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RESEARCH PAPER

Dry Direct Seeded Rice Emerged as Viable Option based on Energetics and Economics- Experiences from Middle Gangatic-Plains of Bihar, India

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ABSTRACT

In the Indo-Gangetic plain of India, rice (*Oryza sativa*) is grown in around 60-70% of cultivated land. Therefore, finding an energy-efficient approach for rice establishment techniques is crucial for environmental sustainability and food security. In order to determine the most effective rice establishment techniques for increasing productivity, profitability, energy efficiency, and cost effectiveness, the performance of three crop establishment methods-Manual Transplanting (MT), Dry Direct Seeded (Dry DSR), and Wet Direct Seeded (Wet DSR)-was evaluated in the field at Samastipur District of Bihar in the years 2021-2022. Results revealed that Dry DSR recorded significantly higher grain yield as compared to MT and Wet DSR. The Dry DSR and MT method of rice cultivation produced 35.15% and 18.2% higher grain yield as compared to Wet DSR, respectively. Energy input was the highest in manual transplanted rice (20637 MJ ha^{-1}) and the lowest in dry DSR (12752 MJ ha^{-1}). HI is highest in Dry DSR (50%), followed by MT (44%) and Wet DSR (23.1%). The Dry DSR method was the most energy-efficient whereas wet DSR was the least energy efficient. Similarly, the gross returns (₹ 110,940 ha^{-1}), net returns (₹ 79,390 ha^{-1}) and benefit: cost ratio (3.51) was recorded significantly highest under Dry DSR. Among all crop establishment methods, the Wet DSR recorded least profit. Hence, the existing farmer's practices can be profitably replaced with adoption of Dry DSR methods of crop establishment under Indo-Gangetic plain.

HIGHLIGHTS

- Dry direct-seeded rice has superior energy and carbon production efficiencies without dipping economic benefits.

Keywords: Manual transplanted rice, Productivity, Energy efficiency, Gross returns, Benefit: Cost ratio

In world, rice is the most frequently consumed cereal. With 155 million metric tonnes (mt) consumed, China is the nation with the highest per capita rice consumption in the world. India comes second with 108.5 mt per capita (Department of Agriculture & Farmers Welfare 2020). The expanding global population will raise the importance of rice as a staple food. But its continuous supply is under threat in the context of such climate change, unavailability of assured irrigation facility, reduced farm workers and scarce non-renewable resource (Rakshit *et al*. 2020). Since rice is an energy-intensive crop, it requires lots of input like water, land, and

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chemicals in energy form (Thanawong *et al*. 2014). Rice crop consume 27% of the world total fresh water (Bouman *et al*. 2007). It has been reported that with the consumption of 1 m^3 water, less than 1 kg grains were produced (Bouman, 2009). Water scarcity is expected to affect 17- 22 million acres irrigated rice land in Asia by 2025, compelling farmers to adopt water-saving practices (Tuong *et al*. 2003). Globally, water is becoming an increasingly scarce resource (Kumar and Ladha 2011). So, there is need for re-modification, re-finement in rice crop establishment methods. Alternative techniques of crop establishment method have been investigated due to labour shortages for transplanting and excessive water requirements for puddling (Sharma and Singh 2013). Crop establishment method are important aspect of rice production. In rice production, different crop establishment methods are adopted by farmers as MT, Dry DSR and Wet DSR. Among this, MT rice establishment method is mostly adopted. Rice is traditionally grown by transplanting 25 to 30 days old seedlings after puddling to reduce percolation losses, control weeds, and makes transplanting easier. Transplanted rice is always considered to waste water (Bouman 2009) through surface evaporation and percolation (Farooq *et al*. 2011). Manual rice transplanting requires 25-50 person days per ha (Singh *et al*. 2012 and Chakraborty 2017). But in present scenario due to unassured irrigation and increasing water scarcity, increasing labour charges makes it difficult for rice cultivation and food security for the developing country through this technique. Direct seeded rice (DSR) and Drum seeded rice methods is the viable option in such crisis with proper management (Kaur and Singh, 2017). It is an efficient resource conserving technology because of the advantages over transplanting of rice Pathak *et al*., 2011; Zhao *et al*. (2007) documented higher grain yields and lower water use for dry direct-seeded rice compared with transplanted rice. DSR has received much attention because of its low-input demand and to reduce the emission of CH_4 (Kumar *et al.* 2022). It also removes the cost of raising nurseries, this method has cost and operational advantages over traditional planting (Devnani 2008; Din *et al*. 2013). Wet direct-seeded rice (Drum seeded), in which dry seeds or sprouted rice seeds are broadcast or sown in lines on wet and puddled soil (Kumar and Ladha 2011). Husain *et al*. (2008) found that using the drum seeded technique increased production and income in Bangladesh. One of the most important inputs in rice cultivation is energy, which is utilized at every stage, from the initial preparation of the soil to the final consumption. Energy is used in the production, storage, distribution, transportation, application of inputs, which emits greenhouse gases into the environment and a cropping system's energy use efficiency is influenced by a number of variables, like tillage practice, fertilizer application, plant protection techniques, harvesting, threshing activities, and yield (Mandal *et al*. 2015 and Baishya *et al*. 1990). From economics point of view, in transplanting rice establishment method due to the different intercultural operations the cost of cultivation goes high which is not so in dry DSR method. Energy and economic analysis for rice establishment technique is required as it provide the solution to continuous supply of rice to the growing population without harming the natural resource in sustainable manner (Quilty *et al*. 2014 and Murphy *et al*. 2011). This paper reports an energy analysis intended to evaluate the efficiency of three rice establishment techniques. The study also aimed to analyses the production cost for achieving sustainable production systems.

MATERIALS AND METHODS

A field experiment was conducted during *kharif* season of 2016 at Samastipur district of Bihar to evaluate the different rice establishment technique based on energy and benefit cost ratio. Geographically, the experimental site falls under sub humid, sub-tropical climate of Indo-Gangatic plain having alluvial soil and is located at 26.47° North latitude and 82.12° East longitude. The mean maximum and minimum temperature were 34.1˚C to 37.3˚C and to 9 to11^{0}C, total rainfall received was 1300 mm, during the entire crop season, respectively. The soil of the experimental site was silt-loam in texture and slightly alkaline, low in organic carbon and available nitrogen, medium in available phosphorus and potassium.

Crop biometric observations

Various biometric data were recorded at different growth stages of crop from each plot and economic yield was estimated at harvest.

Grain yield

At physiological maturity plant samples from each plot were harvested manually using 1 m × 1 m frame in the center of each plot and separated into straw and panicles. Panicles were manual threshed and filled spikelet was separated from unfilled spikelet. Grain yield was determined from 1 m^2 area in center of each plot and adjusted to standard moisture content of 0.14 g H_2O g^{-1} fresh weight (Kumar *et al*. 2016). The filled grain of 1000 number was counted and weighed for each plot.

Harvest index

The harvest index was calculated by the formula given below (Kumar *et al*. 2016) for each plot.

$$\textit{Harvest index} = (\textit{Grain yield} \div \textit{Biological yield}) \times 100$$

Procedure for Economic and Energy analysis

In economics, cost of cultivation was taken into account for calculating economics of treatments and to work out net returns ha^{-1} (₹ ha^{-1}) and benefit: cost ratio. The gross returns were taken as total income received from produce of grain and straw yield based on prevailing market price. The benefit cost ratio (B/C ratio) was worked out by using the formula uses by Soni *et al*. (2019). Energy use efficiency, Specific energy, Net energy and Energy profitability are calculated as Khan *et al*. (2010). The differences in the calculation of the equivalent of energy are due to different measurement conditions but here used formula for this is given by Mihov *et al*. (2010); Tuti *et al*. (2012) and Zafar-ul-Hye *et al*. (2020) Table 1.

Crop productivity (kg ha^{-1} day^{-1}) = Grain yield (kg ha^{-1})/Total duration of crop (days)

Economic efficiency (₹ ha^{-1} day^{-1}) = Net return (₹ ha^{-1})/ Total duration of crop (days)

Net return (ha^{-1}) = Gross returns (ha^{-1}) – Total cost of cultivation (ha^{-1})

Benefit-cost ratio = Gross returns/Cost of cultivation

Energy use efficiency = Energy output MJ ha^{-1}/ Energy input MJha^{-1}

Specific energy = Energy input (MJ ha^{-1})/ Grain yield (kg ha^{-1})

Net energy = Total energy output (MJ ha^{-1}) − Total energy input (MJ ha^{-1})

Table 1: Energy equivalents of inputs and outputs

Particulars	Units	Energy equivalent (MJ $unit^{-1}$
Human labor	hr	1.96
Diesel	L	56.31
Farm machinery	hr	62.70
Electricity	kWh	11.91
Mineral fertilizers		
N	kg	60.60
P_2O_5	kg	11.10
K_2O	kg	6.70
Seed	kg	0.8
Irrigation water	m^3	1.02

RESULTS AND DISCUSSION

Effect on Yield and Yield Attribute

Yield is the final outcome of a crop's efficiency since it modified by different management approaches showed in Table 2. Yield is also influenced by various climatic and soil factors. The influence of the environment and input on the plants results in the production of the desired economic produce. This is reasoning the total dry matter production as well as the efficiency depends upon various management practices. Overall, yield is the cumulative result of all agronomic practices, genetic potential of genotype and soil and environmental factors. The findings of the present study showed that yield attributes like panicle length, no of tillers/m^2, no grains per panicle, test weight, grain yield, straw yield and Harvest Index differed significantly due to crop establishment methods of rice. Dry DSR methods of rice establishment recorded higher yield attributes compared to MT and Wet DSR. The possible reason to record higher number of tillers/m^{-2} with heavier panicles contributing to higher grain yield with Dry DSR method due to the availability of more nutrients (Thakur *et al*. 2009). Higher yield attributes under Dry DSR method were also reported by Kumar *et al*. (2016) and Kumar *et al*. (2021). The relationship between grain yield and overall biological yield determines the harvest index. Because to the increased grain output of rice per unit biological yield, the dry DSR method recorded a higher harvest index (50%). Similar result was reported by Stoop *et al*. (2005). Harvest index is the function of grain yield to the total biological yield. The higher harvest index was recorded under dry DSR method (50%), due to higher grain yield of rice per unit biological yield.

Effect on economics of Rice

The data presented in Table 3 revealed that the cost of cultivation, gross return, net return and B:C ratio, Crop productivity (kg ha^{-1} day^{-1}) and Economic efficiency (₹ ha^{-1} day^{-1}) varied with crop establishment methods. Various inputs are taken during different rice establishment techniques given in Fig. 1 which is the basis for calculation of energy and cost of cultivation. In various rice cultivation systems, the grain yield had a significant impact on the net economic return. The minimum cost of cultivation (₹ 39,226 ha^{-1}) was found with dry DSR followed by Wet DSR (₹ 42,450 ha^{-1}) and then MT (₹ 45,135 ha^{-1}). It due to the different intercultural operations in MT which is not so in dry DSR method (Mandal *et al*. 2015). The market value of the produce has a direct impact on the gross monetary return. Maximum value of net return ₹ 71,714 ha^{-1} was found with Dry DSR method. In respect of B:C ratio, Dry DSR method showed highest values of 3.21. Similar finding was obtained by Singh and Hensel, (2012). Higher labour expenses for transplanting were to blame for increased input cost. The Dry DSR has operational advantage as it removes the cost of raising nurseries over traditional planting method (Din *et al*. 2013). The higher gross return was obtained in Dry DSR (₹ 110,940 ha^{-1}). This might be due to higher crop production associated with it (Kumar *et al*. 2015). The present study also reveals that Dry DSR has highest economic efficiency as highest net return is associated with it.

Effect on energetics of Rice establishment method

Both grain and straw yields were highest under Dry DSR method among three above mention rice establishment methods (Table 2). The energy equivalent for all inputs and outputs per unit (MJ/ha^{-1}) for rice production in Table 4, and the values of energy use efficiency, specific energy, energy Profitability and Net energy are given in Table 5.

Table 2: Yield, quality of rice as affected by various crop establishment methods

Rice establishment methods	Length of panicle(cm)	No of tillers/ m^2	No of grains/ panicle	Test wt. (g)	Grain yield	Straw yield	HI
MT	19	245	243	25.03	42.37	52.45	0.44
Dry DSR	23.36	254	264	26.30	48.45	56.57	0.50
Wet DSR	18.67	230	213	24.23	35.63	47.81	0.23
S. EM ±	0.79	2.16	1.374	0.41	1.69	0.54	0.014
CD (0.05)	2.74	7.4	4.75	1.45	5.86	1.88	0.074

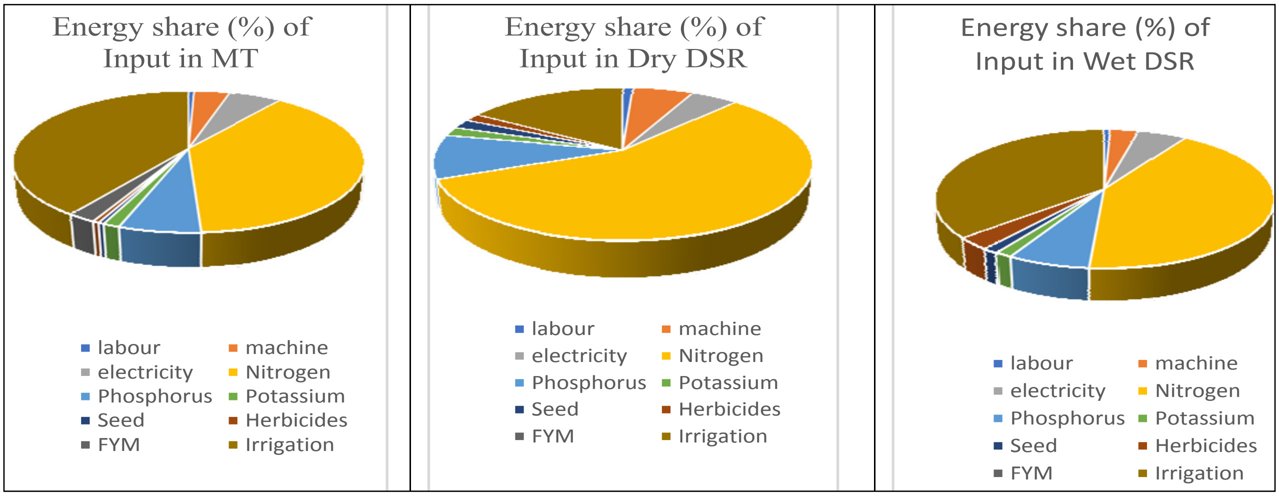

Fig. 1: Energy share (%) of Inputs under different rice establishment techniques

Table 3: Economics of rice (*Oryza sativa*) as affected by various crop establishment

Rice establishment technique	Gross return/ ha (₹)	Cost of cultivation/ ha (₹)	Net return/ ha (₹)	B:C ratio	Crop productivity (kg ha^{-1} day^{-1})	Economic efficiency (₹ ha^{-1} day^{-1})
MT	98,254	45,135	53,119	2.17	0.28	354.12
Dry DSR	110,940	39,226	71,714	3.21	0.32	509.26
Wet DSR	84,481	42,450	47,931	1.9	0.23	319.20

Table 4: Energy input and output of various rice establishment methods

Energy Input	MT		Dry DSR		Wet DSR		Energy Equivalence
	Input	EQ (MJ ha^{-1})	Input	EQ(MJ ha^{-1})	Input	EQ(MJ ha^{-1})	(EQ) (MJ $unit^{-1}$)
Labour	65	127.4	68	133.28	60	117.6	1.96
Machinery	12.8	802.56	12.5	783.75	8.5	532.95	62.7
Electricity	100	1191	50	595.5	75	893.25	11.91
Fertilizer							
N	132	7999.2	120	7272	120	7272	60.6
P_2O_5	117.26	1301.586	107.6	1194.36	107.6	1194.36	11.1
K_2O	39.96	267.732	36	241.2	36	241.2	6.7
Seed	25	90	70	252	60	216	3.6
Herbicide	1	102	2	204	5	510	102
Fym	1500	450		0		0	0.3
Irrigation Water	8143	8305.86	2035.75	2076.465	6107.25	6229.395	1.02
Total Energy Input		20637		12752		17206	
Energy Output							
Grain	4237	62283.9	4845	71221.5	3563	52376.1	14.7
Straw	5245	65562.5	5715	71437.5	4782	59775	12.5
Total Energy Output		127846		142659		112151	

Table 5: Energetics of rice (*Oryza sativa*) as affected by various crop establishment

Sl. No	Energy Indices	MT	Dry DSR	Wet DSR
1	Energy use efficiency	6.19	11.19	6.52
2	Energy Productivity (kg MJ^{-1})	0.21	0.38	0.21
3	Net Energy	107209.00	129907.00	94945.00
4	Specific Energy (MJ Kg^{-1})	4.87	2.63	4.83

Dry DSR had the highest energy output (142659 MJ ha^{-1}) followed by MT and lowest with Wet DSR. The reason behind is that it has highest grain yield and plant biomass compared with the other methods. Similar result was found by Singh and Hensel, (2012). MT had the highest energy input (20637 MJ ha^{-1}) followed by Wet DSR and lowest with Dry DSR. This is due to more inter-cultural operations are required along with higher no of labour, fuel cost etc. similar result was obtained by Kumar *et al*. (2021). The result revealed, the direct seeding approach had a lower energy input than the transplanting system, which led to a greater energy ratio. As data presented in the Table 5 revealed that highest Energy use efficiency (EUE), Energy productivity (EP) and Net energy was recorded highest with Dry DSR followed by wet DSR and MT, respectively and Reverse trend was found with the Specific energy (SE).Similar result was reported by Basavalingaiah *et al*. (2020). Data obtained for the sustainability assessment indices viz. EUE, EP and SE only Dry DSR is found sustainable practice out of three practices (Singh *et al*. 2016; Manoj *et al*. 2022 and Ghosh *et al*. 2021) and also suggested that it will improve rice production's energy efficiency and sustainability (Eskandari *et al*. 2015). Similar result was found by Mandal *et al*. (2015). Fertilizer is the key contributor during enumeration of energy calculation. It was observed that nitrogen fertilizer has highest energy contributor in the dry DSR method thus there were some kinds of substitution may take place with the energy smart nitrogen input viz. organic manures, biofertilizers, green manuring and at least one legume crop in crop rotation which help to reduce in total energy input for the same practice of for making it more sustainable. While in Manual transplanting, irrigation as the main energy contributing input followed by nitrogenous fertilizer Fig. 1.

CONCLUSION

The study on effect of different rice establishment techniques on rice crop indicated its usefulness. Based on the results obtained, it can be concluded that Dry DSR method is a better establishment method of rice because it produces more yield and gross monetary economic return than other methods and higher energy use efficiency.

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