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RESEARCH PAPER

Recent production technologies of rice (*Oryza sativa* L.) for its sustainable cultivation in Haryana

GURU PREM*, RAKESH CHOUDHARY, AMIT KUMAR, RAMESH JHORAR AND VIKRAM D. SINGH
Krishi Vigyan Kendra, AMBALA (HARYANA) INDIA (Email: gpgrover79@gmail.com; rakeshnitharwal9@gmail.com; amitbaliyan2009@gmail.com; rjhorar73@gmail.com; vdskvkambala@gmail.com)

Abstract : The rice crop in the Indo-Gangetic Plains is with particular reference to Haryana is vital for food security in India. Its sustainability is at risk as the current production practices are inadequate resulting in high cost of cultivation and inefficient use of inputs such as water, labour and energy. In a field study, we evaluated resource conserving and cost-saving alternative tillage and crop establishment options with an aim to improve productivity and input use efficiency. Treatments included manual transplanting, mechanical transplanting and direct-seeding of rice after conventional and reduced tillage. Tillage and crop establishment method had a significant effect on rice yield. Dry-DSR and unpuddled mechanical transplanting have almost equal (average of both years) grain yield *i.e.* 41.71 and 41.80 qtl ha^{-1}, but a marginal higher yield 42.90 qtl ha^{-1} under DSR_{vatter} than mechanical transplanted and DSR_{dry} was observed. On an average of both years, manual transplanted rice in puddled and unpuddled conditions has produced 7-9 per cent less grain yield than mechanical transplanted and direct seeded rice. The growth duration of manual transplanted rice was 8-10 days more than direct-seeded rice, while, it was 4-5 days more in mechanical transplanting than DSR treatments. In both years, the direct-seeded rice sown in vatter condition received the lesser water and puddled manual transplanted rice consumed more water. Saving in cost under DSR-drill and mechanical transplanter in comparison to manual transplanting was 76 and 26 per cent, respectively. Saving of 85 to 97 per cent labour requirement was observed in DSR-drill and mechanical transplanter over manual transplanting. The B:C ratio of both the DSR systems (2.81and 2.88) was higher than puddled (2.31) and unpuddled manual transplanted rice (2.52) and unpuddled mechanical transplanted rice (2.39), respectively. Direct-seeded rice can be more efficient and profitable alternatives to current practice (puddled transplanted rice).

Key Words : Rice, Sustainable cultivation

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INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important crops in India, covering an area of about 43.97 mha with the total production and productivity of 104.32 mt and 2.37 t/ha, respectively during 2011-2012 (Anonymous, 2013). While the average productivity of rice in India, at present, is 2.2 tons/ha, which is far below the global average of 3.7 tons/ha. The productivity of rice is higher than that of Thailand and Pakistan but much lesser than

*** Author for correspondence:**

that of Japan, China, Vietnam and Indonesia (Anonymous, 2011). In the last few decades, annual increases in growth rates for food grain production (wheat 3.0%, rice 2.3%) in the IGP have kept pace with population growth. But evidence is now appearing that rice–wheat system productivity is plateauing because of a fatigued natural resource base (Ladha *et al.*, 2003). India is expected to surpass its demand by the year 2030, if the rice production grows at 1.34 per cent per annum. But it will remain in deficit of around 2.5 million tons, if the present growth rate of 1.14 per cent continues upto the year 2030.

In irrigation commands rice is largely grown by manual transplanting of seedlings into puddled soils. Puddling is a tillage operation, which involves repeated tillage in ponded soils with an aim to create a soft mud in the tilled layer. It helps in reducing water losses through percolation and controlling weeds by water stagnation in rice fields. Though manual transplanting gives uniform crop stand it is quite expensive and requires lot of labour besides involving lot of drudgery. Singh *et al.* (1985) reported that transplanting takes about 250-300 man hours/ha which is roughly 25 per cent of the total labour requirement of the crop. Decreased availability and increasing cost of labour have increased the cost of rice cultivation through conventional methods Pandey and Velasco (2005). Further, due to rapid industrialization, migration to urban areas and implementation of government policies has been creating a labour scarcity at the time transplanting with hike in the wages of labour, manual transplanting found costly leading to reduced profits to farmers. In addition, the plant population of rice remains quite low in manual transplanting compared to the recommended plant density. In order to compensate for lower plant population, farmers often use excessive nitrogenous fertilizer to encourage tillering, which generally results in complex problems of insect-pests and diseases and ultimately lower yields.

In irrigated areas, rice is mainly grown by transplanting seedlings into puddled soil. Such a rice production system, however, requires a large amount of water during puddling and transplanting Chauhan (2012) and Chauhan *et al.* (2012). In general, rice accounts for 34 - 43 per cent of the world's irrigation water Bouman *et al.* (2007). In India, water use for rice has been reported as 1140 mm in Bihar and 1560 mm in Haryana Gupta *et al.* (2002). Water, however, is becoming an increasingly scarce resource in India Kumar and Ladha (2011) and Mahajan *et al.* (2012). In north-western India, for example, increased use of groundwater for rice cultivation has led to a decline in the water table by upto 1 m per year Hira (2009) and Rodell *et al.* (2009). Therefore, the increasing water scarcity threatens the productivity and sustainability of the irrigated rice system in India.

Therefore, to sustain the long-term production of rice; more efficient alternative methods of rice productions are needed Saharawat *et al.* (2010). Rice can be successfully dry seeded into unpuddled soils, with or without prior cultivation in the north Indo-Gangetic plains Hobbs *et al.* (2002) and Qureshi *et al.* (2004). The effective weed management in direct seeded rice can give similar yields to that of puddled transplanted rice Malik and Yadav (2008). Direct seeded rice appears to have the greatest potential in irrigated agriculture, because it helps in saving both labour and water. Another less expensive and laboursaving method of rice transplanting without yield loss is the urgent need of the hour Tripathi *et al.* (2004). The mechanical transplanting of rice has been considered the most promising option, as it saves labour, ensures timely transplanting and attains optimum plant density that contributes to high productivity. Following these leads, a 2-year study was conducted in KVK-Ambala and farmers field of Ambala (Haryana) to evaluate the performance of rice production technologies with a goal of finding most suitable ones with a potential to cover large area of 1.23 million ha in the state. Specifically, we monitored following key performance indicators to evaluate various practices: crop productivity, irrigation water application, water use efficiency, energy use and net returns.

MATERIAL AND METHODS

Experimental site and soil :

The experiment was conducted at the farm of Krishi Vigyan Kendra, Ambala (Haryana) (30º18´20" N and 76 º55´46" E, and 265 m above mean sea level) during 2011-2012. Haryana is an intensively rice-wheat growing state in India. Conventional rice-wheat rotation was being followed on the field from last 15 years. The climate of the area is semiarid, with an average annual rainfall of 1100 mm (75–80% of which is received during July to September), minimum temperature of 0 to 4ºC in January, maximum temperature of 38-42ºC in June, and relative humidity of 67 to 83 per cent throughout the year. The experimental soil (0-15 cm) was silt loam in texture, with a bulk density of 1.52 Mgm^{-3}, pH 8.1, $EC_{1:2}$ 0.4 dS m^{-1}, organic carbon 0.42 per cent, available nitrogen N=127 kg ha^{-1}, Olsen P=15 kg ha^{-1} and 1 MNH$_4$OAC extractable K=101 kg ha^{-1}.

Experimental design and treatments :

The experiment was carried out with Randomized Block Design with three replications during 2011-2012 (Year 1) and 2012-2013 (Year 2). The plot area for each treatment was half acre (2000 m^2). The treatments are (T_1) Conventional tilled puddled manual transplanted (T_2) Reduced tilled unpuddled manual transplanted, (T_3) Reduced tilled unpuddled mechanical transplanted, (T_4) Reduced tilled direct seeding at vatter, (T_5) Reduced tilled direct seeding in dry field and details of practices followed in each treatments are described in (Table 1).

Seeding and seed rate :

Rice cultivar Pusa-1121, commonly used in the study area, was sown in nurseries at seed rate 15 kg ha^{-1} for manual transplanting (T_1 and T_2) on dated 8 June, 25 kg ha^{-1} for unpuddled mechanical transplanting (T_3) on dated 10 June. Seed rate of 20 kg ha^{-1} used for direct-seeding (T_4 and T_5) in main field on 15 June in both the year. The 28 and 21 days old rice seedlings were transplanted (T_1 and T_2) and (T_3) at spacing of 20×20 cm and 23.8×12 cm on 5 July and 30 June in both year, respectively.

Mechanical transplanting was done by self-propelled rice transplanter. It is a single wheel driven and fitted with a 4 H.P. diesel engine and covers 8 rows with 23.8 cm row spacing along with hill to hill spacing of 12 to 14 cm at corresponding operating speeds of 1.50 km/hr, number of seedlings per hill (2-4) and depth of transplanting (upto 6 cm). Transplanting was done in unpuddled *i.e.* field was prepared in dry conditions only. After this, a light irrigation was given and let the soil settled for 12-24 hours. Fields were again replenished with 2-3 cm standing water to avoid floating of seedlings. While, primed (bavistin @1g/kg seed and streptocychline 1 g/ 8 kg seeds) seeds were direct seeded at a spacing of 22×10 cm using a direct seeding drill (paddy) on 15th June every year in the both the treatments (T_4 and T_5).

Water application and measurements :

In puddled transplanting (T_1), the puddling (wet tillage) operation was done in submerged field with 12 cm irrigation water using rotavator and transplanting was done after 30 hours of puddling. In case of unpuddled manual transplanting (T_2) and unpuddled mechanical transplanting (T_3) a light irrigation of depth 5 cm was given and allowed for 12-24 hours for soil settling. To avoid floating of seedlings fields were again replenished with 2 cm standing water just before transplanting. In T_1, T_2 and T_3, after transplanting the subsequent irrigations were given to maintain 3 cm submergence for an initial 2 weeks and subsequent 5 cm submergence during the crop period upto 15 days before harvest.

DSR in vatter (T_4) included one pre-sowing irrigation of 6 cm before sowing and then applied 1st irrigation (3 cm) after one week of sowing. While, in treatment T_5, 3 cm irrigation was applied immediately after seeding and soil saturation was maintained for initial two weeks. Subsequent irrigations in DSR (T_4 and T_5) were applied at the appearance of hair line cracks at the soil surface as prescribed by Bhushan *et al.* (2007). Irrigation water, measured with water meter (Dasmesh Co., India), was applied in each plot using polyvinyl chloride pipes of 10 cm diameter. The quantity of water applied and the depth of irrigation were computed using the equation described by Bhushan *et al*. (2007). Rainfall data were recorded using a rain gauge shown in (Fig. A). Total amount of water applied was computed as the sum of water received through irrigations and rainfall. Water use efficiency was computed for each treatment as given by Bhushan *et al*. (2007).

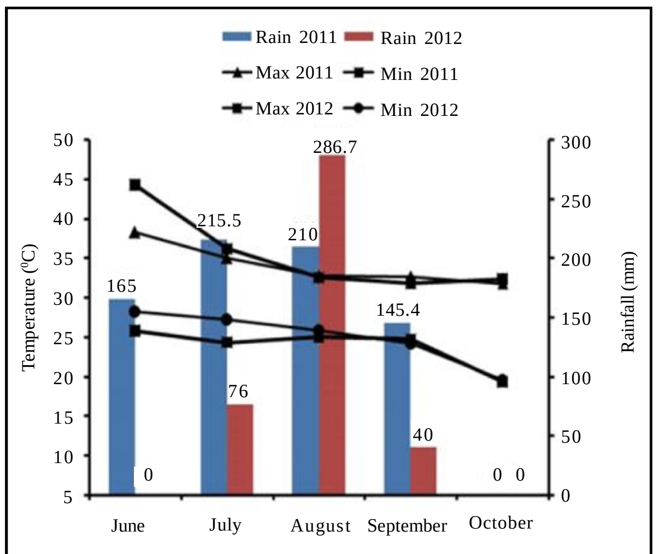

Fig. A : Monthly rainfall and maximum and minimum temperature

Fertilizer application :

A fertilizer dose of 90 kg N, 30 kg P and 25 kg zinc sulphate ha^{-1} was applied in T_1, T_2 and T_3 and 75 kg N, 30 kg P and 25 kg zinc sulphate ha^{-1} in T_4 and T_5 treatments. Foliar application of 1 per cent ferrous sulphate solution was also done in both the cases of T_4 and T_5. In transplanted rice (T_1) and (T_2 and T_3), 1/3 N and full dose of P and Zn fertilizers were applied at the time of puddling and after 5 days of transplanting. Whereas, in treatments T_4 and T_5, 1/3 N and full dose of P 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 transplanting and sowing (DAS) in all the treatments.

Weed management :

The plots were kept weed-free throughout the growing season by using pre-emergence or post-emergence herbicides and need based additional hand-weeding. Pre-emergence herbicides used were butachlor (3 kg ha^{-1}) applied at 3 days after transplanting (DAT) followed by bispyribac-Na 250 ml ha^{-1} at 25 DAT in transplanted rice (T_1, T_2 and T_3). Pre-emergence herbicide application of stomp 30 EC@ 3.25 lit. ha^{-1} just after sowing followed by tank mix application of bispyribac-Na 10 SC @ 250 ml ha^{-1} and pyrazosulfuron 150 g ha^{-1} at 25 DAS in DSR (T_4 and T_5).

Yield and yield attributes :

At maturity all the paddy plots were harvested manually 10 cm above ground level and threshed manually. 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 14% moisture content). Transplanted rice (T_1, T_2 and T_3) was harvested on November 1, October 30 and October 28 in year 2011 and October 30, October 29 and October 28 in year 2012, respectively. Whereas corresponding harvest dates in direct-seeded rice (T_4 and T_5) were October 29 in year 1 and October 28 in year 2, respectively.

Labour use :

Machine and human labour uses were recorded in paddy from each treatment for each field operation, *viz.*, tillage, seeding, irrigation, fertilizer and pesticide application, weeding, harvesting, and threshing. For human labour, 8 hour were considered equivalent to 1 man day, whereas, for tractor-drawn and self-driven machines, time taken to complete a operation was recorded and expressed on an ha basis. Time (h) required to irrigate a particular plot and consumption of diesel (lit h^{-1}) by the machinery was also recorded. The ground water was pumped from a depth of 100 m with a 25 horse power (HP) pump and irrigation was given by surface-flooding method.

Economic and energy 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 price of paddy, Rs. 2000 per qtl in 2011 and Rs. 2300 per qtl in 2012 and straw selling rate of Rs. 85 and Rs. 90 per qtl in year 1 and 2, respectively. Rs. 110 per qt straw. Net income of the farmers was calculated as the difference between gross income and total cost. Input energy requirement

Table 1: Treatments and details of tillage and crop establishment methods

Treatments	Treatment description	Tillage: Dry	Tillage: Wet	Crop establishment method
T_1	Conventional tilled (puddled) transplanted rice (CT-PTR)	2 harrowing fb cultivator and planking	2 pass of rotavator	Manual transplanting
T_2	Reduced tilled (unpuddled) transplanted rice (RT-UnPTR)	2 harrowing fb cultivator and planking	none	Manual transplanting
T_3	Reduced tilled (unpuddled) mechanical transplanted rice (RT-UnMTPR)	2harrowing fb cultivator and planking	none	Mechanical transplanting
T_4	Reduced tilled direct seeded rice in vatter condition (RT-DSR_{vatter})	2 harrowing fb cultivator and planking	none	DSR-drill sowing
T_5	Reduced tilled direct seeded rice in dry condition (RT-DSR_{dry})	2 harrowing fb cultivator and planking	none	DSR-drill sowing

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).

RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Grain yield and yield components :

In both years of the study under DSR method (T_4 and T_5), the panicles m^2 were higher than in unpuddled mechanical transplanting (T_3) followed by T_1 and T_2 (manual transplanting). Mechanical transplanting (T_3) also achieves higher panicle m^{-2} than manual transplanting, while the same were did not varied much more among manual transplanted rice (T_1 and T_2). The effective panicles m^2 was also observed higher in case of direct seeded rice (T_4 and T_5) than transplanted rice, despite higher panicle sterility in both the years. The higher number of effective panicle under mechanical transplanting (T_3) than manual transplanting (T_1 and T_2) was may be attributed to higher panicle m^{-2}. Srilatha and Vani (2013) and Gill *et al.* (2006) also reported that effective tillers m^{-2} were significantly higher under direct sowing than transplanting and more tillers m^{-2} were due to greater plant population rather than tillers plant^{-1}. Panicle length and test weight were not differ significantly among methods of sowing. We also found that the number of grains per panicle and test weight has no significant difference among all the treatment in both the years. In both years, spikelet sterility was higher in direct-seeding rice (T_4 and T_5) than in transplanted rice (T_1, T_2 and T_3). The spikelet sterility in transplanted rice varied from 4 to 6 per cent, whereas in direct-seeded rice, it ranged from 10-12 per cent. Saharawat *et al*. (2010) also confirmed these results in previous study and observed 8-10 per cent panicle sterility in DSR, which might be due to relatively less moisture in DSR compared to puddled transplanted rice.

Crop establishment method had a significant effect on rice yield. Dry-DSR and unpuddled mechanical transplanting have almost equal (average of both years)

Table 2 : Yield components (plant height, panicle number, effective panicles, number of grains per panicle, test weight, grain yield) values are means of three replicates

Treatments	Plant height (cm)		Panicle per m^{-2} (Nos.)		Effective panicles m^{-2} (Nos.)		Grains per panicle (Nos.)		Test weight (g)		Grain yield (qt ha^{-1})	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
T_1	134.66	133.66	266.33	265.00	244.33	241.00	73.00	73.00	25.34	25.09	39.90	37.76
T_2	131.66	130.66	260.00	260.00	241.00	238.00	71.00	70.66	23.33	23.38	39.46	38.70
T_3	131.33	130.33	281.66	281.00	251.33	247.33	74.66	74.00	25.70	25.96	42.40	41.20
T_4	127.00	126.66	296.66	296.66	258.33	253.33	75.00	73.33	24.01	24.92	43.63	42.16
T_5	126.33	126.00	292.33	287.66	252.66	250.33	71.33	72.00	23.80	23.72	42.11	41.30
C.D. (P=0.05)	1.84	4.06	7.188	9.541	8.327	7.455	NA	NA	NA	NA	1.666	2.408
S.E. ±	0.558	1.22	2.171	2.881	2.514	2.251	1.685	1.362	1.031	1.214	0.503	0.727

Table 3: Effect of crop establishment methods on field duration, growth duration and production efficiency

Treatments	Field duration (days)		Growth duration (days)		Production efficiency			
					Kg grain $ha^{-1}day^{-1}$		Kg biomass $ha^{-1}day^{-1}$	
	2011	2012	2011	2012	2011	2012	2011	2012
T_1	119	117	147	145	27.15	25.99	68.32	66.15
T_2	117	116	145	144	27.16	26.93	68.39	68.42
T_3	120	120	141	141	30.14	29.22	74.05	72.73
T_4	137	136	137	136	31.85	30.94	77.01	75.51
T_5	137	136	137	136	30.67	30.46	75.54	75.07
C.D. (P=0.05)	NA	NA	3.013	4.003	1.321	2.360	3.203	2.585
S.E.±	NA	NA	0.910	1.209	0.399	0.713	0.967	0.781

grain yield *i.e.* 41.71 and 41.80 qtl ha^{-1}, but a marginal higher yield 42.90 qtl ha^{-1} under DSR_{vatter} (T_4) than T_3 and T_5 was observed. The manual transplanted rice (T_1 and T_2) has produced 7-9 per cent less grain yield than mechanical transplanted (T_3) and direct seeded rice (T_4 and T_5) given in (Table 2). Mechanical transplanting and DSR method of rice establishment have comparatively higher yield than manual transplanting in both the years, which is attributed to higher number of panicles m^{-2} due to transplanting of more seedlings per hill in case of mechanical transplanting and good germination and higher seed rate and good germination of direct seeded rice. Similar results in case of mechanical transplanting were also reported by Choudhary and Varshney (2002).

Field, growth duration and production efficiency :

In rice, main-field and seed-to-seed growth durations were affected by crop establishment methods (Table 3). The growth (seed to seed) duration of manual transplanted rice (T_1 and T_2) was 8-10 days more but the main-field duration was 18-20 days less than that of direct-seeded rice (T_4 and T_5) during year 2011 and 2012. The growth duration of mechanical transplanting in puddled (T_3) was 4 days more than DSR treatments (T_4 and T_5) during 2011, whereas it was 5 days more in 2012. Main field duration was 16 to 17 days less in mechanical transplanting (T_3) during year 2011 and 2012, than that of DSR (T_4 and T_5). 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) and Gill (2008) also found similar results in his study that direct seeding matures 12 days early than transplanted rice, due to better root establishment from the day of germination and lack of transplanting shock.

The grain production efficiency and biomass production efficiency (kg grain ha^{-1} day^{-1}) of direct seeded rice (T_4 and T_5) was significantly higher than manual and mechanical transplanted rice (T_1, T_2 and T_3) during both the years of study (Table 3). The higher production efficiency in DSR (T_4 and T_5) was due to higher grain yield. Highest grain production efficiency of 31.85 and 30.94 kg ha^{-1} day^{-1} was recorded in direct seeded rice, sown in vatter condtion (T_4) in both the years. Likewise T_4 had the highest biomass production efficiency of 77.01 and 75.51 kg ha^{-1} day^{-1} during both the years, respectively.

Water application and its efficiency in rice :

The crop has received 5 per cent more total irrigation water in the year 2011 than that of year 2012, which was because of differences in rainfall (735.90 mm in year 1 *vis-a-vis* 402.7 mm in year 2) (Table 4). While, the irrigation water applied through tubewell was more in the year 2012 *i.e.* 1444 mm as compare to 1197 mm in year 2011 due to less rainfall in the later case. In both years, the direct-seeded rice sown in vatter condition (T_4) received the lowest water (1776 mm in year 1 and 1733 mm in year 2) and puddled manual transplanted rice (T_1) received the highest (2056 mm in year 1 and 1953 mm in year 2). During both the years, irrigation water application in T_2 and T_3 with and without puddling was almost similar but higher by 9 per cent than direct seeded rice (T_4 and T_5). In T_1 (puddled manual transplanted), water application was 12 per cent higher as compared to T_4 and T_5 (direct seeded rice) during both the years. In both the years, irrigation water use efficiency was lower in T_1 (1.94 kg ha^{-1} mm^{-1} in year 1 and 1.93 kg ha^{-1} mm^{-1} in year 2) as compared to other treatments (Table 4). In both years, per day water use was in dry direct-seeded rice (T_4 and T_5) was approximate 12.83 mm ha^{-1} day^{-1} (avg. of both the years), was 19 to 24 per cent lower than other treatments.

Table 4: Water application and water use efficiency with different crop establishments of paddy

Treatments	Rainfall (mm)		Irrigation water applied (mm)		Total water input (mm)		Water use efficiency (kg mm^{-1})		Water use day (mm day^{-1})	
	2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
T_1	735.90	402.70	1320	1550	2055.90	1952.70	1.94	1.93	17.28	16.65
T_2	735.90	402.70	1280	1480	2015.90	1882.70	1.96	2.05	17.18	16.28
T_3	735.90	402.70	1275	1490	2010.90	1892.70	2.11	2.17	16.80	15.77
T_4	735.90	402.70	1040	1330	1775.90	1732.70	2.46	2.43	12.96	12.71
T_5	735.90	402.70	1070	1370	1805.90	1772.70	2.33	2.32	13.15	13.07
C.D. (P=0.05)	NA	NA	28.117	26.094	28.229	26.007	0.085	0.112	0.378	0.464
S.E. ±	NA	NA	8.490	7.879	8.524	7.853	0.026	0.034	0.114	0.140

Machine performance :

The field capacity of the self-propelled rice transplanter was 0.18 ha/hr with field efficiency of 72 percent was comparatively less against 0.40 ha/hr field capacity and 77 per cent field efficiency of DSR-drill, respectively. Time taken to cover one hectares of area was about 5 hour and 55 minutes which was comparatively high against 2 hour 50 minutes in direct seeded rice. Less fuel consumption *i.e.* 6.25 lit ha^{-1} in mechanical transplanter was observed against 10 lit ha^{-1} fuel consumption in DSR-drill. Saving in cost under DSR-drill and mechanical transplanter in comparison to manual transplanting was 76 and 26 per cent, respectively (Table 5). Payback period of the DSR-drill was one year if operated for 50 hours only. Manjunatha *et al.* (2009) observed that mechanical transplanter has reduced cost by 50 per cent as compared to manual transplanting. Kumar *et al.* (2011) also found similar findings and found labour saving of 86 per cent and cost saving of 87 in DSR in sowing as compared to manual transplanting.

Labour use :

Labour requirement for sowing/transplanting was 5 man-hours ha^{-1} in mechanical transplanter as against 24 man-hours ha^{-1} in and 165 man-hours ha^{-1} in manual transplanting. Thus, a saving of 85 to 97 per cent labour requirement was observed in DSR-drill and mechanical transplanter over manual transplanting (Table 6). Manjunatha *et al.* (2009) observed that mechanical transplanter has reduced labour requirement by 90 per cent as compared to manual transplanting. As there is no need for nursery raising in DSR (T_4 and T_5), therefore, 100 per cent saving in labour in case of labour incured in nursery raising *i.e.* in case of transplanted rice. In DSR, weeds are the major constraint in its cultivation or say adoption. When we apply herbicides,

Table 5 : Comparative field performance of manual transplanting, mechanical transplanter and DSR-drill

Sr. No.	Parameter	Manual transplanting	Mechanical transplanter	DSR machine
1.	Power source (H.P.)	-	4	35-50 tractor trailing
2.	No. of rows	-	8	9
3.	Row to row spacing (cm)	20	23.8	22
4.	Width covered (m)	-	1.90	1.98
5.	Speed of operation (km/hr)	-	1.30	4.5
6.	Time taken to cover 1 ha area	-	5.55	2.5
7.	Actual field capacity (ha/hr)	--	.180	.40
8.	Theoretical field capacity (ha/hr)	--	0.25	.52
9.	Field efficiency (%)	--	72	77
10.	Depth of sowing/transplanting (cm)		5	1.25-3.75
11.	Hill to hill distance (cm)	20	12-14	10
12.	Labour requirement (man-h/ha)	165	24	5
13.	Labour saving (man-h/ha)	--	85	97
14.	Fuel consumption (l/ha)	--	6.25	10
15.	Cost of operation (Rs./ha)	4750	3500	1100
16.	Cost saving (Rs./ha)	--	26	76

Table 6: Average labour use with different crop establishments of paddy (man-h ha^{-1})

Treatments	Labour use in tillage	Labour use in nursery raising	Labour use in sowing/ transplanting	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
T_1	10	24	165	5	230	790	1224
T_2	9	24	170	10	203	790	1206
T_3	9	35	24	10	200	790	1068
T_4	7.5	-	5	75	180	790	1058
T_5	7.5	-	5	80	185	790	1068

whether pre or post emergence does not control all the weeds, they are controlled by manual weeding. By this, 85 to 90 per cent more labour required in case of DSR (T_4 and T_5) to the labour required in weed control in transplanted rice. 7 to 10 per cent labour saving observed in both the DSR methods over all the transplanted rice methods, in labour spent in irrigation of crop. Overall, manual transplanting (T_1 and T_2) consumed 11-14 per cent more labour in comparison to manual transplanting (T_3) and direct seeded rice (T_4 and T_5). Saharawat *et al.* (2010) also observed 13-16 per cent labour saving in DSR as compared to manual puddled transplanted rice.

Economics and energy :

The pooled data of both years for economics and energy is presented in the Tables. The cost of production was in the following order DSR unpuddled manual transplanting<puddled transplanting<mechanical transplanting. While the net return was significantly higher under DSR (T_4 and T_5) than manual and mechanical transplanting (T_1, T_2 and T_3). The B:C ratio of both the DSR_{dry} (2.81) and DSR_{vatter}(2.88) was higher and they were followed by T_2 (2.52), T_3 (2.39) and T_1 (2.31), respectively. Srilatha and Vani (2013) and Kumar *et al.* (2011) also observed similar findings and found higher B:C ratio under DSR as compared to manual puddled transplanted rice given in (Table 8). Energy output: input ratio was also found highest in both the DSR systems (4.306 and 4.304), while it was at par among rest of the three treatments *i.e.* 3.657, 3.654 and 3.697, respectively (T_1, T_2 and T_3). Similar results were found for the net energy and energy productivity.

Conclusion :

For the management of natural resources and increase farm mechanization, direct seeding of rice practice under vatter and dry conditions, unpuddled mechanical transplanting were evaluated with conventional practices. Yield of direct seeded rice significantly higher (9 %) than manual transplanted rice during both the years. Though mechanical transplanted rice also produce at par yield with direct seeded rice but due to higher cost of production and difficult nursery raising, it don't win the heart of farmers. On the front of water saving DSR (T_4 and T_5) consumed 8-15 per cent less water as compared to manual and mechanical transplanted rice (T_1-T_3) during both the years. However, the occurrence and distribution of rainfall during the cropping season had considerable influence on the savings in irrigation water. The field capacity of the DSR-drill (0.40 ha/hr) was also higher than self-propelled rice transplanter (0.18 ha/hr). Saving of 85 to 97 per cent labour requirement was observed in DSR-drill and mechanical transplanter over manual transplanting for sowing/transplanting, but, overall labour saving of 11-14 per cent was observed. The B:C ratio of both the DSR_{dry} (2.81) and DSR_{vatter}(2.88) was also higher than puddled manual transplanting (2.31), unpuddled manual

Table 7 : Average net returns with various tillage and crop establishment techniques

Treatments	Grain yield (qt ha^{-1})	Straw yield (qt ha^{-1})	Cost of production (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	BCR
	2011-12	2011-12	2011-12	2011-12	2011-12	2011-12
T_1	38.83	59.44	38325	88530	50205	2.31
T_2	39.08	59.77	35375	89201	53826	2.52
T_3	41.80	61.55	39875	95165	55290	2.39
T_4	42.90	61.32	33775	97489	63714	2.88
T_5	41.71	61.08	33775	94955	61180	2.81

Table 8 : Energy use in different tillage and crop establishment methods in paddy

Treatments	Input energy ($x10^4$ kcal ha^{-1})	Energy output ($x10^4$ kcal ha^{-1})	Net energy ($x10^4$ kcal ha^{-1})	Energy output: Energy input	Energy productivity
	2011-12	2011-12	2011-12	2011-12	2011-12
T_1	40944	149516	108572	3.657	0.255
T_2	39416	143590	104174	3.654	0.255
T_3	39890	147243	107352	3.697	0.258
T_4	35005	149843	114838	4.306	0.300
T_5	34826	148680	113854	4.304	0.302

transplanting (2.52) and mechanical transplanting (2.39), respectively.

The results of the study revealed that direct in the front of labour and water scarcity, the direct seeding of rice can be better option over the traditional puddled manual transplanted rice. by following the scientific package of practice of its cultivation. Some of the factors are constraining the full adoption of the direct seeded rice are lack of land levelling, skill in operating seed drill, weed control and poor water management in the fields. If farmers overcome these constraints then it will make remarkable performance than the traditional method. This method gained a momentum in up-scaling the paddy productivity and created a positive impact on farming community.

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