

Effect of establishment methods in rainy season (*kharif*) and tillage practices in winter season (*rabi*) on yield and economics of rice (*Oryza sativa*)–maize (*Zea mays*) cropping system under coastal saline ecosystem

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ABSTRACT

A field experiment was carried out during 3 consecutive rainy seasons (*kharif*) June–November and winter (*rabi*) December–May seasons of 2013–16 at Canning Town, West Bengal to evaluate 3 rice (*Oryza sativa* L.) establishment methods, viz. dry direct seeding (DSR), unpuddled transplanting (UNPT) and puddled transplanting (PT), followed by 3 tillage practices for sowing *rabi* maize (*Zea mays* L.), viz. zero tillage (ZT), conventional tillage (CT) and raised bed sowing (RBS). The DSR was done in the last week of May when the soil salinity was higher (12–15 dS/m); however, it reduced to 4–5 dS/m in the month of June due to leaching of salts by monsoon rain. The transplanting in the UNPT and PT plots was done during the first week of July using 40 days old seedlings. Submergence caused by the heavy rain, affected the transplanted rice (PT and UNPT) but not the DSR, as the plants with DSR were sufficiently above the standing water due to higher plant height. The mean grain yields in 3 establishment methods of rice (5,117; 4,477 and 4,740 kg/ha in PT, UNPT and DSR respectively) were statistically at par. However, net returns (₹36,000/ha) and benefit: cost ratio (2.2) were the highest in DSR owing to 24% reduction in cost of cultivation than PT rice. The positive effects of DSR also observed on the succeeding *rabi* maize crop in terms of 7.4 ha-cm less irrigation water requirement and 27% higher irrigation water productivity. Maize gave the highest yield (5,600 kg/ha), net returns (₹37,910/ha) and benefit: cost ratio (BCR) 1.86 with RBS tillage practices. The system rice-equivalent yield, net returns and BCR were 11,659 kg/ha, ₹77,470/ha and 2.05, respectively, for dry direct-seeded rice-raised bed sown maize with higher mean irrigation water productivity (79 kg/ha-cm) and energy productivity (461 kg/GJ) of *rabi* maize.

Key words: Dry direct sowing, Energy use, Maize, Puddling, Raised bed, Rice, Zero tillage

Rice yield during the rainy (*kharif*) season in the coastal areas are highly variable mainly due to improper selection of varieties, soil salinity and submergence/flooding by heavy rain following transplanting. Rainfed shallow lowland in coastal areas often suffers from stagnant flooding of 25–50 cm, generally coinciding with transplanting period of rice, and damage occurs as the crop is still in the transplanting shock stage (Saranghi *et al.*, 2016). Submergence during initial 5–6 weeks of transplanting causes severe damage due to poor survival of the plants. Prolonged partial flooding with 30–60 cm water depths reduces rice productivity due to high mortality, suppressed tillering capacity, reduced panicle size and high sterility. Therefore, mechanism to withstand such problem is essen-

tial to increase the yield and sustainability in the coastal areas. Approach of early establishment of the crop before the maximum probability of flooding event may be an alternative. Direct sowing before the onset of monsoon to the dry ploughed soil can be a possibility given the fact that rice is comparatively tolerant to salt stress during germination (Pandey *et al.*, 2010). The method of direct seeding of rice during *kharif* season as well as transplanting without puddling were not tested under the coastal saline soil conditions in a system perspective with effects on the succeeding *rabi* crops. When the rice crop is established by transplanting the soil structure is damaged and there is problem on subsequent *rabi* crop tillage and establishment.

The crops during the winter (*rabi*) and summer season on heavy-textured coastal saline soils also suffer a considerable loss after a medium to heavy rains and at times, it leads to almost a total crop failure. Such events are com-

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mon once or twice in the *rabi* season in coastal area due to torrential rain. This also often hinders successful second cropping in the area, which are primarily monocropped area with *kharif* rice. There is a need to develop and test appropriate *rabi* season tillage practices like zero tillage (ZT) and sowing on raised bed (RBS) to reduce the effect of salinity, crust formation and waterlogging. Since irrigation water is scarce, by the improved tillage and establishment technologies, the *rabi* season rain can be effectively utilized instead of allowing it to damage the crops. The ZT for *rabi* crops may also help in advanced sowing, earlier crop emergence, less weed growth and use of residual soil moisture. There is a potentiality of growing of low water-requiring *rabi*/ summer season crops, which are commercially viable, and having good market demand. One such crop is maize which is having wide adaptability and versatile uses. Maize is a profitable crop owing to its various industrial uses besides serving as human food as well as feed for poultry, piggery and other animals. It requires much less water than dry season rice, and due to its higher water productivity, this cropping system will be less detrimental to the environment as there will be less withdrawal of precious ground water in the coastal region. During *rabi* season in the coastal region temperatures during the growth period does not go below 10 °C, radiation are generally excellent and maize being a photo-insensitive crop has better option for adaptation in the changing climatic scenario. Keeping these facts in view the present study was conducted to find out suitable crop establishment and tillage methods for rice–maize cropping system in the low-lying salt-affected land of coastal West Bengal, to study the effect of crop-establishment methods in a system perspective on productivity, profitability, soil properties, and to achieve sustainable cropping system intensification during *rabi* season in the rice-fallow areas.

MATERIALS AND METHODS

A field experiment was conducted at the research farm of ICAR-Central Soil Salinity Research Institute, RRS, Canning Town, West Bengal (22° 15' N, 88° 40' E; 3.0 m above mean sea-level) during *kharif* and *rabi* seasons of 2013–16. Climate of this region is tropical monsoon, with average annual rainfall of 1802 mm. The mean maximum temperature in May, which is the hottest month of the year, ranges from 35° to 40°C, while the mean minimum temperature in the coldest month of January ranges from 12° to 15°C. Soil is heavy textured, with 43% clay, 47% silt and 10% sand. The initial pH of the experimental soil varied from 5.6 to 6.2, with average bulk density of 1.47 g/cc and low in organic carbon (0.45%). Soil was low in available N (152.7 kg/ha), medium in available P (14.3 kg/ha) and high in available K (287 kg/ha). Experiment consisted

of 3 methods of *kharif* rice establishment, viz. dry direct seeding (DSR), unpuddled transplanting (UNPT) and puddled transplanting (PT) in main plot and 3 methods of *rabi* maize tillage practices, viz. zero tillage direct sowing/dibbling after harvesting of rice (ZT), sowing in flat land with conventional land preparation (CT) and raised bed sowing (RBS), in subplot. Experimental design was split-plot with 9 treatments as described above and 3 replications. The DSR for *kharif* rice was done in the last week of May in each year before the onset of monsoon. On the day monsoon rain started (mostly in the first to second week of June) nursery sowing was done for other 2 treatments. Rice variety Amal-Mana of 155–165 days duration, 150–160 cm plant height, long slender grain, with salt tolerance (4.0–6.0 dS/m) and average grain yield of 4,500 kg/ha was used. Transplanting was done in 20 cm × 15 cm spacing as per treatments. For DSR and UNPT treatments, only 1 summer ploughing was done by tractor in the mid of May and then sowing/transplanting was done in lines, 20 cm apart. In PT plots, in addition to summer ploughing, 2 ploughings by power tiller, then twice puddling and leveling were done before transplanting.

Rabi maize under ZT treatment was sown by dibble sowing of seeds immediately after harvesting of *kharif* rice by making a hole at the place of seeding and covering the seeds by dry farmyard manure (FYM); the crops under second tillage practice (CT) involves the drying of the residual soil moisture from the fields and then ploughing by a tractor followed by secondary tillage operations by power tiller and third tillage practice (RBS) was making raised beds in the cultivated soil with beds of width 30 cm base and 15 cm top. The ZT was done in the first week of December immediately after harvesting of *kharif* rice to use the residual soil moisture, whereas CT and RBS were done in the third week of December when soil moisture attained ploughable condition. These treatments were imposed on the same layout of *kharif* season crop establishment (CE) methods as main plot treatment. Maize was sown with a spacing of 60 cm × 30 cm in sub-plots. Crop-growth rate (CGR) and relative growth rate (RGR) of *rabi* maize crop were calculated by using the dry-matter weights at 30 days after sowing (DAS), 60 DAS and at harvesting. The kernel yield of *rabi* maize was converted into rice grain-equivalent yield (REY) by taking into account the prevailing market price and using the following formula.

$$REY = (\text{Kernel yield of maize crop} \times \text{price of maize kernel}) / \text{Price of rice grain}$$

Soil organic carbon and bulk density were determined before the start of experiment in May 2013 and after harvest of *kharif* rice crop. Soil salinity was observed by using Systronic Electrical Conductivity Meter from the satu-

ration extract (ECe in dS/m) of the soil collected from 0–20 cm layer. All data were subjected to the analysis of variance (ANOVA) for split-plot design with F-test. Significant differences between treatments were compared using of critical difference (CD) values calculated by the use of standard error of means and t-table values at error degrees of freedom with 5% level of probability. Economic evaluation of different treatments was done based on cost of cultivation, gross return, net return, and benefit: cost ratio (BCR). Energy input from direct and indirect sources in the form of seed, chemical and organic fertilizer, pesticides, human power, fuel consumed, machinery used etc. for various operations in the crop production and output in the form of yields were converted into equivalent value of chemical energy (MJ/ha) by using energy equivalents as given by Devasenapathy *et al.* (2008). The energy productivity and output: input ratio were calculated by the following formulae.

$$\text{Energy productivity (kg/GJ)} = \frac{\text{Crop yield (kg/ha)}}{\text{Energy inputs to crop production (GJ/ha)}}$$

$$\text{Energy output-input ratio} = \frac{\text{Energy output (GJ/ha)}}{\text{Energy inputs to crop production (GJ/ha)}}$$

RESULTS AND DISCUSSION

Effect of establishment methods in kharif on soil salinity, germination and crop stand of rice

Soil salinity was the highest in May and suddenly decreased in June (Fig. 1) due to the onset of monsoon, and decreased gradually in the subsequent months and became the lowest during August–September. Initially there was not much variation in salinity in different establishment methods. There was a significant effect of *kharif* rice-establishment methods on the soil-salinity development in the subsequent *rabi* crop, being the highest in the PT plot (>4 dS/m), followed by UNPT (3 dS/m) and the least in the direct-sown crop (2 dS/m) in December (Fig. 1). Germination of rice seeds was significantly higher in DSR compared to UNPT and PT plots (Table 1).

Number of tillers in *kharif* rice increased in all the es-

tablishment methods from July to October (Table 1). However, it was significantly higher in DSR during the maximum vegetative stage (July–August). The transplanting in the UNPT and PT plots were done in the first week of July when the seedlings were 40 days old. Aged seedlings are transplanted in the salt-affected coastal rainfed areas to cope with salinity stress and waterlogging prevalent in this ecosystem (Sarangi *et al.*, 2016). After transplanting, there was submergence stress in UNPT and PT plots; as a result the tillers/m² were less in these treatments. Due to heavy rain in July and September 2013, in July 2014 and 2015, there was mortality of seedlings in the transplanted plots, therefore about 20–25% of plants were gap filled in these plots with the extra seedlings from the nursery. Therefore, additional management in terms of gap filling was needed to maintain optimum plant population.

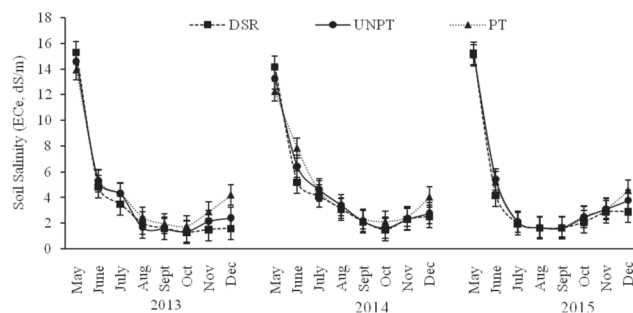


Fig. 1. Soil salinity during *kharif* and beginning of *rabi* season for 3 years of study at Canning Town, West Bengal under three rice establishment methods (DSR, Dry direct seeding; UNPT, unpuddled transplanting; PT, puddled transplanting)

Effect of tillage practices in rabi on soil salinity

Soil salinity on surface (0–20 cm) soil during *rabi* increased with progress of season in all the years (Fig. 2). In each treatment, the soil salinity increased from December to April; however, there was significant variation in soil salinity due to different *rabi* tillage. Mean soil salinity increased from December to January, January to February, February to March and March to April, being 19.7, 70.6, 17.3 and 6.9% respectively. The salinity build up was 43%

Table 1. Effect of establishment methods in *kharif* on germination and tiller density of rainfed low land rice

Treatment	Germination (%)			Tillers/m ²											
	2013	2014	2015	July			August			September			October		
				2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015
DSR	84.5	83.3	84.4	355	375	347	412	424	418	426	403	380	401	525	463
UNPT	83.0	82.4	82.2	120	149	143	348	359	352	344	361	378	421	438	404
PT	82.4	82.1	82.5	169	160	170	394	378	362	404	387	370	426	402	414
SEm±	0.28	0.09	0.11	6.39	7.46	7.23	4.82	7.35	4.49	15.04	8.79	7.19	5.53	8.50	7.77
CD (P=0.05)	1.09	0.34	0.45	25.09	29.27	28.38	18.92	28.84	17.64	59.02	NS	NS	NS	33.38	30.50

DSR, Dry direct seeding; UNPT, unpuddled transplanting; PT, puddled transplanting

less in RBS and significantly highest in the ZT plots. Soil salinity was 14% higher in the ZT plots than that in CT plots. Ploughing created dust mulch on the soil surface, resulted in breakage of sub-surface capillary pores and thereby curtailed the upward movement of salts through the evaporation pull as a result there was less salinity build up. Therefore, ploughing of land during start of *rabi* season help in reducing salinity problem (Sarangi and Maji, 2017).

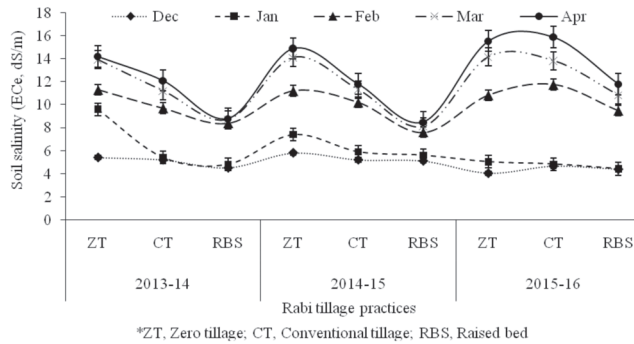


Fig. 2. Soil salinity during *rabi* season under different tillage practices

Effect of establishment methods in kharif on growth of rice

There was significant response of rice to submergence stress due to different crop-establishment methods. Submergence due to heavy rain during July–September 2013 damaged the normal transplanted (UNPT and PT) crop as the plant height (15–54 cm) was almost the same with standing water (12.5–55 cm), whereas in the DSR plot the crop was not affected as the plants (52–113 cm) were sufficiently above the standing water (Fig. 3a). The rice crop was affected in *kharif* 2014 just after transplanting due to submergence in July when the crop is still in transplanting shock stage (Fig. 3b). During *kharif* 2015, the rainfall received in July was 834 mm, which was 224% of 49 years average rainfall for the month of July (372 mm). Due to the heavy rainfall during *kharif* 2015, the transplanted crop was affected by flooding (Fig. 3c) in the initial 3 weeks after transplanting but the DSR crop was not affected, as the canopy height was sufficiently above the field water depth.

Maize crop growth observed at different stages revealed that though plant height, CGR and RGR were higher due to the effect of DSR, but the difference was not statistically significant over UNPT and PT in all the years (Table 2). During 2014–15, at 30 days after sowing (DAS) plant height of *rabi* maize was significantly higher due to the effect of DSR over UNPT and PT treatments. In 2013–14, significant effect of DSR was also observed on the plant height of *rabi* maize at 60 DAS and at harvest, how-

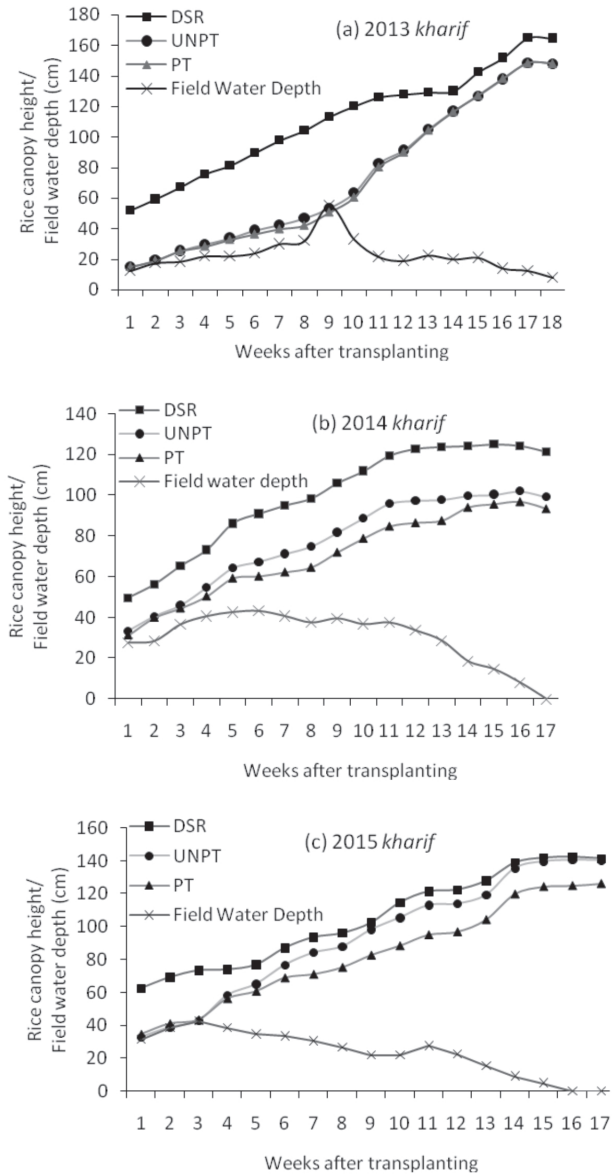


Fig. 3. Rice field water depth and rice canopy height under different establishment methods during the three *kharif* seasons: a, 2013; b, 2014; c, 2015

ever in other years the differences were non-significant. *Rabi* tillage practices had a significant effect on the growth parameters of maize (Table 2). Plant height at 30 DAS was 0.4–1.6% and 13.2–21.5% higher in RBS, over CT and ZT respectively. At 60 DAS, the plant height was 7.0–9.5% lower in CT and 23.0–39.0% lower in ZT compared to RBS tillage practices. This trend of increase in plant height due to RBS also observed at harvesting stage with mean plant height of 157.3, 187.3 and 200.5 cm in ZT, CT and RBS respectively. The CGR of *rabi* maize at 30–60 DAS was 0.19–0.46 g/plant/day in ZT, 0.54–0.97 g/plant/day in CT and 1.14–1.21 g/plant/day in RBS. During sub-

Table 2. Effect of establishment methods in *kharif* and tillage practices in *rabi* on growth parameters of maize

Treatment	Plant height (cm)						CGR (g/plant/day)						RGR (g/plant/day)								
	30 DAS		60 DAS		Harvesting		30-60 DAS		60 DAS-harvesting		30-60 DAS		60 DAS-harvesting								
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15							
<i>Kharif</i> (CE)																					
DSR	22.3	26.6	24.7	96.1	106.2	112.9	171.3	197.5	189.5	0.63	0.95	0.81	4.18	4.30	4.37	0.12	0.14	0.12	0.05	0.04	0.05
UNPT	22.2	24.5	23.5	92.5	115.0	103.9	165.2	193.0	184.0	0.62	0.89	0.77	3.62	4.25	3.99	0.12	0.13	0.12	0.05	0.04	0.04
PT	21.9	25.0	23.5	87.3	111.5	106.5	164.4	190.0	179.3	0.62	0.80	0.72	3.60	4.46	4.18	0.11	0.13	0.11	0.05	0.04	0.05
SEm±	0.30	0.34	0.26	1.62	5.10	2.33	1.33	5.67	5.42	0.07	0.07	0.06	0.13	0.09	0.10	0.004	0.002	0.004	0.002	0.001	0.002
CD (P=0.05)	NS	1.34	NS	6.35	NS	NS	5.22	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<i>Rabi</i> (Tillage)																					
ZT	20.4	22.3	21.7	69.8	94.9	77.9	135.7	176.7	159.6	0.19	0.46	0.33	2.46	3.53	3.26	0.06	0.12	0.10	0.04	0.04	0.04
CT	23.0	26.7	24.8	97.9	114.6	117.9	172.0	197.0	192.8	0.54	0.97	0.77	3.78	4.47	4.27	0.14	0.13	0.13	0.05	0.04	0.05
RBS	23.1	27.1	25.2	108.2	123.2	127.5	193.2	207.6	200.6	1.14	1.21	1.19	5.14	5.01	5.01	0.14	0.13	0.13	0.06	0.05	0.05
SEm±	0.41	0.69	0.39	1.74	2.96	2.69	2.76	3.65	2.78	0.08	0.04	0.05	0.10	0.19	0.21	0.01	0.002	0.01	0.002	0.001	0.002
CD (P=0.05)	1.27	2.12	1.19	5.37	9.13	8.27	8.50	11.24	8.56	0.25	0.13	0.15	0.30	0.58	0.63	0.02	0.01	0.02	0.005	0.003	0.005

CE, Crop establishment; DSR, dry direct sowing; UNPT, unpuddled transplanting; PT, puddle transplanting; ZT, Zero tillage; CT, conventional tillage; RBS, raised bed sowing; CGR, crop growth rate; RGR, relative growth rate; DAS, days after sowing

sequent stage (60 DAS–harvesting), the CGR also significantly higher by 1–2 g/plant/day in RBS over ZT and CT. RGR at 30–60 DAS was higher in RBS than ZT and CT. The mean RGR at 60 DAS-harvest was 0.04, 0.05 and 0.06 g/plant/day in ZT, CT and RBS respectively.

Effect of establishment methods in kharif on yield and economics of rice

There was no significant variation in grain yields under DSR, UNPT and PT respectively of rice with different establishment treatments (Table 3). This may be due to the use of improved stress tolerant rice variety coupled with improved agronomic practices like proper spacing, seedling number/hill and combining chemical fertilizers with farmyard manure (Sarangi *et al.*, 2016). The same trend was observed for straw yields except in 2015, during 2015 the straw yield was significantly higher in DSR (12,340 kg/ha) over PT rice (9,350 kg/ha). Raising of seedbed, puddling, transplanting and gap filling resulted in higher cost of cultivation of about ₹ 5,000–8,000/ha and ₹ 17,000–18,000/ha in UNPT and PT respectively, which corresponds to 16–28 and 47–68% higher cost over DSR (Table 3). Among the 3 *kharif* rice-establishment methods, there were no variation in gross return; however, net return and benefit: cost ratio were higher in DSR over UNPT and PT. Net return was at par for UNPT and PT methods, but it was significantly higher in DSR over UNPT and PT rice. The BCR remained the highest in DSR than UNPT and PT. Therefore, from economics point of view and the effect of *kharif* tillage practices (puddling) on the succeeding crops, the alternative methods like DSR and UNPT alongwith stress-tolerant varieties are recommended for this agro-ecosystem.

Effect of establishment methods in kharif on soil organic carbon and bulk density

After the harvesting of *kharif* rice in November 2015, soil properties like bulk density (BD) and soil organic carbon (SOC) were compared with the initial value in each treatment. Initial SOC was 0.45%, however due to the effect of different establishment method of *kharif* rice like DSR, UNPT and PT, the respective values were 0.46, 0.44 and 0.45% in 2013; 0.53, 0.51 and 0.41% in 2014 and 0.56, 0.51 and 0.41% in 2015. Similarly, from the initial BD value of 1.47 g/cc, the respective changes due to DSR, UNPT and PT were 1.42, 1.44 and 1.48 g/cc in 2013, 1.32, 1.41 and 1.54 g/cc in 2014 and 1.29, 1.40 and 1.56 g/cc in 2015. The BD of soil after two and half years was significantly higher (11–21%) in PT plot (1.56 g/cc) in comparison to DSR (1.29 g/cc) and UNPT (1.40 g/cc); whereas SOC increased in DSR (0.56%) and UNPT (0.51%) compared to PT (0.41%) plots. Singh *et al.*

(2014) at New Delhi also observed that SOC increased in non-puddled/no-tillage practice in rice (0.68%) compared to puddled/conventional tillage (0.65%) after 4 crops in rice–wheat system. Transplanting needs puddling, which has negative effect on soil physical properties because there is breakdown of soil aggregates, destruction of macropores, formation of hard pan with a consequent increase in soil bulk density and lowering in hydraulic conductivity below the plough layer (Singh *et al.*, 2009). Since, the soils in the coastal areas become soft after wetting, transplanting may be possible without puddling. Puddling is essentially not a pre-requisite for higher yield. It deteriorates the physical properties of soil, adversely affects the performance of succeeding *rabi* crops and contributes to methane emissions.

Effect of establishment methods in kharif and tillage practices in rabi on yield attributes and yield of maize

Number of cobs/plant was significantly higher in RBS than ZT and CT. Most of the plants were observed with single cob in ZT and CT; however, in RBS more number of plants produced 2 cobs/plant. Similarly, the kernels/cob were higher in RBS maize, being 57 and 87 numbers higher over CT and ZT respectively (Table 4). Statistically there was no variation in 1,000 kernel weight due to the effect of *kharif* and *rabi* crop establishment and tillage practices. Ihsanullah *et al.* (2001) reported that under ridge planting of maize, cobs/plant, kernels/cob and grain weight were significantly higher than other methods (furrow, line and broadcast), which resulted in about 11% higher yield in hybrid maize than broadcast method of establishment.

There was a significant effect of *kharif* rice crop establishment (CE) methods on the yield of subsequent *rabi* maize crop (Table 4) except during 2014–15. The DSR resulted in significantly highest kernel yield of *rabi* maize than UNPT and PT in 2013–14. The kernel yield was at par for DSR and UNPT, but significantly higher than PT in 2015–16. Kernel yield and energy productivity of *rabi* maize was increased by 13–14% due to DSR over PT rice. Owing to cultivation of *rabi* maize in UNPT *kharif* rice

plots there was about 8% higher yield over PT rice. Therefore, DSR and UNPT are suitable alternative *kharif* rice crop-establishment methods for coastal region, which has positive effect on the subsequent *rabi* crop like maize.

Irrigation water use, water and energy productivity during rabi season

Depth of irrigation water (IW) applied (ha-cm) and irrigation water productivity (IWp) of *rabi* maize under different establishment and tillage practices are given in Table 5. There was significant effect of *kharif* rice-establishment methods on irrigation water use of subsequent *rabi* maize crop. Dry direct seeding method of rice reduced the irrigation requirement of maize by about 7.4 and 4.9 ha-cm than puddled transplanting and unpuddled transplanting methods respectively. Similarly, the IWp was also higher by 27 and 9% owing to DSR over PT and UNPT respectively. Ramesh *et al.* (2014) observed 6.5–9.6% increase in IW and 6.5–9.6% decrease in IWp in maize – wheat cropping system due to ZT in a silty clay loam soil as compared to sowing by multi-crop planter. In maize, the amount of irrigation water applied to zero-tilled direct-sown crop was significantly higher by 9.6 and 4.2 cm than RBS and CT respectively. The IWp was significantly higher in RBS than CT and ZT. Soil salinity and irrigation water scarcity are the major constraints for *rabi* season cropping in coastal saline region. Due to scarcity of fresh surface water during dry season, farmers resort to pumping groundwater for irrigation, this leads to lowering of groundwater piezometric levels (Sarangi *et al.*, 2015). Therefore, suitable establishment and tillage practices are essential for efficient use of irrigation water. Irrigation water saving in RBS was achieved because of less development of soil cracks, less build up of salts and less surface runoff.

There was effective utilization of applied irrigation water in RBS; on the other hand the soil cracks developed in these heavy-textured soils in the unploughed ZT plots resulted in loss of irrigation water beyond the root zone of the crop very rapidly before it is absorbed by the plant roots. RBS establishment in maize provided efficient

Table 3. Effect of establishment methods in *kharif* on yield and economics of lowland rice under coastal saline ecosystem

Treatment	Grain yield (kg/ha)			Straw yield (kg/ha)			Gross returns ($\times 10^3$ ₹/ha)			Cost of cultivation ($\times 10^3$ ₹/ha)			Net returns ($\times 10^3$ ₹/ha)			Benefit: cost ratio		
	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015	2013	2014	2015
<i>Crop establishment</i>																		
DSR	4,930	4,950	4,340	9,870	8,420	12,340	69	68	64	25	32	36	44	37	28	2.7	2.2	1.8
UNPT	4,550	4,420	4,460	10,430	9,010	1,0820	65	62	64	32	37	44	33	25	20	2.0	1.7	1.5
PT	5,080	5,530	4,740	10,830	7,700	9,350	72	75	66	42	50	53	30	25	14	1.7	1.5	1.3
SEm±	459	774	370	780	849	770	2.46	2.51	0.86	0.29	0.20	0.17	1.36	2.44	0.95	0.04	0.07	0.02
CD (P=0.05)	NS	NS	NS	NS	NS	2660	NS	NS	NS	1.16	0.79	0.68	5.32	9.59	3.75	0.18	0.27	0.07

Table 4. Yield attributes and yield of *rabi* maize under different establishment methods in *kharif* and tillage practices in *rabi*

Treatment	Cobs/plant			Kernels/cob			1,000 kernel weight (g)			Kernel yield (kg/ha)			Stover yield (kg/ha)		
	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16
<i>Kharif</i> (CE)															
DSR	1.3	1.3	1.4	287.9	444.4	368.8	205.6	234.8	223.6	5,538	4,824	3,682	12,920	14,987	9,172
UNPT	1.3	1.3	1.4	288.5	423.5	357.2	202.4	216.5	211.6	4,848	4,940	3,622	11,349	14,932	9,291
PT	1.3	1.3	1.3	263.0	433.1	349.3	200.5	229.9	213.4	4,708	4,531	3,196	10,964	15,249	8,746
SEm±	0.05	0.04	0.05	4.89	18.06	11.59	1.67	3.54	4.28	75.3	336.4	98.3	225.3	438.6	529.6
CD (P=0.05)	NS	NS	NS	19.19	NS	NS	NS	13.88	NS	295.7	NS	385.9	884.2	NS	NS
<i>Rabi</i> (Tillage)															
ZT	1.1	1.1	1.2	236.0	398.9	319.4	203.9	234.0	217.8	3,783	4,033	2,874	7,596	11,377	6336
CT	1.3	1.3	1.4	274.7	419.6	350.2	203.1	228.8	217.0	5,219	4,426	2,754	11,436	16,256	8,027
RBS	1.5	1.5	1.6	328.6	482.4	405.7	201.5	218.3	213.7	6,092	5,836	4,873	16,202	17,535	12,845
SEm±	0.05	0.03	0.02	5.12	15.83	8.66	3.37	5.39	3.63	112.4	297.0	213.4	329.8	504.2	365.6
CD (P=0.05)	0.16	0.10	0.08	15.78	48.76	26.68	NS	NS	NS	346.4	915.2	657.4	1,016.1	1,553.6	1,126.4

CE, Crop establishment; DSR, dry direct sowing; UNPT, unpuddled transplanting; PT, puddled transplanting; ZT, Zero tillage; CT, conventional tillage; RBS, raised bed sowing; CGR, crop growth rate; RGR, relative growth rate; DAS, days after sowing

drainage during torrential rain which are becoming usual events under changing climatic situations in coastal region. The raised beds dried more rapidly and prevented waterlogging situation quickly in comparison to other tillage practices. During the dry period the soil moisture was significantly higher in raised beds in the 0–15 cm soil layer, as the water-holding capacity was more in the ridge plots due to high looseness of soil particles (Memon *et al.*, 2007).

Energy productivity (Ep) of *rabi* maize was higher owing to DSR and UNPT methods of *kharif* rice-establishments compared to PT method. However, the differences due to establishments was statistically significant in 2013–14 and 2015–16 (Table 5). Islam *et al.* (2013) reported that UNPT rice saved 20% energy input compared to PT rice cultivation mainly due to reduction of 13–20% energy input in land preparation for UNPT compared to PT. Tillage practices during *rabi* also influenced the Ep of maize in all the years of study and it was significantly higher in RBS compared to ZT and CT. Energy output: input (Eoi) ratio was also higher owing to DSR and UNPT methods, but it was only significantly higher than PT in 2013–14, being 25, 22 and 21 for DSR, UNPT and PT methods of establishment respectively. Tillage practices significantly affected the Eoi ratio in all the years. It was the highest in RBS (23–31) followed by CT (15–28) and ZT (14–23).

Effect of establishment methods in kharif and tillage practices in rabi on economics of maize

Cost of cultivation of maize crop was affected by the establishment methods of previous *kharif* rice crop. It was at par for DSR and UNPT, but higher under PT. However, the differences were non-significant in 2015–16 (Table 6). Average gross return of maize was 11 and 7% higher in DSR and UNPT, respectively, over PT method of *kharif* rice establishment. Similarly, the net return and benefit: cost ratio (BCR) also higher in maize because of DSR and UNPT methods than conventional PT method of establishment. Though the cost of cultivation of *rabi* maize under RBS was higher than other methods (ZT and CT), the gross return, net return and BCR were significantly higher in RBS over other tillage practices (Table 6). Gross return in RBS was significantly higher than CT and ZT. Net return of *rabi* maize increased significantly owing to RBS by about ₹16,650/ha over CT (₹21,260/ha) and by ₹27,666/ha over ZT (₹10,243/ha). Similar trend also observed for BCR, being significantly higher in RBS compared to CT and ZT.

Rice–maize system yield and economics

In case of rice–maize cropping system, the highest sys-

tem REY was observed in DSR–RBS, which was at par with UNPT–RBS except during 2013–14 (Table 7). Therefore, DSR and UNPT methods of *kharif* rice establishments resulted in better system yield than the conventional puddled transplanting method. In rice–maize cropping system the highest cost of cultivation was incurred in PT–RBS, but the gross and net returns and BCR were highest in DSR–RBS (Table 7). Conventional transplanting required more number of labourers for critical operations like land preparation, nursery raising and transplanting in the month of July. As a result, during this period there is shortage of labourers. However, in case of DSR as the sowing started early in the month of May, there was no such labourer constraint. The spread-out labour requirement in DSR helped in making full use of family labour and having less dependence on hired labour (Kumar and Ladha, 2011). There were also other benefits with DSR

such as reduction in drudgery by eliminating transplanting operation, reduction in methane emissions (6–92% depending on types of direct seeding and water management), better recharge of rain water to the aquifer in the coastal saline region owing to intact capillary pores, reduced cost of cultivation (16–32%), increased income and timely planting of subsequent crop due to early harvesting of DSR by 7–14 days. The risks/limitations associated with DSR in other ecosystems such as sudden rain immediately after seeding did not arise in the coastal saline areas, as the soil profile was very dry and unsaturated during the start of the monsoon to absorb all the rain water. When the soil profile was saturated and there was waterlogging, the DSR crop attained sufficient height to withstand this stress. During the *rabi* season due to sowing of maize in raised beds, the crop was not affected by salinity and occasional waterlogging caused by incessant rain. The

Table 5. Depth of irrigation water applied (IW), irrigation water productivity (IWp), energy productivity (Ep) and energy output: input ratio (Eoi ratio) of *rabi* maize under different establishment and tillage practices

Treatment	IW (ha-cm)			IWp (kg/ha-cm)			Ep (kg/GJ)			Eoi ratio		
	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16
<i>Kharif</i> (CE)												
DSR	55.5	52.3	53.7	100.9	94.6	68.7	573.9	505.7	386.2	25.0	27.2	17.7
UNPT	57.9	54.9	56.5	85.1	94.0	63.1	500.1	517.0	376.9	22.0	27.3	17.6
PT	62.7	59.6	61.6	77.0	81.1	49.9	483.9	474.1	332.2	21.2	27.1	16.3
SEm±	0.35	0.24	0.43	2.86	6.22	4.95	8.37	35.11	9.81	0.30	0.26	0.93
CD (P=0.05)	1.37	0.95	1.67	11.24	NS	NS	32.85	NS	38.51	1.20	NS	NS
<i>Rabi</i> (Tillage)												
ZT	63.2	60.1	62.0	60.9	67.9	46.7	422.7	455.9	324.2	16.8	22.8	13.7
CT	59.2	56.0	57.7	88.3	86.2	41.1	531.7	456.9	283.7	22.4	28.3	14.6
RBS	53.7	50.8	52.1	113.9	115.5	93.9	603.5	584.1	487.4	28.9	30.5	23.2
SEm±	0.44	0.46	0.45	3.29	5.49	5.07	11.97	30.93	22.53	0.51	0.98	0.48
CD (P=0.05)	1.36	1.41	1.39	10.12	16.92	15.64	36.89	95.30	69.43	1.56	3.02	1.49

Table 6. Economics of maize cultivation as influenced by different establishment methods in *kharif* and tillage practices in *rabi*

Treatment	Cost of cultivation ($\times 10^3$ ₹/ha)			Gross returns ($\times 10^3$ ₹/ha)			Net returns ($\times 10^3$ ₹/ha)			Benefit: cost ratio		
	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16	2013–14	2014–15	2015–16
<i>Kharif</i> (CE)												
DSR	40.90	40.93	43.63	77.16	69.58	57.73	36.26	28.65	14.10	1.9	1.7	1.3
UNPT	40.90	40.93	43.64	67.56	72.06	56.42	26.66	31.13	12.78	1.6	1.7	1.3
PT	40.91	40.94	43.67	65.59	67.75	50.82	24.68	26.81	7.16	1.6	1.6	1.2
SEm±	0.0008	0.0013	0.0160	0.98	4.00	3.03	0.98	4.00	3.03	0.02	0.09	0.07
CD (P=0.05)	0.0033	0.0051	NS	3.84	NS	NS	3.85	NS	NS	0.09	NS	NS
<i>Rabi</i> (Tillage)												
ZT	40.31	40.13	42.81	52.22	57.20	44.57	11.90	17.07	1.76	1.3	1.4	1.0
CT	39.95	40.13	42.22	72.42	69.31	44.34	32.47	29.18	2.13	1.8	1.7	1.1
RBS	42.45	42.53	45.91	85.67	82.88	76.06	43.23	40.35	30.15	2.0	1.9	1.7
SEm±	0.0029	0.0010	0.0750	1.52	3.89	3.12	1.52	3.89	3.09	0.04	0.09	0.07
CD (P=0.05)	0.0089	0.0032	0.2300	4.67	12.00	9.61	4.67	12.00	9.52	0.12	0.29	0.22

Table 7. System rice equivalent-yield (REY) and economics of rice-maize cropping system under different establishment methods in *kharif* and tillage practices in *rabi*

Treatment	Rice-maize system REY (kg/ha)			Cost of cultivation ($\times 10^3$ ₹/ha)			Gross returns ($\times 10^3$ ₹/ha)			Net returns ($\times 10^3$ ₹/ha)			Benefit: cost ratio		
	2013-14	2014-15	2015-16	2013-14	2014-15	2015-16	2013-14	2014-15	2015-16	2013-14	2014-15	2015-16	2013-14	2014-15	2015-16
DSR-ZT	10,562	9,649	8,330	65.47	71.68	78.81	134.20	125.34	116.17	68.73	53.66	37.36	2.05	1.75	1.47
DSR-CT	11,042	10,193	7,714	65.10	71.67	78.20	141.46	133.94	108.56	76.35	62.27	30.36	2.17	1.87	1.39
DSR-RBS	12,812	12,122	10,044	67.60	74.08	81.84	162.92	154.03	138.97	95.32	79.95	57.13	2.41	2.08	1.70
UNPT-ZT	8,739	9,408	7,754	71.99	77.38	86.42	113.98	121.36	106.98	41.97	43.98	20.57	1.58	1.57	1.24
UNPT-CT	10,477	9,716	7,796	71.63	77.38	85.84	134.27	132.57	108.60	62.64	55.19	22.76	1.87	1.71	1.27
UNPT-RBS	11,612	11,648	10,668	74.13	79.78	89.57	148.54	148.28	145.28	74.41	68.50	55.71	2.00	1.86	1.62
PT-ZT	8,668	10,148	7,643	81.96	89.66	95.47	113.83	129.99	104.19	31.87	40.34	8.72	1.39	1.45	1.09
PT-CT	11,542	10,689	7,792	81.59	89.66	94.87	146.89	146.52	109.51	65.30	56.86	14.64	1.80	1.63	1.15
PT-RBS	11,730	11,827	10,106	84.09	92.06	98.57	150.90	151.43	137.56	66.81	59.37	38.99	1.79	1.64	1.40
SEm \pm	230	608	437	0.005	0.002	0.129	2.63	6.75	5.40	2.63	6.75	5.35	0.03	0.05	0.06
CD (P=0.05)	709	1873	1346	0.015	0.005	0.398	8.09	20.78	16.65	8.09	20.79	16.49	0.10	0.16	0.19

Price of rice, ₹ 11/kg; Price of maize, ₹ 13/kg

DSR-RBS methods of establishment and tillage practices resulted in the highest net return and BCR. However, the net return due to DSR-RBS and UNPT-RBS were at par during 2014-15 and 2015-16. The PT-ZT resulted in the lowest system net return and BCR.

This study revealed that dry direct seeding is a suitable alternative establishment method of rice during *kharif* season with higher net return (₹36,330/ha) and benefit: cost ratio (2.2) than conventional puddled transplanting. If direct seeding is not possible then unpuddled transplanting should be followed, which results in higher BCR of 1.7 compared to traditional puddled transplanting (BCR of 1.5). During subsequent *rabi* season, maize crop should be sown in raised beds, which results in higher yield (5,600 kg/ha) compared to conventional tillage (4,133 kg/ha) and zero tillage (3,563 kg/ha). Raised bed sowing saved about 5-9 ha-cm of irrigation water, increased water productivity to the extent of 108 kg/ha-cm and energy productivity to 558 kg/GJ. Direct-seeded rice followed by raised bed-sown maize resulted in the highest system rice-equivalent yield (11,659 kg/ha), net return (₹77,467/ha) and benefit: cost ratio (2.1).

REFERENCES

- Devasenapathy, P., Ramesh, T. and Gangwar, B. 2008. *Efficiency Indices for Agriculture Management Research*, 148 pp. New India Publishing Agency, New Delhi.
- Ihsanullah, M.A., Khan, S., Ghani, F. and Yousafzai, H.K. 2001. Response of maize varieties to different planting methods. *Sarhad Journal of Agriculture* **17**(2): 159-163.
- Islam, A.K.M.S., Hossain, M.M., Saleque, M.A., Rabbani, M.A. and Sarker, R.I. 2013. Energy consumption in unpuddled transplanting of wet season rice cultivation in north west region of Bangladesh. *Progressive Agriculture* **24**(1 and 2): 229-237.
- Kumar, V. and Ladha, J.K. 2011. Direct seeding of rice: recent developments and future research needs. *Advances in Agronomy* **111**: 297-413.
- Memon, S.Q., Mirza, B.B. and Mari, G.R. 2007. Tillage practices and effect of sowing methods on growth and yield of maize crop. *Agricultura Tropica Et Subtropica* **40**(3): 89-100.
- Pandey, M.P., Verulkar, S.B. and Sharma, D. 2010. Rice research: past achievements, present scenario and future thrust. *Indian Journal of Agricultural Sciences* **80**(6): 447-469.
- Ramesh, Rana, S.S., Negi, S.C., Kumar, S. and Subehia, S.K. 2014. Effect of resource-conserving and planting techniques on productivity of maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy* **59**(1): 34-40.
- Sarangi, S.K. and Maji, B. 2017. Sustainable rice cultivation in coastal saline soils: a case study. (In) *Achieving Sustainable Cultivation of Rice*, vol. 2. pp. 69-103. Sasaki, T. (Ed.). Burleigh Dodds Science Publishing Limited, Cambridge, UK.
- Sarangi, S.K., Burman, D., Mandal, S., Maji, B., Tuong, T.P., Humphrey, E., Bandyopadhyay, B.K. and Sharma, D.K. 2015. Reducing irrigation water requirement of dry season rice (*boro*) in coastal areas using timely seeding and short

- duration varieties. (In) *Proceedings of International Conference on Revitalizing the Ganges Coastal Zone: Turning Science into Policy and Practices*. Humphreys, E., Tuong, T.P., Buisson, M.C., Pukinskis, I. and Phillips, M. (Eds). CGIAR Challenge Program on Water and Food, Colombo, pp. 68–79.
- Sarangi, S.K., Maji, B., Singh, S., Sharma, D.K., Burman, D., Mandal, S., Singh, U.S., Ismail, A.M. and Haefele, S.M. 2016. Using improved variety and management enhances rice productivity in stagnant flood-affected tropical coastal zones. *Field Crops Research* **190**: 70–81, <http://dx.doi.org/10.1016/j.fcr.2015.10.024>.
- Singh, A., Kumar, S., Singh, Y.V. and Bhatia, A. 2014. Carbon sequestration and yield of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) soils amended with different organic manures and tillage practices. *Indian Journal of Agronomy* **59**(2): 215–220.
- Singh, U.P., Singh, Y., Kumar, V. and Ladha, J.K. 2009. Evaluation and promotion of resource-conserving tillage and crop establishment techniques in the rice–wheat system of eastern India. (In) *Integrated Crop and Resource Management in the Rice-Wheat System of South Asia*, pp. 151–176. Ladha, J. K., Singh, Y., Erenstein, O. and Hardy, B. (Eds.), International Rice Research Institute, Los Banos, Philippines.