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Productivity and economics of direct seeded rice (*Oryza sativa* L.)

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Abstract: A field study was conducted during *Kharif* season of 2011 and 2012, to evaluate direct seeded rice options as compared to transplanted rice with an objective to improve farm productivity and efficiency. Labour and cost saving of 97% and 80% were observed in direct seeded rice (DSR) as compared to manual puddled transplanted rice in sowing/transplanting. Tillage and crop establishment methods had a significant effect on rice yields. Yield of manual puddled transplanted rice was significantly higher (10-12%) than DSR during both the years. DSR consumed 12-17 percent less water as compared to puddled transplanted rice during 2011, whereas, it consumed 5-9 per cent more water as compared to puddled transplanted rice during 2012. When compared to manual puddled transplanted rice, a labour saving of 7-8 percent (overall) was observed in DSR during both the years. The B: C ratio was highest in DSR in zero till condition (1.74) as compared to manual puddled transplanted rice (1.62). The study showed that the conventional practice of puddled transplanting could be replaced with zero till DSR to save water and labour.

Keywords: Direct seeded rice, Energy output, Field capacity, Tillage, Water use efficiency

INTRODUCTION

Rice (*Oryza sativa L.*) is cultivated on about 150 mha area in the world (9% of total cultivated area) and provides the stapple food of about half of the world population. In India, rice is cultivated round the year in one or other part of the country in diverse ecologies spread over 44.6 mha producing 132 million tonnes of rice with a productivity of 2.96 t/ha. Increasing yields achieved during green revolution through increase in cultivated areas, high yielding varieties, intensive use of fertilizers, better agronomical practices and expansion of irrigation facilities are showing sign of stagnation across Indo-Gangetic Plains (IGP) and factor productivity is declining (Ladha *et al.,* 2003a). The demand of cereals to meet the food requirements of the burgeoning population is increasing, while on the other hand most vital inputs of agriculture *viz.* water and labour are depleting in the area. The conventional system of rice production (conventional tilled-transplanted rice) in this region is basically water, labour and energy intensive, adversely affecting the environment. Therefore, to sustain the long-term production of rice; more efficient alternative methods of rice productions are needed (Saharawat *et al.*, 2010).

Rice is grown traditionally in the first fortnight of July in puddled soil (wet tillage) and kept under continuous sub-mergence. Rice transplanted after puddling leads to weed suppression, reduction in percolation losses and creation of anaerobic conditions, however, repeated puddling destroys soil structure and creates shallow hard pan and delays planting of a succeeding wheat crop, which in-turn adversely affect not only the performance of crop but also emits large quantity of methane (CH_4), which is one of the major green house gas (GHGs) contributing to global warming (Hobbs and Moris, 1996).

Water scarcity is becoming major concern for the productivity and sustainability of the rice-wheat cropping system. Agriculture's share in fresh water supply is likely to decline by 8-10% due to increasing competition from urban and industrial sector (Toung and Bhuiyan, 1994). Limited irrigation water is available to the farmers in many rice-growing areas and, in the future, predictions are that, 17 million ha. of irrigated rice areas in Asia may experience ''physical water scarcity'' and 22 million ha may have ''economic water scarcity'' by next 15-20 years to come (Bouman and Tuong, 2001). Thus, water scarcity threatens the productivity and sustainability of irrigated rice ecosystems as it may no longer be

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feasible for the farmers to have wet cultivation and flood fields for ensuring good crop establishment and suppressing weeds (Johnson and Mortimer, 2005).

The problem is likely to be further exacerbated by the climate change. Climate extremes and poor water availability will necessitate growing more food with less and less water in coming years. An average 1°C rise in temperature will increase the demand for irrigation water by 2-3 per cent to sustain production at the current level (Reeves, 2010).

Rice, in many parts of IGP, is normally irrigated almost continuously with water pumped from the groundwater (Sarkar *et al.,* 2009). Since the Green Revolution in 1970s, the water table in the region has shown a steady decline of 30–100 cm per year. This over exploitation of groundwater threatens the sustainability of rice production, and is driving farmers and researchers to find ways of reducing water consumption for rice cultivation (Ambast *et al*., 2006; Hira, 2009).

The conventional method of rice growing is not only water-guzzling but also cumbersome and laborious. Rice transplanting requires 200-250 man-h ha^{-1}, which is 25% of the total requirement for the rice crop production. The problem has further been intensified with the timely unavailability of labour. Transplanting of rice is mainly done in June-July in all the northern states of India, when the normal temperature is over 40°C and the labour prefer to work in the industries or under Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA) scheme in spite of working at farms in hot and humid conditions. Delay in transplanting beyond optimum time due to labour scarcity is creating a reduction in rice yield. In Punjab, a yield decline of 7-16% was observed when transplanting was delayed from 15^{th} June to 5^{th} July. Further, reduced labour availability is increasing the cost of transplanting and squeezing the farmer's profit as the cost of transplanting is increasing continuously. Paddy transplanting by labour also results in low and non-uniform plant population due to which crop yields are reduced (Mahajan *et al*., 2009).

The productivity and sustainability of rice-based systems are threatened because of the inefficient use of inputs; increasing scaricity of resources, especially water and labour; changing climate; the emerging energy crisis and rising fuel prices; the rising cost of cultivation and emerging socio-economic changes such as urbanization, migration of labour, preferences of non-agricultural work, concerns about farm-related pollution (Kumar and Ladha, 2011).

Conventional tillage and crop establishment by transplanting is the most input intensive process in an agro-system and, therefore, more efficient alternatives are urgently needed. Potential solutions includes a shift from intensive tillage to no or reduced tillage and/or from manual transplanting to direct seeded rice (DSR). Direct seeding of rice and wheat after no tillage performed as well as the conventional practice but with significant savings in water and labour use (Bhusan *et al.*, 2007). Direct-seeding is cost-effective, can save water through earlier rice crop establishment, and allows early sowing of wheat (Ladha *et al*., 2003a; Singh *et al*., 2003). With alternate wetting and drying cycles in DSR, the crop is subjected to greater weed competition than transplanted rice because weeds emerge before or at the same time as the rice. Therefore, heavy weed infestation is a major problem in direct seeded rice and its success lies in effective weed control measures (Singh *et al*., 2003; Rao *et al.*, 2007), as failure to eliminate weeds may result in low or no yield (Estorninos and Moody, 1988).

Keeping in view, present study was conducted in Karnal district of Haryana state, a major food basket of India, to evaluate DSR as compared to manual puddled transplanting for crop productivity, profitability, water requirement and energy use with a goal for finding most suitable ones with a potential to cover large area with similar agro ecological conditions in the IGP.

MATERIALS AND METHODS

Experimental site : The experiment was conducted at farmers' field in Karnal district of Haryana state in India during *Kharif* season of 2011 and 2012. Conventional rice-wheat rotation was being followed on the field from last 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), minimum temperature of 0-5^{o}C in January, maximum temperature of 40-45^{o}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 Mgm^{-3}, pH 8.6, EC (Saturation extract) 0.34 dSm^{-1} and organic carbon 0.52%.

Treatments: The three treatments (T_1 to T_3) were taken in paddy crop including direct seeding (zero and vatter) and conventional practice (manual puddled transplanting). Each experimental unit consisted of 50.0m × 9.0m plot. The treatments and details of tillage and crop establishment methods are summarized in Table 1.

Seeding and seed rate: Rice variety CSR-30, was sown in nurseries at seed rate of 12 kg ha^{-1} for manual puddled transplanting (T_3) on 20^{th} May during both years. Manual transplanting (T_3) was done after 30 days of nursery sowing. Seed rate of 20 kg ha^{-1} was used for direct seeding (T_1 and T_2) and seeding was done at a spacing of 20 cm × 10 cm using a paddy DSR machine on 20^{th} May in both the years.

Water application and measurement: In puddled transplanting (T_3), the puddling (wet tillage) operation was done in submerged field with 12 cm standing water using rotavator and transplanting was done after 30 hours of puddling. DSR in vatter (T_1) included one pre-sowing irrigation of 6 cm before sowing and then applied 1st irrigation (3 cm) after one week of sowing. In treatment T_2, 3 cm irrigation was applied immediately after seeding and soil saturation was maintained for initial two weeks. Subsequent irrigations in DSR (T_1 and T_2) were applied at the appearance of hair line cracks at the soil surface as prescribed by Bhusan *et al.* (2007). Rainfall data (Fig. 1) were recorded using a rain gauge. Water use efficiency was computed for each treatment as given by Bhusan *et al.* (2007).

Fertilizer application: A fertilizer dose of 90 kg N, 60 kg P, 40 kg K and 25 kg zinc sulphate ha^{-1} was applied in all the treatments. In transplanted rice (T_3), 1/3 N and full dose of P, K and Zn fertilizers were applied at the time of puddling, whereas, in treatments T_1 and T_2, 1/3 N and full dose of P, K and Zn were 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 (DAS).

Weed management: In no-till plot (T_2), existing weeds, prior to the seeding of rice, were killed by preseeding application of glyphosate (0.6%). Pre-emergence herbicides used were anilophos (0.4 kg ha^{-1}) applied at 3 days after transplanting (DAT) in transplanted rice (T_3) and oxadiargyl 100 g ha^{-1} applied just after sowing in DSR in vatter (T_1) and just after first irrigation in DSR in zero (T_2) followed by bispyribac-Na 25 g ha^{-1} at 25 DAT/DAS. Additional need based hand weeding were done to keep the field weed-free.

Yield and yield attributes: Yield attributing parameters i.e. total number of panicles/m^2, effective panicles/m^2, number of grains per panicle and 1000-grain weight were recorded using 1m^2 quadrate from three places in each plot at different stages of observation. At maturity, rice was harvested manually 10 cm above ground level and threshing was also done manually. DSR plots (T_1 and T_2) were harvested on October 11 during 2011 and October 10 during 2012, whereas, manual transplanted (T_3) was harvested on October 15, during both the years.

Machine performance: The field evaluation of DSR machine was done by taking consideration of field capacity, efficiency, row spacing, hill distance, no. of hills/m^2, no. of missing hills/ m^2, fuel consumption, cost of operation, labour requirement and payback period of the machine.

Labour use: Human labour uses were recorded in paddy crop for each treatment in each field operation, *viz*. tillage, seeding, irrigation, fertilizer and pesticide application, weeding, harvesting and threshing. For human labour, 8 hours were considered equivalent to one man day.

Economic analysis: Cost of cultivation of various treatments was estimated on the basis of approved market rates for inputs by taking into account cost of seed, fertilizer, herbicides, pesticides, hiring charges of human labour and machines for different field operations. Gross returns were calculated on the basis of market rates (Rs. 2500 per q).

Energy analysis: Input energy requirement was calculated by considering energy from all 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).

Data analysis: 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 differences between the treatments. Unless indicated otherwise, differences were considered significant only when $P<0.05$.

RESULTS AND DISCUSSION

Field, growth duration and production efficiency: In rice, field and growth durations were affected by crop establishment methods (Table 2). The growth duration of manual transplanting in puddled (T_3) was 4 days more than DSR treatments (T_1 and T_2) during 2011, whereas it was 5 days more in 2012. Main field duration was 26 days less in manual transplanting (T_3) during 2011 and 25 days in 2012 than that of DSR (T_1 and T_2) (Table 2). Balasubramanian and Hill (2002) and BRRI (2005) also reported that DSR (wet and dry) occupies the main field for 10-15 days more and matured earlier by 7-10 days. The longer duration in transplanted rice could be attributed to transplanting shock (Dingkuhn *et al*., 1991). The grain production efficiency and biomass production efficiency (Kg grain ha^{-1} day^{-1}) of transplanted rice in puddled (T_3) was significantly higher (25-35%) then DSR (T_1 and T_2) during both the years of study (Table 2). The higher production efficiency in puddled transplanted rice (T_3) was due to higher grain yield and shorter main field duration.

Grain yield and yield components: In rice, number of effective panicles m^{-2} was higher in treatment T_3 followed by T_2 and T_1 during both the years (Table 3). Panicle sterility was higher in DSR (T_1 and T_2) than transplanted rice in puddled (T_3) during both the years. The panicle sterility in DSR (T_1 and T_2) was 10-12% higher than puddled transplanting (T_3) during both the years. Saharawat *et al.* (2010) also confirmed these results in previous study and observed 8-10% panicle sterility in DSR, which might be due to relatively less moisture in DSR compared to puddled transplanted rice. Numbers of grains/panicle were also higher in puddled transplanted rice (T_3) as compared to DSR treatments (T_1 and T_2) in both the years. Treatments T_3 had around 4-5 per cent higher 1000-grain weight than DSR treatment T_1 and T_2 during both the years of study (Table 3). Tillage and crop establishment method

Table 1. Treatments and details of tillage and crop establishment.

Treatments	Treatment description	Tillage (dry)	Tillage (wet)	Crop establishment method
T_1	Direct seeded rice (DSR) in vatter	2 harrowings followed by cultivator and planking	None	Drill sowing
T_2	Direct seeded rice (DSR) in zero	No- tillage	None	Drill sowing
T_3	Manual transplanting in puddled	2 harrowings followed by cultivator and planking	1 Rotavator pass	Manual transplanting

Table 2. Effect of various crop establishment methods in paddy on field duration, growth duration and production efficiency.

Treatment	Field duration (day)		Growth duration (day)		Production efficiency			
					kg grain $ha^{-1}day^{-1}$		kg biomass $ha^{-1}day^{-1}$	
	2011	2012	2011	2012	2011	2012	2011	2012
T1	144*	143	144	143	18.59a	17.83a	20.45a	19.61a
T2	144	143	144	143	18.78a	17.83a	20.66a	19.61a
T3	118	118	148	148	25.03b	24.11b	27.54b	26.52b

*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 3. Yield attributes of rice under different crop establishment methods in paddy.

Treatment	Panicles m^{-2} (Nos.)		Effective panicles m^{-2} (Nos.)		No. of grains/ panicle		Test weight (g)		Yield (q/ha)	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
T1	220b*	224b	190a	190a	73a	71a	19.3a	18.9a	26.77a	25.50a
T2	220b	222bb	192a	190a	73a	71a	19.3a	18.9a	27.05b	25.50a
T3	210a	208a	195b	192a	75b	73b	20.2b	20.3b	29.54c	28.45b

*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. Effect of various crop establishment methods in paddy on crop seasonal water applied and water saving.

Treatment	Irrigation water applied (mm)		Rainfall (mm)		Water use efficiency (kg mm^{-1})		Water use per day (mm day^{-1})	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
T1	1080a*	1550a	704	315	1.50a	1.37a	12.39a	13.04a
T2	1025a	1495a	704	315	1.56b	1.41a	12.01a	12.66a
T3	1230b	1420b	704	315	1.53ab	1.64b	16.39b	14.70b

*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

had a significant effect on rice yields. Yield of manual transplanting in puddled (T_3) was significantly higher than DSR treatments (T_1 and T_2) during both the years. (Table 2). Singh *et al*. (2006) also observed 10% yield loss in DSR as compared to manual puddled transplanted rice. Bhusan *et al.* (2007) and Ladha *et al.* (2009) also observed that direct seeding on soils with no tillage often resulted in some loss of rice yield.

Water application and its efficiency in rice: Water requirement under different treatments depends upon rainfall. Paddy crop received 15-46 percent more water in different treatments during 2012 as compared to 2011, which was because of large difference in rainfall (704 mm in 2011 vis-à-vis 315 mm in 2012) (Fig. 1). DSR (T_1 and T_2) received 12-17 percent less water as compared to transplanted rice (T_3) during 2011, whereas it received 5-9 per cent more water as compared to transplanted rice (T_3) during 2012 (Table 4). Saharawat *et al*. (2010) reported that there was 10-12 per cent saving of irrigation water in DSR as compared to transplanted rice in puddled, whereas, in earlier study of Utter Pradesh, savings were shown up to 23 per cent suggesting wide variations which may depend on agro eco-logical conditions including rainfall

Table 5. Comparative field performance of paddy transplanter and DSR machine.

S. N.	Parameters	DSR Machine	Manual transplanting
1.	Actual field capacity (ha/h)	0.40	-
2.	Field efficiency (%)	75	-
3.	Row to row spacing (cm)	20	20
4.	Hill to hill distance (cm)	10	20
5.	No. of plants, m^{-2}	48	25
6.	Missing hills, %	4	-
7.	No. of floating hills, m^{-2}	-	-
8.	Fuel consumption (l/h)	3	
9.	Labour requirement, man-h/ha	5	160
10.	Labour saving, %	97	-
11.	Cost of operation, Rs/ha	1000	5000
12.	Cost saving, %	80	-
13.	Payback period	1	-

Table 6: Labour use under different crop establishment methods in paddy. (In man-h/ha)

Treatment	Labour use in tillage	Labour use in nursery raising	Labour use in sowing/ transplant-ing	Labour use in weeding	Labour use in irrigation	Other operations	Total Labour use
	2011-12	2011-12	2011-12	2011-12	2011-12	2011-12	2011-12
T1	6.8	-	5.0	100	180	812	1103.8a*
T2	-	-	5.0	100	180	812	1097.0a
T3	9.3	25	150	-	200	812	1196.3b

*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 7. Comparison of yield economics and energy use in various crop establishment methods in paddy.

S.N.	Parameters	T1	T2	T3
1	Grain yield, Kg/ha	26.14	26.28	29.00
2	Straw yield, kg/ha	28.75	28.90	31.89
3	Cost of production, Rs/ha	41850	37850	44700
4	Gross return, Rs/ha	65350	65700	72500
5	Net return, Rs/ha	23500a*	27850b	27800b
6	Benefit: Cost ratio	1.56	1.74	1.62
7	Input energy, million kcal/ha	5.48	5.12	5.36
8	Energy output, million kcal/ha	17.77	17.87	19.72
9	Energy output: Energy input	3.24	3.49	3.68

*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

pattern (Bhusan *et al*., 2007). Water use efficiency of DSR (T_1 and T_2) was at par with manual puddled transplanting (T_3) during 2011, whereas, it was significantly lower during 2012 (Table 4). This might be due to large variation in rainfall. Per day water use was higher in T_3 (16.39 mm day^{-1}) during 2011 and (14.70 mm day^{-1}) during 2012 as compared to DSR treatments.

Machine performance: The field capacity of DSR machine was found to be 0.4 ha/h with efficiency of 75 % (Table 5). The number of plants per meter square was 50 in DSR machine as compared to 20 in manual transplanting. There was 4 % missing hills in DSR machine. There were labour saving of 97% and cost saving of 80 % in DSR machine sowing as compared to manual puddled transplanting (T_3). Payback period of the machine was one year only if operated for 50 hours only. Kumar (2011) also observed similar findings and found labour saving of 86 percent and cost saving of 87 in DSR in sowing/transplanting as

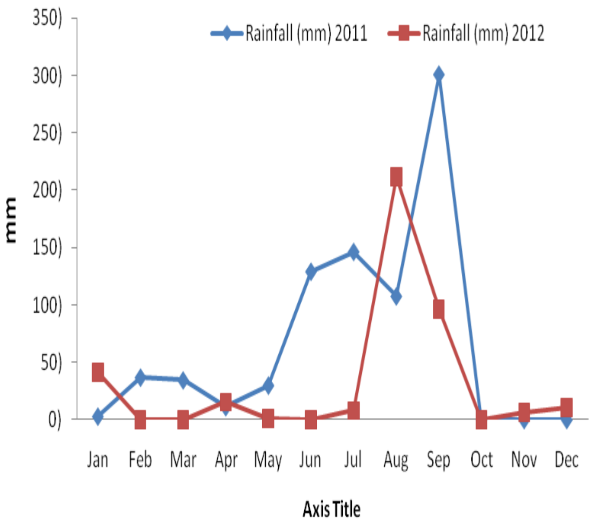

Fig. 1. *Amount of rainfall received during different months of 2011 and 2012 (Source: CCSHAU, Hisar).*

compared to manual transplanting.

Labour use: In paddy, a labour saving of 95-99 percent in DSR (T_1 and T_2) was observed as compared to manual puddled transplanting (T_3) in sowing/ transplanting during both the years (Table 6). In paddy, total labour use mainly depends on the weed management. In present study we made two hand weeding in DSR to cope up with weeds as the herbicide used were not so effective, which ultimately resulted in more labour use and higher cost of production. In overall, DSR treatments (T_1 and T_2) had 7-8 percent labour saving as compared to manual transplanting (T_3) during both the years (Table 5). Sehrawat *et al*. (2010) also observed 13-16% labour saving in DSR as compared to manual puddled transplanted rice.

Economics and energy: Economics and energy analysis was done by taking pooled data of both the years. Net returns in DSR in zero (T_2) was at par with manaul puddled transplanting (T_3) and were significantly higher than DSR in vatter (T_1) (Table 7). B: C ratio was highest in T_2 (1.74) followed by T3 (1.62) and T_1 (1.56). Energy output: input ratio was highest in T_3 followed by T_2 and T_1 with 3.68, 3.49 and 3.24, respectively. Kumar (2011) also observed similar findings and found higher B:C ratio (1.19-1.27) in DSR as compared to (1.08) in manual puddled transplanted rice (T_3).

Conclusion

In this study, direct seeding of rice practice was evaluated with conventional practices. It is clear that direct seeded rice practices may not perform similarly in all agro ecological conditions and savings, especially in term of irrigation water, depends on rainfall. Yield of manual puddled transplanted rice was significantly higher (10-12%) than DSR during both the years. Direct seeded rice (DSR) consumed 12-17 percent less water as compared to puddled transplanted rice during 2011, whereas, it consumed 5-9 per cent more water as compared to puddled transplanted rice during 2012. However, the occurrence and distribution of rainfall during the cropping season had considerable influence on the savings in irrigation water. When compared to manual puddled transplanted rice, a labour saving of 7-8 percent (overall) was observed in DSR during both the years. The B: C ratio was highest in direct seeded rice (DSR) in zero till condition (1.74) as compared to manual puddled transplanted rice (1.62).The data presented in the study shows that DSR under no till condition can also be a viable solution under scarcity of labour and water. but, there is need to develop proper weed management practices and requires further study to access the long term effects of herbicides on soil, water and development of weed flora.

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