Effect of Different Machinery on Rice Crop Establishment and their Influence on Subsequent Wheat Crop in India

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Abstract

A field experiment was conducted during 2003 to 2006 to study different machinery for the establishment of rice (*Oryga satva L.*) and the effect on subsequent crop growth, productivity and energy. The study was made for direct seeding (dry bed), drum seeding (wet bed), mechanical transplanting (puddled and unpuddled) and manual transplanting (puddled) in subsequent crops of wheat. The mean yield of hybrid rice was higher (8.52 t/ha) with drum seeding (wet bed) that was at par with direct seeding (dry bed) and mechanical transplanting (puddled) as compared to manual transplanting (puddled) and mechanical transplanting (unpuddled). Direct seeding (dry bed) adopted in previous rice crops gave higher mean yield of wheat (5.70 t/ha) followed by drum seeding (wet bed), mechanical transplanting (unpuddled), manual transplanting (puddled) and mechanical transplanting (puddled). The net return energy of the system was high in drum seeded (170,926 MJ/ha) followed by direct seeded (169,070 MJ/ha) and lowest of 150,542 MJ/ha in manually transplanted (puddled). The drum seeded rice required 3.6 % less input energy and gave 8.9 % higher output energy, whereas, direct seeded required 2.6 % less input and gave 8.2 % higher output energy as compared to manually transplanted (puddled). The direct seeded (dry bed) and drum-seeding (wet bed- unpuddled) saved irrigation water by 13 to 19 % when compared to manual transplanting (puddled).

Introduction

Traditionally, rice (*Oryga satva L.*) is grown followed by wheat (*Triticum aestivum L.*) in India (*Sharma et al., 2004*). The rice-wheat system is a predominant cropping system of the Indo-Gangetic Plains regions, where rice is mostly grown by transplanting 21 to 35 day old seedlings in puddled fields. The disadvantages this technique is that it is labour intensive and requires continuous ponding of the water for the first fifteen days. It leads to nutrient loss through de-nitrification, leaching and evapo-transpiration during the hot summer. Moreover, transplanting by unskilled contractors often leads to sub optimal plant population (16-22 hill/m^2) compared with recommended populations (35 hills/m^2). Continued puddling over decades has led to deterioration in soil physical properties through structural breakdown of soil aggregates and capillary pores and clay dispersion. Puddling forms a puddled layer and a plough pan at about 15 to 20 cm depth that restricts water movement causing temporary water logging and restricted root penetration and growth for succeeding crops after rice (*Meelu et al.*, 1979; *Kirchhof* and *So*, 1996). It is, therefore, important that alternative methods that are less water-efficient and less labour-intensive be developed to enable farmers to produce more at less cost. One way to reduce water demand is to grow direct dry-seeded rice (DSR) instead of the conventional puddle, transplanted rice. Direct dry seeded rice avoids puddling, does not need continuous submergence and, thus, reduces the overall water demand for rice culture. In South Asia, DSR is being practices in medium-deep and deep water rice ecologies of the eastern Gangatic plains of India and Bangaladesh, and on terraced and sloping lands in the northeastern and northwestern Himalayan region and western Ghats along west coasts of India (Timsina and Connor, 2001). The area of direct seeded rice in India, Pakistan, and Bangladesh is 4.2 million hectare. Thus, DSR occupies 26 % of the total rice area in South Asia (*Gupta et al., 2006*). Productivity of DSR is often reported to be comparable with transplanting (*De Datta,* 1986). As per the above advantages of growing direct dry-seeded rice (DSR) instead of the conventional puddled transplanted rice, the intervention of the machineries are definitely required to evaluate the different DSR machines and compare with a transplanter. Therefore, the present experiment was to study the effect of different machines on crop establishment and the growth and yield of hybrid rice and a subsequent crop such as wheat and the resultant energy input and output.

Materials and Methods

Site Characteristics

A for 3 year (2003 to 2006) field study was conducted at Project Directorate for Cropping Systems Research, Modipuram, Meerut, U.P., India (29^{o} 4' N and 77^{o} 46' E) at an elevation of 237 m. a. s. l. The climate of Modipuram is semi-arid subtropical, characterized by very hot summers and cold winters. The hottest months are May and June (maximum temperature 45-46 ^{o}C), whereas during December and January, the minimum temperature often goes below 5 ^{o}C. The average annual rainfall is 863 mm, 75-80 %, which occurs through the northwest monsoon during July-September. The soil of the experimental field was sandy loam in texture (64.2 % sand, 18.5 % silt and 17.3 % clay) (Typic -Ustochrept), pH 8.1, electrical conductivity 0.42 ds/m, organic carbon 0.49 %, available nitrate nitrogen 74 mg/kg, Olsen P 12.6 mg/kg and 69.1 mg/kg of available K.

Treatment

The four treatments were in rice crop established by different machineries along with their tillage levels and the fifth treatment was the conventional method of rice transplanting as practice by farmers. The treatments are presented as below.

T_1: Direct seeding (2 harrow + 2 cultivator + 2 planking) − dry bed
T_2: Drum seeding (2 harrow + 2 cultivator + 2 planking) − wet bed
T_3: Mechanical transplanting (2 harrow + 1 planking +2 passes of puddler) − puddled
T_4: Mechanical transplanting (2 harrow + 2 planking) − unpuddled
T_5: Manual transplanting (2 harrow + 2 cultivator + 1 planking + 2 passes of puddler) − puddled

The succeeding crop; wheat with common tillage operations (2 harrow + 2 cultivator + 2 planking) was evaluated in randomized block design with four replications. Hybrid rice (cv. PHB 71) was sown 20 cm apart with a seeding rate of 40 kg/ha. Wheat (PBW 243) was grown 20 cm apart at a seed rate of 100 kg/ha. The gross plot size was 33 m × 4 m for rice and 10 m × 4 m for wheat

Table 1 Technical specifications of self- propelled rice transplanter

Items	Specifications
Model	2 ZT-238-8
Dimension (L × W × H), cm	241 × 213.1 × 130
Engine power, kW	2.4
Fuel	Diesel
Cooling system	Air cooled
Weight, kg	320
Walking mechanism	Single wheel driven
Type of float	Fiber glass
Working mechanism	Separate crank connecting rod transplanting mechanism
Number of rows	8
Row spacing, cm	23.8
Hill to hill spacing, cm	10, 12 and 14
Frequency of transplanting, strokes/ min	238
Depth of transplanting	Adjustable with screw rod (2 to 12 cm)
Traction wheel	
a) Diameter, cm	70
b) No. of lugs	15
c) Lug angle, degree	22 upward
Frequency of strokes of fingers in maximum displacement of tray, no.	14
Max. depth of finger entering the mat, cm	1.7

Table 2 Technical specifications of drum seeder and zero-till drill

Items	Drum seeder	Zero-till drill
Make	CRRI, Cuttak	National Agro machineries, Ludhiana
Type	Manually operated, pre-germinated paddy	Inverted-T type furrow opener
Power source	Two persons	Tractor
Number of rows	8	9
Row spacing	20 cm	22 cm
Overall dimensions		
Length	1,425 mm	1,850 mm
Width	750 mm	600 mm
Height	670 mm	1,450 mm
Weight	16 kg	250 kg
Depth of seeding	Surface of wet field	3-6 cm
Cost of machine	Rs. 1,400.00	Rs. 18,000.0

throughout the study.

Machinery Used Self Propelled Rice Transplanter

A Chinese made self propelled 8-row rice transplanter (Model: 2 ZT-238-8), marketed by M/S V. S. T. Agro Inputs, Banglore, was used (**Fig. 1**). It had fixed 23.80 cm row to row spacing and variable plant to plant spacing of 10, 12 and 14 cm at corresponding operating speeds of 1.57 and 1.94 km/h, respectively. The detailed technical specifications of the transplanter are given in **Table 1**.

Drum Seeder

A drum seeder was used for sowing of sprouted rice in dry bed. Specifications are given in **Table 2**. The 8-row pre-germinated paddy seeder was developed at the Central Rice Research Institute (CRRI), Cuttak, India. The seeder had a perforated drum mounted over the axle of the ground drive wheel, a float, five furrow openers, a frame and a handle. The drum had 8 rows of holes with 7 holes in each row.

Fig. 1 Rice seeding in wet bed by drum seeder

Fig. 2 Rice seeding in the dry bed by seed drill

Fig. 3 Direct seeded rice crop in dry bed

Fig. 4 Mate type seedling growing for self-propelled rice transplanter

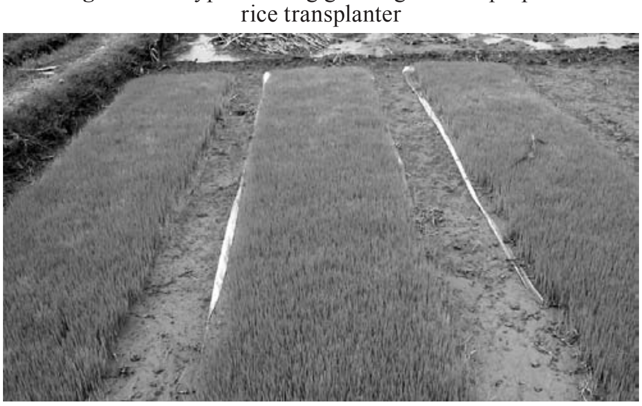

Fig. 5 Operation of self-propelled rice transplanter in the field

It had four drums 30 cm diameter and 30 cm long with circular holes on the periphery 3 cm apart and 20 cm lateral distance. The rice seed from each drum dropped in rows 20 cm apart with in row spacing of 2-3 cm. The drum seeder was half-filled with pre-germinated paddy seeds which dropped through the holes of the drum. It was pulled by two labours in a wet field.

Direct Seeded Rice

The direct seeded rice was sown with a 9-row fluted roller type tractor drawn zero till drill (**Fig. 2**) that was made by National Agro Machineries, Ludhiana. The fluted roller type metering device was used for direct seeding of rice in a dry bed. The seed rate was maintained at 55-70 kg/ha by changing the length of the fluted roller as required by the crop. Row spacing was adjusted at 20 cm (**Table 2**).

Table 3 Energy conversion factors as adopted/advised

Particulars	Units	Equivalent energy (MJ)
Human Power		
a) Adults man	Man-hour	1.96
b) Woman	Woman-hour	1.57
Tractor	hour	332.0
Diesel	liter	56.31
Chemical Fertilizers		
i) Nitrogen (N)	kg	60.60
iii) Phosphorus (P)	kg	11.10
iii) Potash (K)	kg	6.70
Plant protection		
a) Superior chemical (Granular)	kg	120
b) Inferior chemical	kg	10
c) Liquid chemical	ml	0.102
Farm Yard Manure		
Crop Produce (grain)	kg (dry mass)	0.30
i) Rice	kg	14.70
ii) Wheat	kg	15.70

Source: Gopalan et al., (1978) and Binning et al., (1983)

Crop Management

The fertilizers for hybrid rice were 150 kg N/ ha, 60 kg P/ha, 60 kg K/ha and 5.5 kg Zn/ha. P, K and Zn. N was applied in four splits (1/4 basal dressing, 1/4 at tillering, 1/4 at active tillering and 1/4 at panicle initiation). Two sprays of $FeSO_4$ at 0.2 % solution 30 and 40 days after planting were given in direct seeding and drum seeding to correct iron deficiency. One hundred twenty kg N/ha were applied to wheat and 60 kg P/ha and 60 kg K/ha were applied as basal with N applied to wheat in these splits (1/2 basal dressing, 1/4 at first irrigation, 1/4 at ear emergence). In hybrid rice, to control weeds, pendimethalin 35 % at 1.25 kg a.i. in 800 liters of water was sprayed at 1-4 days after sowing in direct seeding (dry bed) and for drum seeding (wet bed) butachlor was applied at 1.5 kg a.i./ha at 3 days after transplanting. Thereafter, one hand weeding was done at 30 days after sowing. In wheat, isoproturon at 1.25 kg a.i./ha in 600 liters of water was applied after 30 days of sowing to control the Phalaris minor for providing weed free environment to these crops.

Table 4 The field performance parameters of the self propelled rice transplanter

Parameter	Value
Hill spacing, mm	120
Row spacing, mm	235
Depth of transplanting, mm	30-50
Number of hills, m^2	33-35
Number of seedling/hill	3-5
Fuel consumption, l/h	0.45
Missing hills, %	3-4
Floating hills, %	1.5
Field capacity, ha/h	0.74
Cost of operation, Rs/ha	1,150
Energy requirement, MJ/ha	250

Water Measurement

The direct seeded rice was kept moist during the first week to ensure proper germination and water was not allowed to accumulate to avoid seed rotting. In the drum seeded rice, water was applied before sowing of seed to wet the seed bed. Thereafter, irrigations were applied at 3 day intervals in both treatments. In mechanical transplanting (puddled), manual transplanting (puddled) and mechanical transplanting (puddled) rice, the continuous ponding of water was kept for the first 15 days for better crop establishment. The subsequent irrigations were given 2 days after ponded water infiltrated into soil. The last irrigation to transplanted rice crop was applied 15 days before harvesting. The measurement of irrigation water was done by Parshall flume. The water productivity was computed by dividing the economic yield (kg/ha) with quantity of irrigation water applied. Since 1 m^3 was equal to 1,000 litres and 100 cm water applied was equal to 10,000 m^3 of water in 1 ha:

$$\text{Water productivity (kg/m}^3\text{)} = \frac{\text{Grain yield (kg/ha)}}{\text{Irrigation water applied (m}^3\text{/ha)}}$$

Irrigation water applied (m^3/ha)

Table 5 Performance parameters of drum seeder and zero till drill for seeding of rice

Parameter	Drum seeder	Zero-till drill
Average length of plumule, mm	2-3	-
Field capacity, ha/h	0.15	0.45
Field efficiency, %	50	70
No of seeds /hill	2-3	Continuous flow
Row spacing, mm	20	20
Hill to hill spacing, mm	10	-
Fuel consumption, l/ha	-	5.6
Cost of operation	Rs. 370 / ha	Rs. 480 / ha
Energy requirement, MJ/ha	52	490
Seed rate	60 kg/ha	55-70 kg/ha

was calculated by multiplying the total depth of water applied through irrigation to the area irrigated.

Energy Estimation

The energy inputs were calculated after multiplying an energy conversion factor to all inputs in the form of the labour, diesel, seed, chemical fertilizer and plant protection (insecticides/pesticides/herbicides) used in all different operations (**Table 3**). The different field operations performed for completion of each activity in the experiment were measured in terms of time taken for human, machinery and fuel consumption and expressed as energy input in mega joules (MJ). The output energy was also estimated in terms of energy output (MJ) using as grain yield under different crops by multiplying an energy conversion factor.

Statistical Analysis

The data were subjected to analysis of variance as per the procedure given by Little and Hills (1978), and treatment means were compared using critical difference (CD) defined as least significant difference beyond which all the treatment differences were statistically significant as CD = ($\sqrt{2VE^{r-1}}$) $t^{5\%}$ where VE is the error variance, r the number of replications of the factor for which CD is calculated, $t^{5\%}$ the table value of t at 5 % level of significance at the error degrees of freedom.

Results and Discussion

Performance of Machines

Self Propelled Rice Transplanter

The performance of the rice transplanter was highly dependent on the puddled soil condition and seedling density (seedlings/cm^2) in the mat (**Table 4**). The average number of hills/m^2 was 33-35. The field capacity of transplanter was 0.74 ha/h and diesel consumption was 2.9l/ha. The row spacing and hill to hill spacing was 12 and 23.5 cm and average number of seedlings/hill was 3-5 and depth of planting was 3-5 cm. The missing hills were 3-4 %. This was dependent on the seedling density in the mat. The floating hills were about 1-1.5 % due to a higher puddling level and less sedimentation period (Chaudhary et al., 2003). The uniform growth of crop was due to uniform depth of placement of seedlings at uniform spacing with equal number of seedlings per hill that resulted in better yield for the mechanically transplanted field than the manual transplanted field. The cost of operation was Rs 1,150/ha. The energy requirement of this machinery was 250 MJ/ha.

Drum Seeder

The performance of the drum seeder was evaluated by the direct seeded rice that sprouted under wet bed in unpuddled condition (**Table 5**). The rate of pre-germinated rice seeds was 40 kg/ha. The field capacity of the drum seeder was very low at 0.13 ha/h. Two to three seeds were dropped in a hill at a spacing of 3-5 cm with row spacing 20 cm. The cost of operation was Rs 300/ha. The energy requirement was estimated as 52 MJ/ha.

Direct Seeded Rice

The performance parameters of zero-till drilling of rice saved about 65 to 80 percent time, labour, fuel, cost and energy saving as compared to conventional methods of rice. The field capacity of direct seeded rice was 0.45 ha/h and diesel consumption was 5.6 l/ha (**Table 5**). The row spacing was 20 cm with continuous flow of seed in the furrow and the depth of seeding was 3-5 cm. The uniform growth of the crop was due to uniform germination of seedlings. The cost of operation was Rs

Table 6 Grain yield (t /ha) of rice and wheat as influenced by different methods of rice planting method

	2003-04		2004-05		2005-06		Mean	
	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat
T_1: Direct seeding (2 harrow + 2 cultivator + 2 planking)- dry bed	7.84	5.62	8.53	5.76	8.55	5.72	8.31	5.70
T_2 : Drum seeding (2 harrow + 2 cultivator + 2 planking)- wet bed	8.11	5.50	8.71	5.63	8.74	5.60	8.52	5.58
T_3 : Mechanical transplanting (2 harrow + 1 planking + 2 passes of puddler)- puddled	7.75	4.74	8.45	4.90	8.46	4.86	8.22	4.83
T_4 : Mechanical transplanting (2 harrow + 2 planking)- unpuddled	7.33	5.48	7.73	5.59	7.86	5.55	7.64	5.54
T_5 : Manual transplanting (2 harrow + 2 cultivator + 1 planking +2 passes of puddler)- puddled	7.46	4.85	7.84	5.06	7.89	5.02	7.73	4.98
CD (P = 0.05)	0.38	0.17	0.19	0.25	0.41	0.24	-	-

480/ha. The energy requirement of this machine was 490 MJ/ha. The direct and drum seeded rice crop matured at about 8-10 days before as compared to transplanted rice.

Crop Yield and Attributes

The grain yield of rice was significantly influenced by different machinery effects on rice crop establishment (**Table 6**). The pooled yield of rice was higher (8.52 t/ha) with drum seeding (wet bed) followed by direct seeding (8.31 t/ha) in (dry bed) and mechanical transplanting (8.22 t/ha) in (puddled) compared to manual transplanting (7.73 t/ha) in (puddled) and mechanical transplanting (7.64 t/ha) in unpuddled conditions. The mean yield of rice for three years was higher by 10.22 % in drum seeding (wet bed) followed by 6.88 % in direct seeding (dry bed) over other methods of rice crop establishment. This was mainly attributable to relatively greater compaction of puddled soil under manual and mechanical transplanting (puddled). Higher values of yield contributing characters (**Table 7**) such as number of panicles/m^2, number of grains/panicle and 1,000 grain weight under drum seeding (wet bed) in rice while number of ears/m^2, number of grain/ear and 1,000 grain weight in wheat were recorded under direct seeding (dry bed) in succeeding crops.

Energy Dynamics in Systems

System wise energy analysis (**Table 8**) indicated that the highest

Table 7 Yield attributing character of rice and wheat as influenced by rice planting methods (pooled data of 3 years)

Treatments	Rice			Wheat		
	No. of panicle/ m^2	No. of grains / panicle	1,000-grain weight (g)	No. of ears /m^2	No. of grains / ear	1,000-grain weight (g)
T_1: Direct seeding (2 harrow + 2 cultivator + 2 planking)- dry bed	363	132	27.1	295	49.72	37.82
T_2 : Drum seeding (2 harrow + 2 cultivator + 2 planking)- wet bed	383	141	27.7	285	48.14	37.59
T_3 : Mechanical transplanting (2 harrow + 1 planking + 2 passes of puddler)- puddled	354	131	26.7	272	41.40	36.95
T_4 : Mechanical transplanting (2 harrow + 2 planking)- unpuddled	300	113	26.3	283	46.54	37.37
T_5 : Manual transplanting (2 harrow + 2 cultivator + 1 planking +2 passes of puddler)- puddled	333	122	26.5	276	41.78	37.06
CD (P = 0.05)	11	9	0.9	4	0.91	0.24

Table 8 Energy dynamics (MJ/ha) of rice-wheat cropping system as influenced by rice planting methods (pooled data of 3 years)

Treatments	Total input energy	Total output energy	Net return energy	Output-input ratio
T_1: Direct seeding (2 harrow + 2 cultivator + 2 planking)- dry bed	42,279	211,350	169,070	5.0
T_2 : Drum seeding (2 harrow + 2 cultivator + 2 planking)- wet bed	41,872	212,798	170,926	5.1
T_3 : Mechanical transplanting (2 harrow + 1 planking + 2 passes of puddler)- puddled	42,873	200,215	157,343	4.7
T_4 : Mechanical transplanting (2 harrow + 2 planking)- unpuddled	41,172	209,091	167,919	5.1
T_5 : Manual transplanting (2 harrow + 2 cultivator + 1 planking +2 passes of puddler)- puddled	43,375	193,916	150,542	4.5

input energy was (43,375 MJ/ha) consumed in manually transplanted (puddled) followed by (42,873 MJ/ha) in mechanically transplanted (puddled) and lowest was 41,172 and 41,182 MJ/ha in mechanically transplanted (unpuddled) and drum seeded, respectively, in rice-wheat system. The fertilizer consumed highest input energy, about 42 to 45 % of total input energy use, followed by 21 to 25 % in irrigation, 11 to 18 % in land preparation, 9 to 10 % in seed and sowing and 2 to 3 % in interculture/weeding in the rice-wheat system. However, the output energy was highest in drum seeded (212,798 MJ/ha), closely followed by direct seeded (211,350 MJ/ha) and the lowest was 193,916 MJ/ha in manually transplanted (puddled). The net return energy of the system was high in drum seeded (170,926 MJ/ha) followed by direct seeded (169,070 MJ/ha) and lowest was 150,542 MJ/ha in manually transplanted (puddled).

The input energy for the manually transplanted was higher due to higher use of inputs as in tillage operations and the sowing operation as compared to direct seeded and drum seeded rice in which the tillage operation was minimum where energy consumed by diesel was much less (*Chaudhary et al.,* 2006). The drum seeded rice required 3.6 % less input energy and gave 8.9 % higher output energy, whereas, direct seeded required 2.6 % less input and gave 8.2 % higher output energy as compared to manually transplanted (puddled). The output energy and net return energy was higher in drum seeded and direct seeded, due to its higher grain yield that resulted from good crop establishment in minimum tillage and unpuddled field.

Water productivity

The direct seeded (dry bed) and drum-seeding (wet bed-unpuddled) have identified one possibility for saving irrigation water by 13 to 19 % when compared to manual transplanting (puddled) (**Table 9**). The saving of water was due to rice crop established in the unpuddled field. Secondly, the crop of direct seeded and drum seeded matured 8-10 days earlier than transplanted crop. The water productivity in direct seeded varied from 0.664 to 0.742 and drum seeded varied from 0.676 to 0.738 kg grain/m^3, whereas, it varied from 0.587 to 0.660, 0.583 to 0.622 and 0.524 to 0.577 kg grain/ m^3 in mechanical transplanting (puddled), manual transplanting (puddled) and mechanical transplanting (unpuddled), respectively.

Conclusions

The present study indicated that drum seeding (wet bed) resulted in the maximum grain yield (8.52 t/ha) of hybrid rice for better crop growth and its establishment while direct seeding (dry bed) adopted in preceding rice crop produced greater yield of the subsequent wheat crop. The substitution of wheat in unpuddled soil drum (wet bed) and direct seeding (dry bed) not only produced relatively higher economic yield but also used less energy. The output energy was highest in drum seeded (212,798 MJ/ha) closely followed by direct seeded (211,350 MJ/ha). The lowest was 193,916 MJ/ha in manually transplanted (puddled). The net return energy of the system was high in drum seeded (170,926 MJ/ha) followed by direct seeded (169,070 MJ/ha) and lowest of 150,542 MJ/ha in manually transplanted (puddled). In addition to this, the direct seeded (dry bed) and drum-seeding (wet bed-unpuddled)

Table 9 Water Productivity of rice as influenced by crop establishment practices and tillage levels

Treatments	Irrigation water applied (cm)			Water productivity (kg grain m^{-3} of irrigation water)		
	2003-04	2004-05	2005-06	2003-04	2004-05	2005-06
T_1: Direct seeding (2 harrow + 2 cultivator + 2 planking)-dry bed	118	115	123	0.664	0.742	0.695
T_2 : Drum seeding (2 harrow + 2 cultivator + 2 planking)-wet bed	120	118	126	0.676	0.738	0.694
T_3 : Mechanical transplanting (2 harrow + 1 planking + 2 passes of puddler)- puddled	132	128	138	0.587	0.660	0.613
T_4 : Mechanical transplanting (2 harrow + 2 planking)-unpuddled	140	134	142	0.524	0.577	0.554
T_5 : Manual transplanting (2 harrow + 2 cultivator + 1 planking +2 passes of puddler)- puddled	128	126	135	0.583	0.622	0.584
CD (P = 0.05)	-	-	-	0.080	0.086	0.083

showed a possible saving of irrigation water by 13 to 19 % when compared to manual transplanting (puddled).

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