2017) to -845 kPa (March 2018). The greatest osmotic potential was measured in the treatment of CP_5 (Fallow - Fallow - T. *aman*) (-1303 kPa in March 2018 in the upper soil layer (0-15 cm)). The higher osmotic pressure was found in mid growth stages of the crop due to more soil water uptake and soil moisture evaporation from the soil surface. Generally, plants struggle to take up water when the total potential of the soil solution exceeds -1000 kPa and will permanently wilt at -1500 kPa. In this study, the osmotic potential was not likely to limit crop production due to standard irrigation scheduling followed by good crop management practices.

Profitability analysis

Total variable cost, gross margin and marginal benefit-cost ratio of the different crops and total cropping systems in a year are shown in Tables 4 and 5. The crop with the highest benefit-cost ratio was T. *aus* during *kharif*-1 season. The benefit cost ratio was slightly higher in CP_1 compared to CP_2, while CP_3 and CP_4 both had lower benefit cost ratios than CP_5. In terms of gross margin, $CP_2 > CP_1 > CP_3$ which were all superior to the traditional cropping pattern, Fallow - Fallow - T. *aman*.

Our study indicates that the benefit-cost ratio was similar among the best treatments, but the gross margin was quite different among the improved cropping patterns. During *kharif*-1 and *kharif*-2 seasons, the modern variety of T. *aman* and T. *aus* achieved lower rice yield due to damage by attracted rats and birds due to early maturity, which reduced the total grain yield. Modern rice varieties provide scope for earlier harvest when market price is higher. If large number of farmers grow such varieties there would not be such a concentrated attack by birds and rats as observed in the experimental fields. Farmers have the opportunity plant early *rabi* crops just after the harvest of this short duration rice. The improved cropping systems have the positive influences on the utilization of the agricultural land. The cropping system intensification patterns like

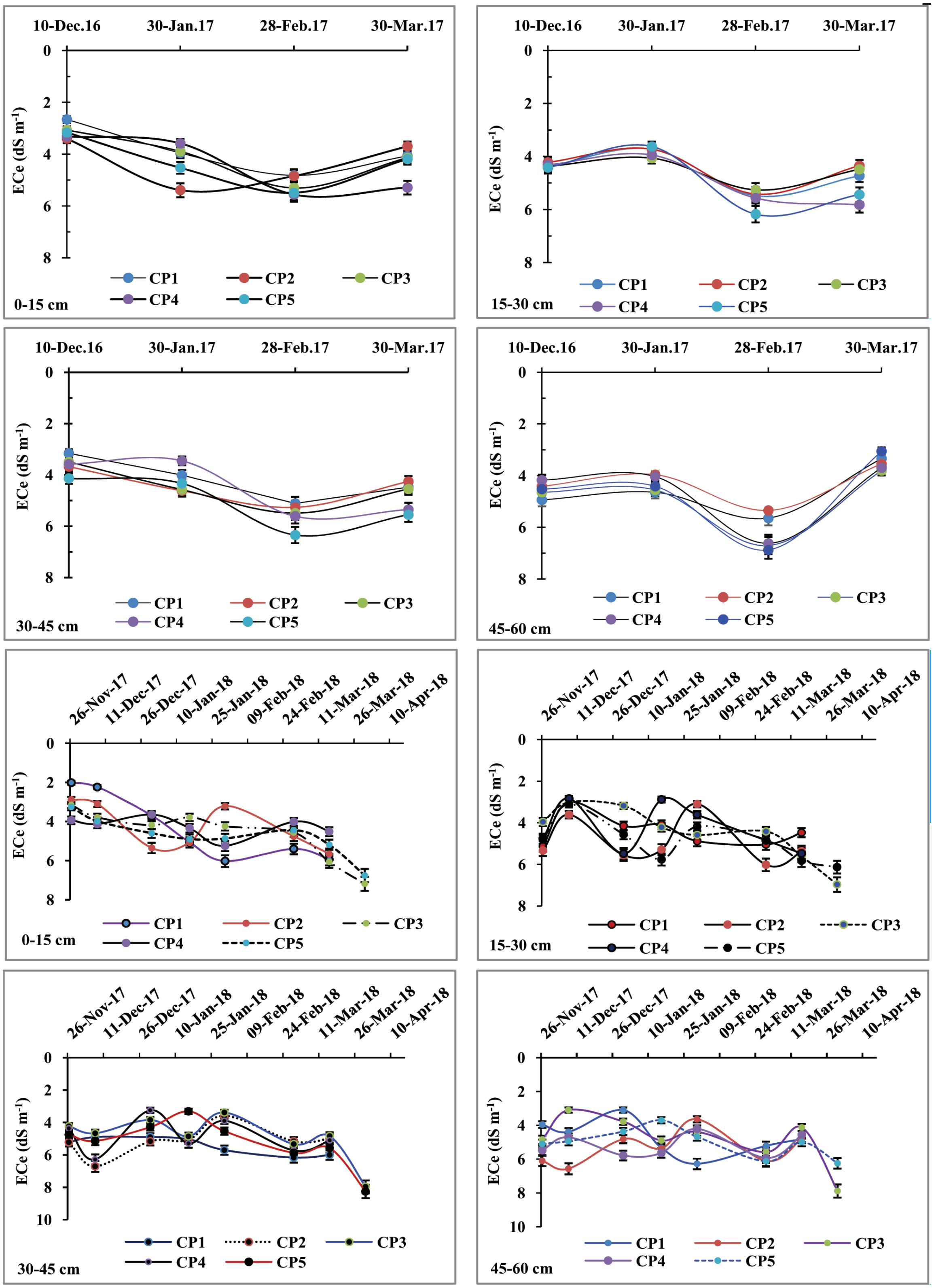

Fig. 3. *Variations of soil salinity dynamics expressed as ECe of soil solution (EC1:5) over the soil profile during crop growth seasons of 2016-2017 and 2017-2018 at salt affected coastal zone of Amtali, Barguna. Bars indicate the error percentage at 5%*

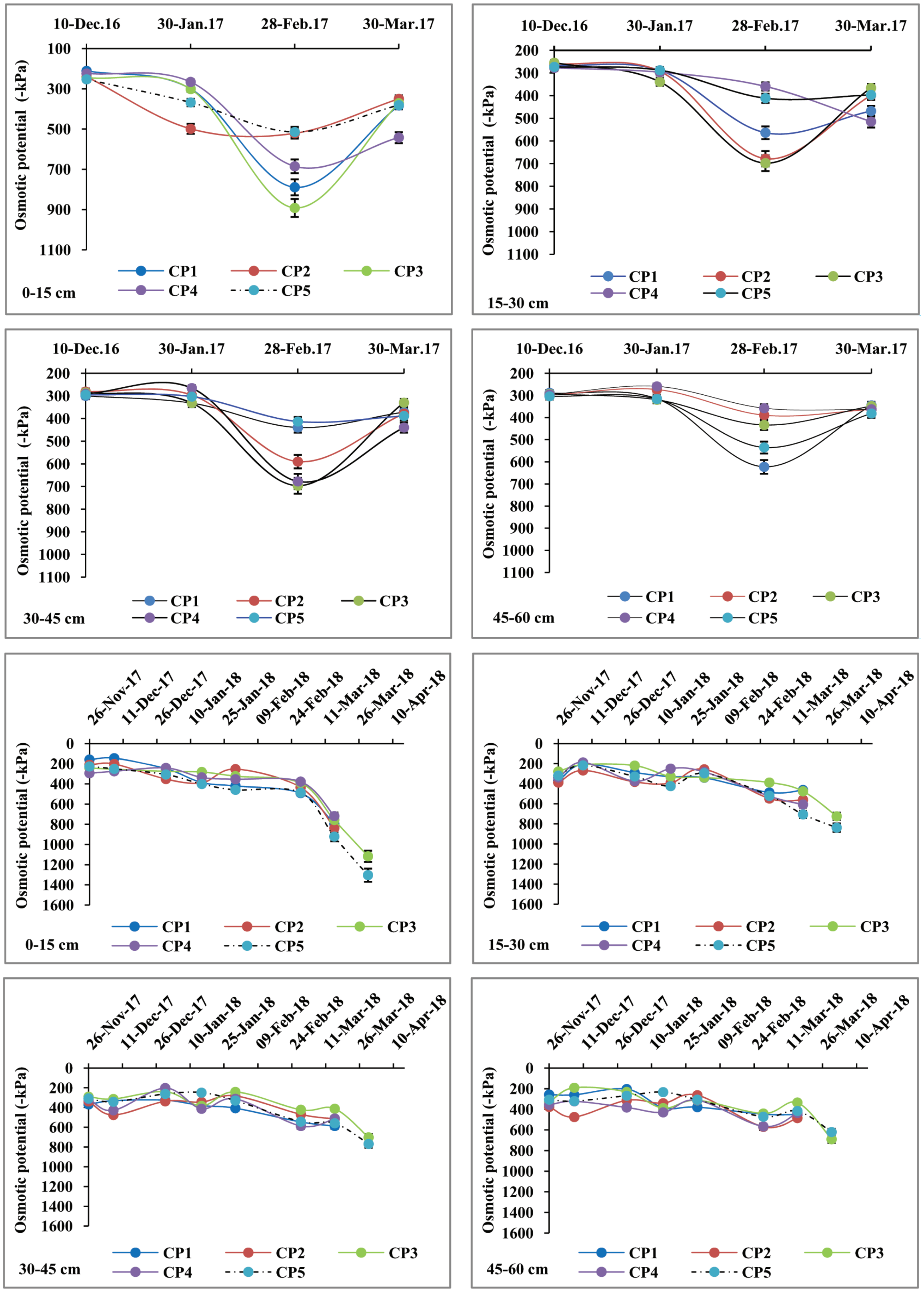

Fig. 4. Variations of soil osmotic potential (-kPa) at different depths of soil profile during the crop growing seasons of 2016-2017 and 2017-2018. Here, the value of kPa indicates negative (-) pressure. Bars indicate the error percentage at 5%

Table 4. *Mean values of total variable cost, gross margin and marginal benefit-cost ratio of different crops based on cropping system at Amtali, Barguna over two years of 2016-2017 and 2017-2018*

Particulars	Crop growing season						
	rabi				*kharif*-1	*kharif*-2	*kharif*-2
	Mustard	Sunflower	Maize	Wheat	T. *aus*	T. *aman*	T. *aman*
Land preparation, [$]Tk ha^{-1}	5250	7850	7850	5250	6676	10500	10500
Fertilizers, Tk	5439	15853	28615	16000	5600	10825	6000
Seeds, Tk ha^{-1}	500	5000	4500	4800	600	900	1500
Chemicals (Insecticides/Pesticides/ Herbicides), Tk ha^{-1}	1125	2250	3375	1125	4000	2000	2400
Irrigation, Tk ha^{-1}	4500	6750	7875	5625	-	-	-
Human labor (400 Tk man-day^{-1}), Tk ha^{-1} (Labor for land preparation, sowing, transplanting, weeding, fertilizers and chemicals application and harvesting).	18000	30000	39,000	21000	30041	26250	26250
Seasonal variable input cost (Tk ha^{-1})	34814	67703	91215	53800	46917	50475	46650
Mean crop yield, kg ha^{-1}	0.95	1.98	6.99	1.19	3.90	4.00	4.07
Gross return, Tk ha^{-1}	52250	99000	104850	29750	76050	78000	71225
Gross margin (Output-Input cost), Tk ha^{-1}	17436	31297	13635	-24050	29133	27525	25450
Marginal benefit cost ratio	1.50	1.46	1.15	0.55	1.62	1.55	1.53

[$]1 US Dollar = 80 Bangladeshi Taka (Tk).

*Fertilizers indicate the total amount of all input fertilizer Urea: 16-17 Tk kg^{-1}; Triple supper phosphate: 22-25 Tk kg^{-1}; Muriate of potash: 15 Tk kg^{-1}; Gypsum: 10-20 Tk kg^{-1}; Zinc Sulphate: 200 Tk kg^{-1}, Zinc: 190 Tk kg^{-1} and boron: 150 Tk kg^{-1}. Short duration high yielding variety was BRRI dhan 73/ BRRI dhan 62

[£]Mean data of local variety was collected from the farmers of the project site through direct field observation and interview. Long duration local variety was Vojon, BR23, etc.

*Mustard economic seed yield @ Tk 55 kg^{-1}, Sunflower economic seed yield @ Tk 50 kg^{-1}, wheat grain yield @ Tk 25 kg^{-1}; maize grain yield @ Tk 15 kg^{-1} and rice grain yield @ Tk 17.5 - Tk 20 kg^{-1}. *Cropping pattern (CP): CP1: Mustard - T. *aus* -T. *aman*; CP$_2$: Sunflower - T. *aus* - T. *aman*; CP$_3$: Maize - T. *aus* - T. *aman*; CP$_4$: Wheat - Mungbean - T. *aman*; CP$_5$: Fallow - Fallow - T. *aman* (Farmers' practice, control).

[£]Mungbean did not establish due to rainfall and high soil moisture content.

Table 5. *Profitability of yearly total system based on variable cost, gross margin and benefit-cost ratio (BCR) of different cropping system crops at Amtali, Barguna over two years of 2016-2017 and 2017-2018*

Cropping pattern (CP)	Total variable cost (Tk ha^{-1})	Total gross return (Tk ha^{-1})	Total gross margin (Tk ha^{-1})	Marginal benefit cost ratio
CP$_1$: Mustard - T. *aus* -T. *aman*	132206	206300	74094	1.56
CP$_2$: Sunflower -T. *aus* -T. *aman*	165095	253050	87955	1.53
CP$_3$: Maize -T. *aus* -T. *aman*	188607	258900	70293	1.37
CP$_4$: Wheat - Mungbean - T. *aman*	104275	107750	3475	1.03
CP$_5$: Fallow - Fallow - T. *aman*	46650	71225	25450	1.52

1 US Dollar = 80 Bangladeshi Taka (Tk).

CP_1, CP_2 and CP_3, through better salinity and water management, will not only provide economic gains but also value for family, community security, wellbeing and maintenance of food security in the future as climatic conditions change. However, this profitability analysis revealed that two or three crops per year instead of one crop in a year may change the economic and livelihood sustainability of household in the coastal zones.

Based on two years of study in the coastal salt-affected areas of Bangladesh, intensified cropping patterns, including recommended irrigation, methods and water management, have the potential to increase the total system productivity. In terms of crop yield, rice equivalent yields, production efficiency, total system of crop and water productivity, profitability of economics and reducing the risk of soil salinity, osmotic pressure and scarcity of available water, the improved cropping systems were: Mustard - T. *aus* - T. *aman*; Sunflower - T. *aus* - T. *aman*; Maize - T. *aus* - T. *aman*. In the salt-affected coastal zone, short duration and high yielding T. *aman* rice variety is necessary for timely sowing/planting of *rabi* (winter) crops for improving the system productivity as well as higher yield and economic return. However, further studies are needed to improve the understanding of risk and to optimize management in achieving the expansion of intensified cropping patterns in the coastal salt-affected areas of Bangladesh.

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REFERENCES

Akanda, A. R., Biswas, S. K., Sarker, K. K., Mondal, M. S., Saleh, A. F. Rahman, M. M. and Mosleuddin, A. Z. M. (2015). Response of wheat, mustard and watermelon to irrigation in saline soils, Proceedings Conference on *Revitalizing the Ganges coastal zone: turning science into policy and practices*, E. Humphreys, T. P. Tuong, M. C. Buisson, I. Pukinskis and M. Phillips (eds.), CGIAR Challenge Program on Water and Food (CPWF), October 21-23, 2014, Dhaka, Bangladesh. pp 492-503.

Ashraf, M. and Saeed, M. M. (2006). Effect of improved cultural practices on crop yield and soil salinity under relatively saline ground water applications. *Irrigation and Drainage Systems* **20**: 111-124.

BBS (Bangladesh Bureau of Statistics). (2011). *Statistical Year Book of Bangladesh*. Bangladesh Bureau of Statistics, Statistics Division, Ministry of Planning, Government of the People's Republic of Bangladesh.

Bhattacharya, J., Mondal, M. K., Humphreys, E. Saha, N. K, Rashid, M. H., Paul, P. C and Ritu, S. P. (2015). Rice-rice-*rabi* cropping systems for increasing the productivity of low salinity regions of the coastal zone of Bangladesh. Proceedings Conference on *Revitalizing the Ganges coastal zone: turning science into policy and practices*, E. Humphreys, T. P. Tuong, M. C. Buisson, I. Pukinskis and M. Phillips (eds.), CGIAR Challenge Program on Water and Food (CPWF), October 21-23, 2014, Dhaka, Bangladesh. pp 436-448.

FAO (Food and Agricultural Organization). (2008). *Land and Plant Nutrition Management Service*. Retrieved from: http:// www.fao.org/ag b/agl/agll/spush.

Gupta, R. K. and Abrol, I. P. (1990). Salt affected soils their reclamation and management for crop production. *Advances in Soil Science* **11**: 223-288.

Haque, A. A. (2006). Salinity problems and crop production in coastal regions of Bangladesh. *Pakistan Journal of Botany* **38**(5): 1359-1365.

http://publications.iwmi.org/pdf/H013403.pdf. *Main Irrigation System Management for Rice-Based Farming Systems in Indonesia*. Retrieved on 27-11-2018.

Islam, S., Ali, S., Biswas, J. K., and Kasem, M. A. (2013). *Modern Rice Cultivation*, Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh. 33 p.

Majumdar, D. K. (2004). *Irrigation Water Management: Principles and Practice*, 3rd printing, Prentice Hill

Company of India Private Limited, New Delhi, India.

Mandal, K. G., Kannan, K., Thakur, A. K., Kundu, D. K., Brahmanand, P. S., Kumar, A. (2014). Performance of rice systems, irrigation and organic carbon storage. *Cereal Research Communications* **42**(2): 346-358.

Maniruzzaman, M., Kabir, M. I., Hossain, M. B., Yesmin, S., Mostafizur, A. B. M., Biswas, J. C., Ali, M. A., Mainuddin, M. and Bell, R. (2019). Adjustment in wet season rice planting for cropping intensification in Coastal Bangladesh. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 123-133.

Michael, A. M. (1978). *Irrigation: Theory and Practice*, First edition, Vikash Publishing House Pvt. Ltd., New Delhi. 801 p.

Mondal, M. K., Paul, P. L. C., Humphreys, E., Tuong, T. P., Ritu, S. P. and Rashid, M. A. (2015). Opportunities for cropping system intensification in the coastal zone of Bangladesh. Proceedings Conference on *Revitalizing the Ganges coastal zone: turning science into policy and practices*, E. Humphreys, T. P. Tuong, M. C. Buisson, I. Pukinskis and M. Phillips (eds.), CGIAR Challenge Program on Water and Food (CPWF), October 21-23, 2014, Dhaka, Bangladesh. pp 449-474.

Patil, E. N., Jowale, S., Mahayan, M. S. (1995). Production potential, economics and fertility status of soil as influenced by wheat-based cropping system. *Indian Journal of Agronomy* **40**: 544-548.

Rahman, M. A., Sarker, M. R. A., Sharma, N., Mondal, M. K., Islam, M. R., Gregorio, G. B., Humphreys, E. and Tuong, T. P. (2015). Challenges and opportunities for *aman rice* cultivation in *ghers* used for brackish water shrimp production. Proceedings Conference on *Revitalizing the Ganges coastal zone: turning science into policy and practices*, E. Humphreys, T. P. Tuong, M. C. Buisson, I. Pukinskis and M. Phillips (eds.), CGIAR Challenge Program on Water and Food (CPWF), October 21-23, 2014, Dhaka, Bangladesh. pp 333-341.

Rahman, M. M., Saeem, A. A. and Mullick, M. R. A. (2016). Spatial explicit assessment of water footprint for rice production in Bangladesh, Proceedings 3rd International Conference on *Advances in civil engineering*, December 21-23, 2016, Chittagong University of Engineering and Technology (CUET), Chittagong, Bangladesh. pp 722-727.

Reddi, G. H. S. and Reddy, T.Y. (2009). *Efficient Use of Irrigation Water*, First edition. Kalyani Publishers, New Delhi, India.

Rengasamy, P. (2010). Soil processes affecting crop production in salt-affected soils. *Functional Plant Biology* **37**: 613-620.

Richards, L. A. (1954). *Diagnosis and Improvement of Saline and Alkali Soils*. Handbook No. 60, United States Department of Agriculture, Washington DC, USA.

Saha, N. K, Mondal, M. K., Humphreys, E., Bhattacharya, J., Rashid, M. H., Paul, P. C and Ritu, S. P. (2015). Triple rice in a year: Is it a feasible option for the low salinity areas of the coastal zone of Bangladesh? Proceedings Conference on *Revitalizing the Ganges coastal zone*: *turning science into policy and practices*, E. Humphreys, T. P. Tuong, M. C. Buisson, I. Pukinskis and M. Phillips (eds.), CGIAR Challenge Program on Water and Food (CPWF), October 21-23, 2014, Dhaka, Bangladesh. pp 421-435.

Sarker, K. K., Akanda, M. A. R., Biswas, S. K., Roy, D.K., Khatun, A. and Goffar, M. A. (2016). Field performance of alternate wetting and drying furrow irrigation on tomato crop growth, yield, water use efficiency, quality and profitability. *Journal of Integrative Agriculture* **15**(10): 2380-2392.

Singh, J. P., Salaria, A., Singh, K. and Gangwar, B. (2008). Efficiency of diversified rice-wheat cropping systems including potato, vegetables peas and groundnut crops in Trans-Gangetic plains. *Potato Journal* **35**(1-2): 53-60.

Siringam, K., Juntawong, N., Chaum, S. and Kirdmanee, C. (2011). Salt stress induced ion accumulation, ion homeostasis, membrane injury and sugar contents in salt-sensitive rice (*Oryza sativa* L. *spp. indica*) roots under isosmotic conditions. *African Journal of Biotechnology* **10**: 1340-1346.

Slavich, P. G. and Petterson, G. H. (1993). Estimating the electrical conductivity of saturated paste extracts from 1:5 soil: water suspensions and texture. *Australian Journal of Soil Research* **31**: 73-81.

Smith, M. (1992). *CROPWAT a computer programme for irrigation planning and management*, FAO Irrigation and Drainage Paper 46, FAO, Rome, Italy.

Tomar, S. S. and Tiwari, A. S. (1990). Production potential and economics of different crop sequences. *Indian Journal of Agronomy* **35**(1&2): 30-35.

Vandana, T., Vinay, P. M., Pragati, S., Shashikanta, P., Kartar, S., Natesan, R., Natraj, S. and Pavan, K. (2014). Rice equivalent crop yield assessment using MODIS sensors' based MOD13A1-NDVI data. *IEEE Sensors Journal* **14**(10): 3599-3605.