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Research Paper

Evaluation of rice (*Oryza sativa*) cultivars under different crop establishment methods to enhance productivity, profitability and energetics of rice in middle Indo-Gangetic Plains of India

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ABSTRACT

Field investigation was undertaken at the ICAR-Research Complex for Eastern Region, Patna to evaluate the performance of nine promising rice (*Oryza sativa* L.) genotypes ('IR83387-B-B-40-1', 'Shusk Samrat', 'Abhishek', 'IR82870 11', 'Sahbhagi Dhan', 'CR Dhan 40', 'IR84899-B-183-CRA-19-1', 'IR83387-B-B-27-4' and 'IR83376-B-B-24-2') under 2-crop establishment methods i.e. puddle transplanted rice (PTR) and unpuddled transplanted rice (UPTR) during the rainy (*kharif*) seasons of 2013 and 2014. Results showed that PTR produced significantly higher grain yield (4.20 t/ha) than UPTR (3.29 t/ha). Among the rice genotypes, 'IR83387-B-B-27-4' (4.38 t/ha) being on par with 'IR83387-B-B-40-1' (4.20 t/ha) recorded significantly higher grain yield over rest of the genotypes. The maximum net returns (25.9×10^3 ₹/ha) and benefit : cost ratio (1.98) were recorded with PTR. Among the rice genotypes, 'IR83387-B-B-27-4' had significantly the highest net returns (34.8×10^3 ₹/ha) and benefit: cost ratio (2.33). UPTR gave the highest energy efficiency, energy productivity and energy profitability (1.9, 0.06 kg/MJ and 0.9 MJ/ha) than PTR (1.5, 0.05 kg/MJ and 0.50 MJ/ha). Hence, growing of rice genotypes 'IR83387-B-B-27-4' and 'IR83387-B-B-40-1' under PTR condition is better option to obtain the maximum productivity and profitability in this region.

Key words: Crop establishment methods, Economics, Energetics, Rice genotypes, Yield

Rice is the most important staple food crop for more than half of the world's population and provides about 21% of the total calorie intake (Parameswari *et al.*, 2014). In India, rice occupies an area of 43.8 million ha with a production of 105 million tonnes with average productivity of 2.2 tonnes/ha. Demand for rice growing is increasing every year and it is estimated that requirement would be 140 million tonnes by 2025 AD. To sustain the present food self-sufficiency and to meet the future food requirement, India has to increase the rice productivity by 3% per annum. The conventional method of crop establishment in rice is manual transplanting of rice seedlings into puddle soil that requires large amount of water, energy and labour, which are becoming increasing scarce and expensive (Mishra and Singh, 2012). Besides, continuous puddling for rice cultivation over decades has led to deterioration of soil physical properties through structural breakdown of soil aggregates and capillary pores and clay dispersion, thereby restricting germination and rooting of succeeding crops. Alternatively, rice can be transplanted under unpuddled condition (UPTR), in which rice seedlings are transplanted in standing water (5 ± 2 cm) without puddling. This practice saves significant amount of power, fuel, time and water which is a major resource constraint in future. However, this method is subjected to more weed infestation than PTR because weed growth is faster in the absence of puddling (Kumar *et al*., 2016). Energy is one of the most valuable inputs in production agriculture system. Agriculture itself is energy user and energy supplier in the form of bio-energy (Kumar *et al.,* 2015a). Sufficient availability of the right energy and its effective and efficient use are prerequisites for improved agricultural production. Energy analysis, therefore, is necessary for efficient man-

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agement of scarce resources for improved agricultural production. Hence, the evaluation and identification of responsive rice genotypes with respect to crop establishment methods is cost effective and safe approach to sustain the rice productivity, particularly by resources poor farmers of this region (Kumar *et al*., 2016). It is therefore, imperative to identify the suitable crop establishment methods and efficient rice genotypes, which can minimize the consumption of time, fuel energy, money and labour with sustainable productivity of entire rice-cropping in the middle Indo-Gangetic Plains. Farmers of the region mainly grow puddle transplanted rice with traditional genotypes; hence crop yields are low, however, quantum of resources used per unit of production is very high. Rice is a semi-aquatic plant and uses approximately 3000-5000 liters of water to produce 1 kg of rice under puddled condition. Sustaining rice production under decreasing water availability and shrinking land area is becoming major challenge under Indo-Gangetic Plains of India. Therefore, it is imperative to identify the high yielding genotypes of rice, which can withstand better in scarce resources without compromising the yield. Hence, the present investigations were undertaken.

MATERIALS AND METHODS

Field experiments were conducted during the rainy (*kharif*) seasons of 2013 and 2014 at the ICAR Research Complex for Eastern Region, Patna (25º30'N", 85º15'E" and 52 m above mean sea-level). Soil at the experimental site was clay loam in texture (42.1% sand, 35.2% silt and 22.7% clay), low in organic carbon (0.49%) and nitrogen (216 kg N/ha), medium in available phosphorus (22.7 kg P_2O_5/ha) and potassium (215 kg K_2O/ha). The treatments comprised of two crop establishment methods, viz. puddled transplanted rice (PTR) and unpuddled transplanted rice (UPTR) in the main plot and nine rice genotypes including four drought tolerant released varieties, viz. 'Sahbhagi Dhan', 'Sushk Samrat', 'CR Dhan 40', 'Abhishek', and five advanced breeding lines. ('IR84899-B-183-CRA-19-1', 'IR83387-B-B-40-1', 'IR82870-11', 'IR83387-B-B-27-4' and 'IR83376-B-B-24-2') as subplots and replicated thrice in a split-plot design. The details of rice genotypes are described in Table 1. The size of each plot was 25 m² (5m×5m). In order to ensure the proper seed germination, seed priming (overnight soaking of seed followed by drying in shades before sowing) was done before nursery raising. Seeds were treated with bavistin fungicide at 2.0 g/kg seed before sowing in the nursery. Nursery for puddled transplanted rice (PTR) and unpuddled transplanted rice (UPTR) was prepared by using a modified mat nursery method using seed rate of 30 kg seed/ha. 21-days old seedlings were transplanted by scooping single seedling. Proper care was taken to transplant the seedlings within half an hour of scooping from the nursery to avoid transplanting shock. Farmyard manure @ 10 t/ha was applied 15 days prior of transplanting to the main field. Recommended dose of fertilizer of 120-60-40-25 kg N-P-K-Zn/ha were applied uniformly in the

Table 1. Characterizations of the rice genotypes used for the trials

Rice genotype	Pedigree	Year of release and place	Grain type	Plant height (cm)	DFF (days)	Maturity duration (days)
'Sahbhagi dhan'	IR 55419-04*2. Way Rarem (IR 55419-04 (IR 12979-24-1 (Brown)/ UPRLRi5)	2009, CRURRS Hazaribagh	Long bold	100–110	85–90	110–115
'Shusk samrat'	C 1064-5/Kalari/IR 54	2007, NDUAT, Faizabad	Long slender	95–100	80–85	105–110
'CR dhan 40'	N 22/RP 20-5	2008, CRURRS Hazaribagh	Short bold	105–115	70–75	100–105
'Abhishek'	CR 314-5-10 (Open Florat mutant)	2007, CRURRS Hazaribagh	Short bold	95–100	90–95	120–125
'IR 84899-B-183-CRA-19-1'	IR78877-208-B-1-1 × IRRI 132	Advanced breeding lines	Short bold	110–115	85–90	115–120
'IR 83387-B-B-40-1'	IR 72022-46-2-3-3-2/ SambhaMahsoori	Advanced breeding lines	Long bold	105–110	85–90	115–120
'IR 82870-11'	IR 82851-16/IR 82855-9	Advanced breeding lines	Long bold	90–95	90–95	120–125
'IR 83387-B-B-27-4'	IR72022-46-2-3-3-2 × SambhaMahsuri	Advanced breeding lines	Long bold	90–95	85–90	115–120
'IR 83376-B-B-24-2'	IR 71700-247-1-1-2/IR 77080-B-34-1–1	Advanced breeding lines	Long slender	100–105	85–90	115–120

CRURRS, Central rainfed upland rice research station; NDUAT, Narendra Dev University of Agriculture and Technology; DFF, days to 50% flowering field through urea, di-ammonium phosphate (DAP), muriate of potash (MOP) and $ZnSO_4$. Half dose of N and full dose of P, K and Zn were applied as basal and remaining half dose of N were applied in 2 equal-splits at maximum tillering and panicle initiation stages. Weeds were controlled through pre-emergence application of butachlor 1.5 kg/ha at 3–4 days after transplanting (DAT) followed by post-emergence application of bispyribac-sodium @ 30 g/ha at 4–6 leaf stage (25–30 DAT) and one hand weeding at 50 DAT. Total rainfall received during cropping season (June-November) was 715.7 and 911.5 mm in 2013 and 2014 respectively (Fig. 1). Mean monthly maximum and minimum temperature varied from 37.3 to 28.4°C and 27.6 to 14.3°C, respectively.

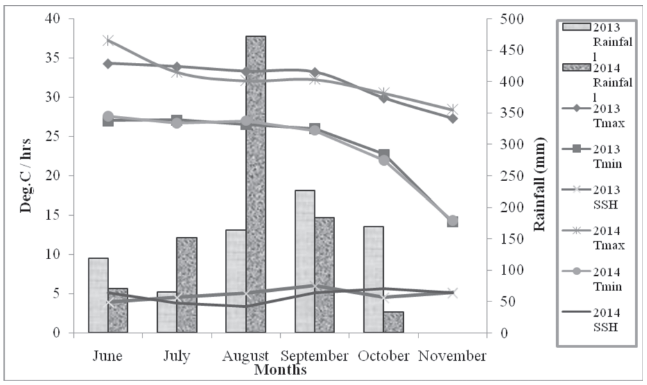

Fig. 1. Weather parameters during the experimentation

All the growth and yield attributes, viz. plant height, number of green leaves, dry matter, panicles/hill, panicle length and grains/panicle were recorded at maturity from randomly selected five hills in each plot following standard procedures. Chlorophyll content was measured at 75 DAT (days after transplanting) as suggested by Hiscox and Israelstam (1979) and expressed as mg/g dry weight. Rate of photosynthesis was measured on fully expanded flag leaves using portable Infrared Gas Analyzer (IRGA LI-6400 Model, LICOR, USA) and expressed as µmol/m^2/second. Economics of rice was calculated based on minimum support price (MSP) declared by the Government of India. Net income was calculated as difference between gross income and total cost of cultivation. Benefit: cost ratio was worked out by dividing the gross returns with cost of cultivation. Crop productivity (kg/ha/day) and economic efficiency (₹/ha/day) was calculated as suggested by Kumawat *et al*., (2012). Economic yield of crops was converted into equivalent value of carbohydrate (t/ha) as suggested by Gopalan *et al*. (2004). Energy fluxes of crop were estimated using crop management (machinery operation and amount of input used) and biomass production record. To study the energy input and output of crop and establishment method, a complete inventory of all crop inputs (fertilizers, seeds, plant protection chemicals, fuels, human labour and machinery power) and outputs of both main and by-products was taken into account. Inputs and outputs were converted from physical to energy unit measures through published conversion coefficients (Devasenapathy *et al.,* 2009 and Tuti *et al*., 2012). The field data obtained for 2 years were pooled and statistically analysed using F-test (Gomez and Gomez, 1984). Significant difference between treatments mean were compared with critical differences at 5% levels of probability.

RESULTS AND DISCUSSION

Growth attributes

The data on growth attributes, viz. plant height; green leaves, dry matter production and tillers/m^2 were markedly influenced with crop establishment methods (Table 2 and Fig. 2). Significantly higher plant height was recorded with UPTR (98.9 cm) as compared to PTR (93.3 cm). The no. of green leaves/meter row was higher with PTR (345) compared to UPTR (309). However, plant height and green leaves/meter row often been described as one of most important factors for weeds competitive ability of crop (Kumar *et al*., 2016). Similarly, PTR recorded significantly higher dry matter production as compared to UPTR at all the stages of crop growth. Maximum dry matter was produced at maturity with PTR (102.6 g/hill) compared to UPTR (94.2 g/hill). The per cent increase of dry matter production of PTR over UPTR was 8.91%. This could be ascribed to vigorous and deeper root system of PTR as compared to UPTR that led to the better crop growth and development (Kumar *et al*., 2015). However, physiological attributes like days to maturity; photosynthesis rate and chlorophyll content were significantly higher with PTR compared to UPTR. Irrespective of the genotypes, UPTR matured early (105 days) as compared to PTR (111 days). This might be owing to less time taken by UPTR to complete its metabolic activities under water stress during their cropping period.

All the growth attributes of rice were markedly influenced by the genotypes (Table 2 and Fig. 2). Among the genotypes, maximum plant height was recorded with 'IR83387-B-B-40-1' (109.4 cm) and minimum with 'Abhishek' (88.4 cm). Number of green leaves/m row at 75 DAT was recorded significantly higher with 'IR82870-11'. Rice genotypes 'IR84899-B-183-CRA-19-1' took significantly less number of days to 50% flowering (80 days) as compared to 'IR83387-B-B-40-1' that took 95 days. Rice genotypes 'IR82870-11' (106 days) and 'Shusk Samrat' (108 days) matured early. Chlorophyll content was significantly higher with 'IR83376-B-B-24-2' (3.96 mg/g), which was statistically similar with 'IR83387-B-B-27-4'

Table 2. Growth and yield attributes of rice genotypes at harvest as influenced by different establishment method (pooled data of 2 years)

Treatment	Plant height (cm)	Green leaves/m row*	Days to 50% flowering	Days to maturity	Tillers/m² (no.) at flowering	Chlorophyll content (mg/g)*	Photosynthetic rate (μmol/m²/S)*	Panicle length (cm)	Grains/ panicle (no.)	Grain filling (%)	1,000-grain weight (g)
Crop establishment method											
PTR	93.3	345	90	111	266	3.62	23.4	24.3	177.3	84.4	23.8
UPTR	98.9	309	91	105	237	3.31	21.7	22.5	169.5	84.1	23.2
SEm±	1.23	8.3	1.2	1.75	7.2	0.28	0.5	0.9	5.7	1.9	0.9
CD (P=0.05)	5.05	29.2	NS	5.1	21.3	0.93	1.4	NS	NS	NS	NS
Genotypes											
'IR 83387-B-B-40-1'	109.4	343	95	114	279	3.65	23.4	25.0	185.9	84.2	23.6
'Sushk Samrat'	88.8	311	89	109	246	3.31	21.2	22.1	178.0	86.5	22.7
'Abhishek'	98.0	338	92	113	280	3.38	22.3	20.9	181.7	86.5	23.2
'IR 82870–11'	90.7	375	86	106	287	3.84	23.4	23.7	176.6	85.8	23.6
'Sahbhagi Dhan'	88.4	306	89	115	243	3.50	23.4	25.5	172.5	81.9	22.6
'CR Dhan 40'	93.7	318	84	111	227	3.46	23.0	26.3	173.4	81.0	20.6
'IR 84899-B-183-CRA-19-1'	90.3	324	80	108	249	2.82	20.0	21.7	180.6	83.2	21.0
'IR 83387-B-B-27-4'	93.4	354	91	115	295	3.92	24.3	26.7	192.7	85.9	25.1
'IR 83376-B-B-24-2'	90.4	275	93	118	223	3.93	22.0	23.3	173.8	80.8	24.8
SEm±	1.03	6.8	1.0	1.37	9.2	0.08	0.5	0.5	4.7	1.5	0.2
CD (P=0.05)	3.07	20.3	3.1	4.1	27.5	0.22	1.2	1.5	14.0	4.4	0.7

*At 75 DAT; PTR, puddled transplanted rice; UPTR, unpuddled transplanted rice

(3.92 mg/g) and 'IR82870-11' (3.84 mg/g). Irrespective of crop establishment methods, the highest photosynthetic rate was observed with 'IR83387-B-B-27-4' (24.32 μmol/m²/S), being on a par with 'IR83387-B-B-40-1' and 'Sahbhagi Dhan'. However, the lowest rate of photosynthetic rate was recorded with 'IR84899-B-183-CRA-19-1' followed by 'Shusk Samrat'. This might be due to increase in chlorophyll content vis correlated with an increase in net photosynthetic rate (Ibrahim *et al*., 2011).

Yield attributes and yield

The yield attributes, viz. panicle length, grains/ panicle, grain filling (%) and 1,000-grain weight was markedly influenced with the establishment methods (Table 2). Panicle length was recorded higher with PTR (24.28 cm) compared to UPTR (22.5 cm). Other yield attributes such as Grains/panicle, grain filling (%) and 1,000-grain weight were recorded higher with PTR, but it could not reach the levels of significance. Kumar *et al.* (2016) also reported that higher grain filing (%) with PTR was owing to effective crop management, which reduced the grain sterility. Significantly higher grain yield (3.75 t/ha), straw yield (4.76 t/ha) and biological yield (8.51 t/ha) were recorded with PTR as compared to UPTR (Table 2). The grain yield difference of PTR over UPTR was 16.5%. It was probably due to higher growth and yield attributes caused by better nutrient absorption from the soil, increased rate of metabolic process, rate of light absorption and photosynthetic activity as compared to other establishment method (Kumar *et al*., 2015b). The crop productivity was significantly higher with PTR (33.5 kg/ha/day) compared to UPTR (28 kg/ha/day) (Table 3). This might be due to higher grain yield with PTR as compared to UPTR. Similarly, higher values of carbohydrate equivalent yield were noted with PTR (2.93 t/ha) as compared to UPTR (2.52 t/ha). This might be due to higher yields associated with the PTR.

The yield attributes of rice were significantly influenced by the genotypes (Table 2). Rice genotype 'IR83387-B-B-27-4' (26.7 cm) being at par with 'CR Dhan 40' (26.3 cm) and Sahbhagi Dhan (25.5 cm) produced the longest panicle and 'Abhishek' (20.8 cm) produced the shortest. Grains/panicle was significantly higher with 'IR83387-B-B-27-4' (192.6) followed by 'IR83387-B-B-40-1' (185.8), 'Abhishek' (181.6) and 'IR84899–B–183–CRA–19–1' (180.5), which were at par with each others. The lowest grains/panicle (172.4) was recorded with 'Sahbhagi Dhan'. However, grain filling (%) was significantly

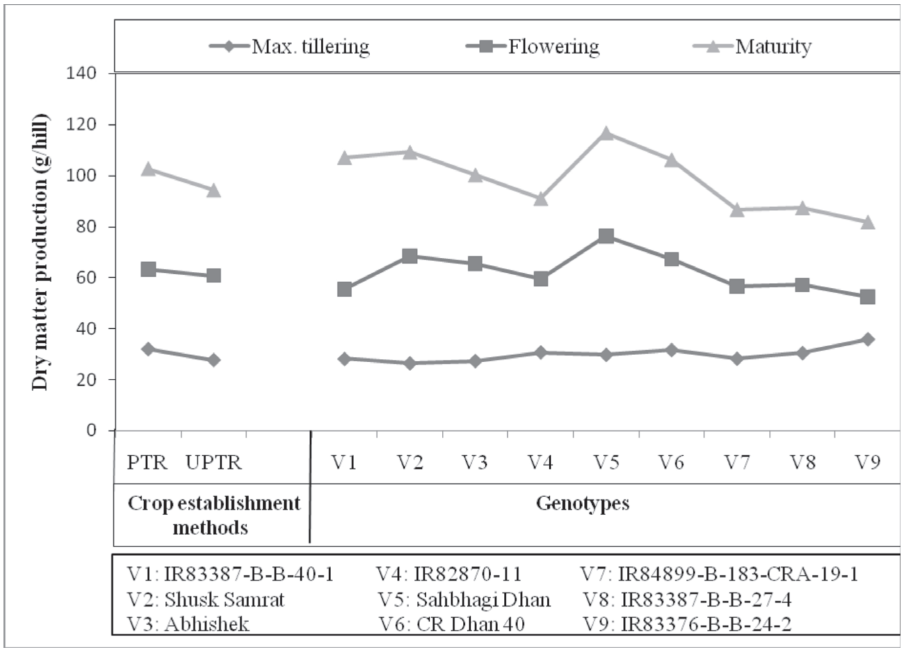

Fig. 2. Dry-matter production of rice genotypes at different stage as influenced by crop establishment method (pooled data of 2 years)

higher with 'Sushk Samrat' (86.5%), but it was noted statistically similar with 'Abhishek' (86.5%), 'IR83387-B-B-27-4' (85.8%) and 'IR82870-11' (85.7%). Grain filling percentage is one of the major yield components and it might be higher due to conversion of source to sink in effectively and insufficient moisture condition and higher weed growth with respective treatment (Kumar *et al.*, 2016). Significantly higher 1,000-grain weight was associated with 'IR83387-B-B-27-4' (25.1 g), but it was noted statistically at par with 'IR83376-B-24-2' (24.8 g). Rice genotype 'IR83387-B-B-27-4' performed significantly better in terms of grain yield (4.38 t/ha), straw yield (5.56 t/ha) and biological yield (9.94 t/ha) compared to rest of the promising genotypes but it was statistically at par with 'IR83387-B-B-40-1' (Table 3). This might be due to the better growth attributes i.e. plant height and leaf-area index, resulted in better suppression of the weeds growth as compared to other genotypes and produced more yield attributes and ultimately higher grain yield. Interaction effect of crop establishment methods and genotypes on grain yield was not significant (Table 4). The crop productivity was significantly higher with 'IR83376-B-B-24-2' (37.8 kg/ha/day) but it was statistically similar with 'IR83387-B-B-40-1' (36.5 kg/ha/day). This might be due to higher yields noted with respective genotypes, which is a genetic charterer. Significantly higher values of the carbohydrate equivalent yield was noted with the rice genotypes 'IR83387-B-B-27-4' (3.42 t/ha).This might be due to the higher yield associated with the respective genotypes.

Economics

Maximum gross returns (52.1×10^3₹/ha), net income (25.9×10^3₹/ha) and benefit: cost ratio (1.98) were recorded with PTR, which was found to be significantly higher than UPTR (44.8×10^3₹/ha, 18.4×10^3₹/ha and 1.73) (Table 3). The PTR had noted 16.4% and 36.6% higher gross and net income over UPTR due to higher grain yield. Among the rice genotypes, 'IR83387-B-B-27-4' had recorded the significantly highest gross returns and net returns (60.9×10^3₹/ha and 34.8×10^3₹/ha) and benefit: cost ratio (2.33). Rice genotype 'IR83376-B-B-24-2' had the lowest gross and net returns and benefit: cost ratio (35.1×10^3₹/ha, 9.4×10^3₹/ha and 1.34) because of its lower yield with the respective genotypes (Table 3). Sale prices of produce for different genotypes were same, thus, difference in net returns was largely due to variation in yield and crop management. The economic efficiency was significantly higher with PTR (₹230.8 ha/day) compared to UPTR (₹167.7 ha/day). This might be owing to higher yield and net returns associated with the respective treatment. Similarly, higher economic efficiency was noted with 'IR83387-B-B-27-4' (₹300.5 ha/day) as compared to rest of the genotypes, but it was statistically similar with 'IR83387-B-B-40-1' (₹281.1 ha/day).

Energetics

Comparison of traction power, time, fuel and time saving, CO_2 emission and consumption of equivalent energy use pattern in different crop establishment methods of rice

Table 3. Yield attributes, yield and economics of rice genotypes as influenced by different establishment method (pooled data of 2 years)

Treatment	Grain yield (t/ha)	Biological yield (t/ha)	Harvest index (%)	Gross returns (×10³₹/ha)	Net returns (×10³₹/ha)	Benefit: cost ratio	Crop productivity (kg/ha/day)	Economic efficiency (₹/ha/day)	Carbohydrate equivalent (t/ha)
Crop establishment method									
PTR	3.75	8.51	44.1	52.1	25.9	1.98	33.5	230.8	2.93
UPTR	3.22	7.31	41.1	44.8	18.9	1.73	28.0	164.7	2.52
SEm±	0.09	0.15	1.8	0.9	0.9	0.05	0.6	8.2	0.05
CD (P=0.05)	0.40	0.90	NS	5.5	5.5	0.21	3.6	49.9	0.31
Genotype									
'IR 83387-B-B-40-1'	4.20	9.53	44.0	58.4	32.3	2.23	36.5	281.1	3.28
'Sushk samrat'	3.29	7.48	42.1	45.8	19.8	1.75	29.8	178.9	2.58
'Abhishek'	3.61	8.19	43.1	50.2	24.1	1.92	31.6	210.9	2.82
'IR 82870-11'	3.27	7.41	44.1	45.4	19.3	1.74	30.4	180.3	2.55
'Sahbhagi dhan'	3.50	7.94	44.0	48.6	22.5	1.86	30.1	194.0	2.73
'CR Dhan 40'	3.12	7.08	44.1	43.3	17.3	1.66	27.6	153.4	2.44
'IR 84899-B-183-CRA-19-1'	3.49	7.92	44.1	48.5	22.4	1.85	31.8	204.5	2.73
'IR 83387-B-B-27-4'	4.38	9.94	44.1	60.9	34.8	2.33	37.8	300.5	3.42
'IR 83376-B-B-24-2'	2.53	5.73	42.1	35.1	9.0	1.34	21.2	76.0	1.97
SEm±	0.07	0.16	0.8	0.9	0.9	0.03	0.6	8.4	0.05
CD (P=0.05)	0.19	0.44	NS	2.7	2.7	0.10	1.7	24.1	0.15

PTR, puddled transplanted rice; UPTR, unpuddled transplanted rice

(Table 5) revealed that highest traction power (5), time (15 hr) and fuel consumption (52.5 litres), CO_2 emission (136.5 kg) and consumption of equivalent energy use (2961.9 MJ/ha) were consumed under PTR. However, the lowest traction power (3), time (9 hr), fuel consumption (31.5 litres), CO_2 emission (81.9 kg) and consumption of equivalent energy (1,773.8 MJ/ha) were consumed with UPTR. In respect to fuel, time and CO_2 emission saving, UPTR saves 66.7% as compared to PTR. Similar findings were reported by Bohra and Kumar (2015) in their field investigation.

Table 4. Interaction effect of crop establishment methods and genotypes on grain yield (pooled data of 2 years)

Rice genotype	Grain yield (t/ha) PTR	Grain yield (t/ha) UPTR	Mean
'IR 83387-B-B-40-1'	4.48	3.92	4.20
'Sushk samrat'	3.56	3.03	3.29
'Abhishek'	3.90	3.32	3.61
'IR 82870-11'	3.53	3.00	3.27
'Sahbhagi Dhan'	3.78	3.21	3.50
'CR Dhan 40'	3.37	2.86	3.12
'IR 84899-B-183-CRA-19-1'	3.77	3.20	3.49
'IR 83387-B-B-27-4'	4.63	4.13	4.38
'IR 83376-B-B-24-2'	2.73	2.32	2.53
Mean	3.75	3.25	3.49
CD (P=0.05)	Establishment (E) =0.40;	Genotypes (G); =0.28	E×G=NS

PTR, puddled transplanted rice; UPTR, unpuddled transplanted rice

Comparison of energy use pattern (Table 6) in different crop establishment method revealed that the highest input energy (76.2×10^3 MJ/ha) was consumed under PTR compared to UPTR (51.7×10^3 MJ/ha). Higher energy consumption under PTR due to more traction operation with the respective treatment (Bohra and Kumar, 2015). However, output energy was significantly higher with PTR (114.6×10^3 MJ/ha) compared to UPTR (98.5×10^3 MJ/ha). Significantly higher net energy returns (46.8×10^3 MJ/ha), energy ratio (1.906) and energy productivity (0.062 kg/MJ) and energy profitability (0.906) were associated with UPTR over PTR. Human energy profitability was recorded the maximum with PTR (46.45) as compared to

Table 5. Traction power, time and fuel consumption and saving, CO_2 emission and consumption of equivalent energy in rice under different crop establishment methods

Crop establishment methods	Tractor operation (number of pass)	Time (hr/ha)	Fuel consumption (litres)	Fuel saving (%)	Time saving (%)	CO_2 emission (kg/ha)	Consumption of equivalent energy (MJ/ha)
PTR	5	15	52.5	–	–	136.5	2,961.9
UPTR	3	9	31.5	66.7	66.7	81.9	1,773.8

Table 6. Energy input-output relationship of genotypes with crop establishment methods

Treatment	Input energy ($\times 10^3$ MJ/ha)	Output energy ($\times 10^3$ MJ/ha)	Net energy returns ($\times 10^3$ MJ/ha)	Energy ratio	Energy productivity (kg/MJ)	Energy profitability (MJ/ha)	Human energy profitability	Energy output efficiency (MJ/ha/day)	Energy intensiveness (MJ/₹/ha)
Crop establishment method									
PTR'	76.2	114.6	38.4	1.50	0.049	0.50	46.45	1023	2.64
UPTR	51.7	98.5	46.8	1.90	0.062	0.90	32.52	857	1.58
SEm±	–	2.1	2.1	0.06	0.002	0.06	1.58	18	–
CD (P=0.05)	–	12.1	12.1	0.20	0.007	0.20	4.54	84	–
Genotype									
'IR 83387-B-B-40-1'	64.0	128.3	64.4	2.05	0.067	1.05	40.28	1117	2.11
'Sushk samrat'	64.0	100.7	36.7	1.60	0.053	0.60	44.13	912	2.11
'Abhishek'	64.0	110.3	46.3	1.76	0.058	0.76	39.94	965	2.11
'IR 82870-11'	64.0	99.8	35.9	1.59	0.052	0.59	42.77	930	2.11
'Sahbhagi dhan'	64.0	106.9	43.0	1.70	0.056	0.70	38.13	919	2.11
'CR Dhan 40'	64.0	95.3	31.4	1.52	0.050	0.52	42.66	845	2.11
'IR 84899-B-183-CRA-19-1'	64.0	106.6	42.7	1.70	0.056	0.70	53.52	971	2.11
'IR 83387-B-B-27-4'	64.0	133. 9	69.9	2.15	0.070	1.15	30.89	1155	2.11
'IR 83376-B-B-24-2'	64.0	77.2	13.3	1.23	0.040	0.23	23.02	647	2.11
SEm±	–	2.0	2.0	0.02	0.001	0.003	0.88	15	–
CD (P=0.05)	–	6.0	6.0	0.09	0.003	0.09	2.28	53	–

PTR, puddled transplanted rice; UPTR, unpuddled transplanted rice

UPTR (32.52). Energy output efficiency was significantly higher with PTR (1023 MJ/ha/day) as compared to UPTR (857 MJ/ha/day). Similarly energy effectiveness was higher with PTR (2.647 MJ/₹/ha) over UPTR (1.58 MJ/₹/ha). This might be due to higher energy-use efficiency under particular crop establishment method was mainly attributed to higher energy production with less use of energy (Kumar *et al.,*2017).

With respect to rice genotypes, output energy was recorded significantly higher with 'IR 83387-B-B-27-4' (133.9×10^3 MJ/ha) as compared to rest of the genotypes but it was found statistically at par with 'IR 83387-B-B-40-1' (128.3×10^3 MJ/ha). Similarly, significantly higher net energy returns (69.9×10^3 MJ/ha), energy ratio (2.15) and energy productivity (1.15 kg/MJ) were associated with 'IR 83387-B-B-27-4'. Further, human energy profitability was recorded markedly higher with 'IR84899-B-183-CRA-19-1' (53.52) amongst the tested genotypes. Rice genotype 'IR 84899-B-183-CRA-19-1' (1155 MJ/ha/day) being at par with 'IR 83387-B-B-40-1' (1,117 MJ/ha/day) and produced significantly higher energy-use efficiency over rest of the genotypes. However, higher energy use efficiency of rice genotypes was mainly attributed to higher yields with use of lesser energy.

Hence, the present study suggest that advanced breeding lines 'IR 83387-B-B-27-4' and 'IR 83387-B-B-40-1' having the higher yield potential achieved the more monetary returns when planted with puddle transplanted rice in middle Indo-Gangetic Plains of India.

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