



Evaluation of alternative tillage and crop establishment methods in rice (*Oryza sativa*) cultivation

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ABSTRACT

A two-year field study was conducted during 2011 and 2012 at Karnal (Haryana), to evaluate tillage and crop establishment (TCE) options with an objective to improve yield, water productivity and profitability in rice (*Oryza sativa* L.). The TCE methods had a significant effect on rice yields. Grain yield of mechanically transplanted rice (MTR) in puddled soil was significantly higher (10-22%) than all the other treatments in both the years of study. Conventional till direct seeded rice (CT-DSR) and zero-till direct seeded rice (ZT-DSR) consumed 12-17% less water as compared to puddled transplanted (manual or mechanical) rice during 2011, whereas during 2012, it consumed 5-9% more water than puddled transplanted rice. DSR (CT or ZT) and mechanical transplanting (under both puddled and unpuddled conditions) resulted in a labour saving of 7-8% and 6-12% as compared to manual puddled transplanting, respectively. The benefit: cost ratio was highest in MTR in puddled soil followed by ZT-DSR and was minimum in mechanically transplanted rice in unpuddled soil. Energy output: input ratio was highest in MTR (4.1) in puddled soil followed by manual transplanting (3.7) and was minimum in MTR in unpuddled soil (3.2).

Key words: Direct dry seeded rice, Mechanical transplanting, Tillage, Transplanted rice, Water use efficiency

Rice (*Oryza sativa* L.) is one of the most important cereal crop for food security in India, which is cultivated on an area of about 42 million ha. Total annual rice production in the country is 85 million tonnes and the mean productivity is quite low (Survey of Indian Agriculture 2010). The small states of Punjab and Haryana often referred to as the “Food Bowl” of the country contributes 50% to the total national rice production (Dhillon *et al.* 2010).

In many parts of Indo-Gangetic Plains (IGP) rice is generally transplanted in puddled soil (wet tillage) maintaining continuous submerged conditions (Sarkar *et al.* 2009). Puddling and transplanting operations are however, highly labour, water and energy intensive. Water and labour scarcities are becoming major concerns for the productivity and sustainability of the rice-wheat cropping system in the IGP. Agriculture’s share of fresh water supply is likely to decline further by 8-10% due to increasing competition

from urban and industrial sector. The problem of water scarcity will further be exacerbated by the climate change. Since the Green Revolution in 1970s, the water table in the region had a steady decline of 30–100 cm per year (Hira 2009). This overexploitation of groundwater is threatening the sustainability of rice production, and is driving farmers and researchers to find ways of reducing irrigation water consumption for rice cultivation. The advantages of puddling includes weed suppression, reduction in percolation losses and creation of anaerobic conditions, however, it creates hard pan at 15-25 cm depth (Gathala *et al.* 2011).

Conventional rice transplanting requires 200-250 man-h/ha which constitutes 25% of the total labour requirement for the crop production. The problem has further intensified with the timely unavailability of labour and increasing labour wages. Moreover, manual transplanting results in low and non-uniform plant population due to which rice yields are reduced. Potential solutions include a shift from intensive tillage to no or reduced tillage and/or from manual transplanting to mechanical transplanting or dry direct-seeding of rice. Dry direct seeding of rice (DSR) and wheat after no tillage performed similar to the conventional practice but with significant savings in water and labour use (Lal *et al.* 2013). DSR is cost-effective and allows early sowing of wheat (Ladha *et al.* 2003, Devkota 2011). Alternative tillage and crop establishment of rice are site specific and, therefore,

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evaluation under wide agro-ecological conditions is important to have significant adoption (Ladha *et al.* 2009). Present study was conducted to evaluate different tillage and crop establishment practices in rice for their effects on crop productivity, profitability, water use efficiency and energy use in rice cultivation in the North-West IGP.

MATERIALS AND METHODS

The experiment was conducted at farmers' field in Karnal district of Haryana, India during *kharif* seasons of 2011 and 2012. Experimental fields were under conventional rice-wheat rotation for > 15 years. The climate of the area is semi-arid, with an average annual rainfall of 750 mm (75-80% of which is received during July to September), maximum temperature of 40-45°C in June, and relative humidity of 50-90% throughout the year. The experimental soil (0-15 cm) was sandy loam in texture with bulk density 1.55 Mg/m³, pH 8.6, EC (saturation extract) 0.34 dS/m and Walkley-Black organic carbon 0.52%.

The treatments included direct dry seeded rice (zero and conventional till), mechanical transplanted (puddled and unpuddled) rice and conventional manual transplanting of rice in puddle soil. Each experimental plot was 50.0 m × 9.0 m in size. The experiment was laid out in a randomized complete block design with four replications. The treatments and details of tillage and crop establishment (TCE) methods are summarized in Table 1.

Rice (variety CSR-30) was raised in nursery at seed rate of 12 kg/ha for manual puddled transplanting (T₅) and 15 kg/ha for mat-type nursery for mechanical transplanting (T₃ and T₄). Thirty-day-old rice seedlings were manually transplanted (T₅) on 19 June, while 21-day-old seedlings were machine transplanted (T₃ and T₄) on 10 June in both the years. Mechanical transplanting was done at a spacing of 30 cm × 12 cm using paddy transplanter (Kubota make). Seed rate of 20 kg/ha was used for DSR (T₁ and T₂) and seeding was done on 20 May at a spacing of 20 cm × 10 cm using a rice seeder. The transplanting in treatment T₄ was done in submerged field with 5 cm standing water. DSR in (T₁) included one pre-sowing irrigation of 6 cm before sowing followed by 1st post-sowing irrigation (3 cm) one week after sowing. In treatment ZT-DSR (T₂), irrigation

(3 cm) was applied immediately after seeding and soil saturation was maintained for initial two weeks. Subsequent irrigations in DSR (T₁ and T₂) were applied at the appearance of hair line cracks at the soil surface as prescribed by Bhushan *et al.* (2007). Rainfall data were recorded using a rain gauge. Water use efficiency was computed for each treatment as given by Bhushan *et al.* (2007).

A fertilizer dose of 90 kg N, 60 kg P, 40 kg K and 25 kg zinc sulphate/ha was applied in all the treatments. In transplanted rice (T₃ and T₅), 1/3 N and full dose of P, K and Zn was applied at the time of puddling, whereas, immediately before transplanting in T₄, remaining 2/3 of the total N was applied in two equal splits at mid tillering (21 days after transplanting, DAT) and panicle initiation stage (42 DAT). In T₁ and T₂, 1/3 N and full dose of P, K and Zn was placed at a depth of 5 cm using DSR drill at the time of seeding. Remaining 2/3 N was applied in two equal splits at 21 and 50 days after sowing.

In ZT-DSR plots, weeds were controlled by pre-seeding application of glyphosate (0.6%). Pre-emergence herbicides used were anilophos (0.4 kg/ha) applied at 3 days after transplanting (DAT) in transplanted rice (T₃, T₄ and T₅) and oxadiargyl (100 g/ha) applied just after sowing in CT-DSR (T₁) and just after first irrigation in DSR in zero (T₂) followed by bispyribac-Na salt (25 g/ha at 25 DAT/DAS). Additional need based hand weeding were done to keep the field weed-free. Rice crop in different treatments was harvested between 10-15 October in both the years. The duration of DSR (T₁ and T₂) was 3-5 days lower compared to transplanted rice.

Tiller density and panicle density was recorded from pre-demarcated 1 m² area from each plot. Grain number per panicle was recorded from randomly selected 5 panicles from the pre-demarcated area in the plots used for tiller density and panicle density measurement. Grain yield and straw yield was measured from 3 m × 3 m area in each plot and the grain yield was adjusted at 14% moisture. Irrigation water was measured using water flow meter, number of irrigation and time taken at each irrigation.

Labour use, economics and energy analysis was done by taking pooled data of both the years. Input energy requirement was calculated by considering energy from all

Table 1 Treatments and details of tillage and crop establishment

Treatment	Treatment description	Dry tillage	Wet tillage (puddling)	Crop establishment method
T ₁	Conventional till direct dry seeded rice (CT-DSR) in vatter	2 harrowings followed by 1 cultivator followed by 1 planking	None	Drill sowing
T ₂	Zero till DSR (ZT-DSR)	No- tillage	None	Drill sowing
T ₃	Mechanical transplanting in puddled soil	2 harrowings followed by 1 cultivator	1 pass of rotavator in 10-12 cm of standing water	Mechanical transplanted
T ₄	Mechanical transplanting in unpuddled soil	Same as for T ₁	None	Same as for T ₃
T ₅	Manual transplanting in puddled soil	Same as for T ₃	Same as for T ₃	Manual transplanting

source as human, diesel, seed, fertilizer, pesticide, tractor, machinery, irrigation, seed etc during all the operations of paddy cultivation whereas, output energy was calculated by taking into account energy from grain and straw under different treatments as prescribed by Panesar, (2002).

All the data on yield and yield parameters of rice, water use efficiency and economics were analyzed for one way analysis of variance (ANOVA). Duncan's multiple range test (DMRT) was used at the $P < 0.05$ level of probability to test the significant differences between the treatments.

RESULTS AND DISCUSSION

Growth duration of rice

Total growth duration (seed to seed) of manual transplanting in puddled soil (T_5) was 148 days which was 4 days more than DSR (T_1 and T_2) and 2 days more than mechanical transplanting in puddled and unpuddled soil (T_3 and T_4) in both the years. Dhital (2011) and Balasubramanian and Hill (2002) reported that although DSR occupied the main field for 10-15 days more but it matured earlier by 6-10 days compared to manual transplanted crop. The longer duration in transplanted rice (TPR) could be attributed to transplanting shock (Dingkuhn *et al.* 1991).

Yield and yield components

Tiller density was significantly higher in DSR (T_1 and T_2) as compared to manual transplanted rice in both the years (Table 2). Panicle density was however, either lower (2011) or similar (2012) due to 10-12% higher sterility in DSR compared to manual transplanted paddy (T_5). MTR (T_3) had the highest tiller as well as panicle density compared to the other treatments (Table 2). Earlier published reports have also shown higher panicle density and spikelet sterility in DSR than that in TPR (Bhushan *et al.* 2007, Gathala *et al.* 2011). Number of grains/panicle and 1000-grain weight were significantly higher in TPR in puddled soil (T_3 and T_5) compared to unpuddled treatments (T_1 , T_2 and T_4) in both the years (Table 2). Grain yield of MTR in puddled soil (T_3) was significantly higher than all the treatments in both the years. Grain yields of DSR (T_1 and T_2) and MTR in unpuddled soil (T_4) were at par but significantly lower than manual transplanted rice (T_5) during both the years (Table 2). Kumar *et al.* (2012) also reported that MTR in puddled

soil (4.34 tonnes/ha) conventional manual transplanted rice (4.12 tonnes/ha) out yielded DSR (2.87 tonnes/ha). Consistent with our study, Bhushan *et al.* (2007) and Ladha *et al.* (2009) also reported that ZT-DSR often resulted in lower rice yield compared to transplanted rice.

Water use and water use efficiency in rice

Rice received 15-46% more irrigation water in different treatments in 2012 as compared to 2011 due to low rainfall (704 mm in 2011 versus 315 mm in 2012) during the growing season. DSR (T_1 and T_2) needed 12-17% less irrigation water compared to transplanted rice (T_3 and T_5) during 2011 but 5-9% more water as compared to transplanted rice (T_3 and T_5) in 2012 (Table 3). Saharawat *et al.* (2010) reported a saving of 10-12% of irrigation water in DSR compared to puddled TPR. In another study, irrigation savings in DSR were 23% suggesting that magnitude of water saving may depend on agro ecological conditions (Bhushan *et al.* 2007). Water use efficiency (irrigation + rainfall) was significantly higher in MTR in puddled soil (1.68 kg/ha/mm in 2011 and 1.79 kg/ha/mm in 2012) as compared to other treatments in both the years. Water use efficiency of DSR (T_1 and T_2) was at par with manual puddled transplanting (T_5) in 2011, whereas, it was

Table 3 Effect of different tillage and crop establishment methods in rice on amount of irrigation water applied, grain yield and water use efficiency.

Treatment	Irrigation water applied (mm)		Grain yield (tonnes/ha)		Water (irrigation + rainfall) use efficiency (kg grain/ha/mm)	
	2010-11	2011-12	2011	2012	2011	2012
T_1	1080a*	1550a	2.68a	2.55a	1.50a	1.37a
T_2	1025a	1495a	2.71b	2.55a	1.56b	1.41a
T_3	1230c	1420b	3.26d	3.11c	1.68c	1.79b
T_4	1310b	1650c	2.71b	2.58a	1.34d	1.31c
T_5	1230c	1420b	2.95c	2.85b	1.53ab	1.64d

Total rainfall during paddy growing season was 704 mm and 315 mm in 2011 and 2012, respectively. *With in column, means followed by the same letter are not significantly different at 0.05 level of probability by the Duncan's multiple range test

Table 2 Yield attributes of rice under different tillage and crop establishment methods

Treatment	Tiller density (number/m ²)		Panicle density (number/m ²)		Number of grains/panicle		10 000-grain weight (g)		Yield (tonnes/ha)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
T_1	220b*	224c	190a	190a	73a	71a	19.3a	18.9a	2.68a	2.55a
T_2	220b	222bc	192a	190a	73a	71a	19.3a	18.9a	2.71b	2.55a
T_3	228c	228d	215c	210b	75b	73b	20.2b	20.3b	3.26d	3.11c
T_4	218b	220b	192a	192a	73a	71a	19.3a	18.9a	2.71b	2.58a
T_5	210a	208a	195b	192a	75b	73b	20.2b	20.3b	2.95c	2.85b

*With in column, means followed by the same letter are not significantly different at 0.05 level of probability by the Duncan's multiple range test

Table 4 Comparison of yield economics and energy use in different tillage and crop establishment methods in rice.

Parameters	T ₁	T ₂	T ₃	T ₄	T ₅
Labour use in crop establishment (man-h/ha)	11.8	5.0	41.8	39.3	184.3
Total labour use in crop production (man-h/ha)	1104a*	1097a	1054b	1121c	1196d
Straw yield, tonnes/ha	28.75	28.90	35.03	29.05	31.89
Cost of production, Rs/ha	41 850	37 850	42 700	43 725	44 700
Gross returns, Rs/ha	65 350	65 700	79 625	66 025	72 500
Net returns, Rs/ha	23 500a*	27 850b	36 925c	22 300a	27 800b
Benefit: Cost ratio	1.56	1.74	1.86	1.51	1.62
Energy input energy, million kcal/ha	5.48	5.12	5.34	5.66	5.36
Energy output, million kcal/ha	17.77	17.87	21.65	17.95	19.72
Energy output: input ratio	3.24	3.49	4.05	3.17	3.68

*With in a row, means followed by the same letter are not significantly different at 0.05 level of probability by the Duncan's multiple range test

significantly lower in 2012 (Table 3).

Labour and energy use

For crop establishment, labour saving of 95-99% in DSR (T₁ and T₂) and 80-82% in MTR (T₃ and T₄) was observed as compared to manual puddled transplanting (T₅) during both the years (Table 4). Weed management (two hand weedings) in DSR as the herbicides used were not effective, resulted in increased labour use and thereby high cost of production. Overall, DSR treatments (T₁ and T₂) had 7-8% and mechanical transplanting (T₃ and T₄) had 6-12% labour saving compared to manual transplanting (T₅) during both the years (Table 5). Our study confirms the previous reports of less labour use in DSR compared to PTR (Ladha *et al.* 2009, Alizadeh *et al.* 2011). Energy output: input ratio was highest in T₃ followed by T₅ (4.05), T₂ (3.68), and minimum in T₄ (3.17) (Table 6). Similar results were reported by Singh *et al.* (2006). Energy input was similar (17.73-19.72 kcal/ha) in different TCE treatments (Table 4).

Economics

Mechanical puddled transplanting (T₃) gave significantly higher net returns of Rs. 36 925/ha, which was 33% higher than manual transplanting (T₅) and ZT-DSR (T₂), and about 50% higher than CT-DSR (T₁) and unpuddled MTR(T₄) (Table 4). Kumar *et al.* (2012) also reported that MTR reduced the cost of cultivation by Rs. 8 310/ha over conventional PTR but the cost was more than DSR. Net returns in ZT-DSR (T₂) were at par with manual puddled transplanting (T₅) but significantly higher than CT-DSR (T₁) and mechanical unpuddled transplanting (T₄). Benefit to cost (B: C) ratio was highest in T₃ (1.86) followed by T₂ (1.74) and the lowest in T₄ (1.51) (Table 4).

Our study shows that mechanical transplanting using paddy transplanter can be efficient and profitable alternative to current conventional practice of manual transplanting. DSR under zero till condition can also be a viable solution for increasing water use efficiency, reducing labour input and higher profits under scarcity of labour and water. However, there is need to develop effective and economical

weed management practices for DSR. The performance of DSR may however, depend on the season rainfall.

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