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Full Research Article

Studies on Yield, Economics and Energetics of Rice (*Oryza sativa* L.) in Relation to Crop Establishment Methods and Nutrient Management Practices

Tushar Ranjan Mohanty[1*], Swapan Kumar Maity[2], Pravat Kumar Roul[3] and Kishore Chandra Sahoo[1]

[1]Regional Research and Technology Transfer Station, Orissa University of Agriculture & Technology, Keonjhar, Odisha (758 002), India
[2]Institute of Agriculture, Visva-Bharati University, Sriniketan, West Bengal (731 236), India
[3]Directorate of Agro-polytechnique, Orissa University of Agriculture & Technology, Bhubaneswar, Odisha (751 003), India

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Correspondence to

*E-mail: tusharranjan70@gmail.com

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Abstract

Field experiments were conducted during wet seasons of 2009 and 2010 to evaluate three rice crop establishment methods viz. system of rice intensification (SRI), drum seeding (DS) and conventional transplanting (CT) under three nutrient management practices viz. RDF (80:40:40 N: P_2O_5: K_2O kg ha^{-1}) through inorganic fertilizers, integrated nutrient management (INM) i.e. 50% of RDF through inorganic fertilizers+50% of R.D.F. through organic sources (based on nitrogen requirement) and organic management (OM) i.e. 100% of R.D.F. through organic sources (based on nitrogen requirement). SRI registered significantly higher leaf area index, dry matter accummulation, root dry weight and root volume over DS and CT except plant height for CT; further18 and 26% higher grain yield than CT and DS, respectively. The crop supplied with INM recorded the highest grain yield (6435 kg ha^{-1}) which was higher by 11.9 and 19.2% over RDF and OM, respectively. The highest gross return (₹ 77925 ha^{-1}), net return (₹ 43033 ha^{-1}) and return ₹ (2.28) were obtained from SRI. The energy output, energy productivity and the energy ratio were the highest with SRI whereas the CT and DS recorded statistically comparable values of energy indices. SRI with INM recorded the highest productivity (7299 kg ha^{-1}), gross return (₹ 85216 ha^{-1}), net return of (₹ 50274 ha^{-1}) and energy productivity (644.2 kg^{-1} MJ×10^3 ha^{-1}).

1. Introduction

Rice (*Oryza sativa* L.) is one important cereal crop which plays a key role in food security. More than 90% of total rice production in the world is consumed in Asian countries, where it is a staple food for a majority of the population (Mohanty, 2013). During 2012-13, India has recorded production of rice to the tune of 104.4 million tonnes (Directorate of Economics & Statistics, GOI, 2013); but considering the present growth rate of population as well as per capita income, the demand for rice has been projected as 156 million tonnes by 2030 (ICAR, 2010). Though eastern India occupies 61.3% of the rice area of the country (27 million ha), it contributes only 48% of the total rice production and it has much lower growth rate of rice yield compared to other regions of the country (Mahapatra, 2013).

Method of stand establishment influences the performance of rice through its effect on growth and development. Although, transplanting has been reported to be the best establishment method (Jana et al., 1981 and Singh et al., 1997) but due to high water and labour requirement, some alternatives like dry and wet direct seeding are being explored to ensure optimum plant population at a lower cost. Direct seeding of sprouted seeds on to puddled soil (wet seeding) by drum seeder holds special significance in the present day production systems by saving time, labour, energy and increasing profitability (Subbaiah and Balsubramanian, 2000). It is estimated that about 3000-5000 litres of water is required to produce 1 kg of rice by conventional transplanting method of rice cultivation (Rao et al., 2013). Development and adoption of alternative rice production technologies to save water need to be emphasized in the context of water scarcity. The recently developed System of Rice Intensification (SRI) method which decreases the use of inputs such as water and labour, is reported to have 20-30% higher or even more grain yield compared to conventional method of cultivation in India (DRR, 2007 and Mitra et al., 2013). Adequate plant nutrients supply holds the key for improving the food grain production and sustaining soil health. Integrated use of organic manures and chemical fertilizers has advantages over use of only organic manures or chemical fertilizers (Kumar et al., 2009) by not only sustaining agricultural productivity and soil health but also in substituting a part of fertilizer requirement by organics. Rice cultivation requires many energy consuming operations such as tillage, transplanting, irrigation, application of fertilizers, agro-chemicals for plant protection, harvesting, transportation etc. In order to sustain agricultural production, effective energy use is required, since it provides ultimate financial saving, preservation of fossil resources and reduction of environment distortion (Demircan et al., 2006). In the present era of energy crisis, for formulating any policy on energy use and conservation, it is imperative to examine the pattern of energy consumption for agricultural production especially rice. Keeping this in view, a field experiment was conducted at the Instructional farm of Krishi Vigyan Kendra, Mayurbhanj, Shamakhunta, Odisha to evaluate the yield, economics and energetics of different rice crop establishment methods under various nutrient management practices.

2. Materials and Methods

A field experiment was conducted at the Instructional farm of Krishi Vigyan Kendra, Shyamakhunta, Mayurbhanj (21^o 56' N, 86^o 46' E and 50 m above mean sea level) under North Central Plateau Agro-climatic Zone of Odisha during the wet seasons of 2009 and 2010. The experimental soil was sandy clay loam in texture having pH 5.63, organic carbon 0.46% available N - 221 kg ha^{-1}, available P - 10.4 kg ha^{-1} and available K - 139.3 kg ha^{-1}. The experimental design was split-plot consisted of combinations of three establishment methods viz., system of rice intensification (SRI), direct sowing of sprouted seeds under puddled conditions by drum-seeder (DS) and conventional transplanting (CT) as main plot and three nutrient combinations viz. recommended dose of fertilizer i.e. 80 kg N, 40 kg P_2O_5 and 40 kg K_2O ha^{-1} (RDF), integrated nutrient management (INM) i.e.50% of R.D.F. through inorganic fertilizers+50% of R.D.F. through organic sources (based on nitrogen requirement) and organic management (OM) i.e. 100% of R.D.F. through organic sources (based on nitrogen requirement). The organic sources comprised of 50% nitrogen requirement through FYM, 25% through vermicompost and remaining 25% through neem oil cakes. The N content of FYM, neem oil cake and vermicompost used were 0.48%, 3.89% and 1.24% during 2009 and 0.48%, 3.84% and 1.14% during 2010, respectively. The P_2O_5 content was 0.24%, 0.88% and 0.41% during 2009 and 0.26%, 0.84% and 0.48% during 2010 for FYM, neem oilcake and vermicompost, respectively. Similarly the K_2O content was 0.45%, 1.02% and 0.60% during 2009 and 0.47, 0.98% and 0.58% during 2010 for FYM, neem oil cake and vermicompost respectively.

Twenty five-day old rice Pratikshya seedlings (two-three/hill) were transplanted at 20×15 cm^2 spacing in CT method and 12-day old were transplanted at 25×25 cm^2 spacing in SRI method (one seedling/hill) while sprouted seeds were sown by using a four-row paddy drum seeder with rows of 20 cm apart. Water levels of 5 cm were maintained in CT and DS methods while soil moisture saturation was maintained in SRI method. One-fourth of nitrogen and full dose of P and K were applied as basal and remaining nitrogen was top dressed twice *i.e.* half at active tillering stage and one-fourth at panicle initiation stage for all the treatments. The organic manures were incorporated immediately after layout of the experiment as per the respective treatments. Growth and yield parameters were recorded as per standard procedures. The cost of cultivation, gross return, net return (gross return – cost of cultivation) and return re^{-1} invested (gross return/cost of cultivation) were calculated on the basis of prevailing market price of different inputs and outputs. Energy input was estimated in Mega Joule (MJ) ha^{-1} with reference to the standard values prescribed by Mittal et al. (1985). The standard energy coefficients for seed and straw were multiplied with their respective yields and summed up to obtain the energy output. Based on the energy equivalents of inputs and output, the energy indices such as energy ratio (energy output/energy input) and energy productivity (grain yield/energy input) were calculated as per Rafiee et al., 2010.

3. Results and Discussion

3.1. Growth attributes

Plant height, leaf area index and dry matter accumulation was significantly higher under SRI method when compared with DS and CT (Table 1). The tallest plants under SRI, though it was comparable with CT, might be due to optimum plant population and geometry which led to availability of more resources to plants. The increased LAI in SRI was due to open plant structure giving more coverage to the ground area. Further, the lower angle of inclination of leaves in case of SRI from horizontal results in more spread than CT (Thakur et al., 2011). Among the nutrient management practices, INM recorded the highest plant height, numbers of tillers m^{-2}, LAI and dry matter accumulations and the plants supplied with sole organics recorded the lowest values. This might be due to variation in respect of composition, C:N ratio, mineralization pattern etc. of different treatments imposed (Bhadoria and Prakash, 2003).

3.2. Root studies

Results (Table 1) revealed that SRI recorded the highest root dry weight and root volume which were significantly more than those of CT and DS. The younger seedlings in SRI when carefully transplanted by keeping the roots straight (assuring that the roots do not assume 'j' shape) might have encouraged vigorous and deeper root system. Further, the provision of wider spacing between plants in SRI (fewer plants per unit area), alternate drying and wetting of soil and loosening of soil by running of cono weeder to control weeds might have helped rice seedlings to develop profuse root growth. Barisson (2002) reported that because of alternate drying and wetting of soil, the SRI plants were capable of developing greater root penetration in comparison to traditionally grown plants. INM treated plots produced significantly higher root dry weight and root volume as compared to RDF and organically manured plots. This might be due to increase in use efficiency of nutrients particularly nitrogen due to its slow release from the organic source and reductions of nitrogen loss due to blending effect of organic manures on inorganic sources which further helped the prolonged availability of N to match with the absorption pattern of rice plants (Kumari et al., 2010). Besides, the FYM improves the physical properties of soil especially the structure, water holding capacity, porosity and various enzymatic activities that enhance root development and crop growth (Menete et al., 2008).

3.3. Yield attributes

The rice crop establishment methods under study exerted significant influence on the yield attributes of rice (Table 2). From the present experiment, it was found that all the crop establishment methods were comparable to each other in recording number of panicles m^{-2}. However, with respect to number of total spikelets $panicle^{-1}$ and test weight, SRI recorded significantly highest values. The sterility% was also the least with SRI. The other two treatments i.e. CT and DS recorded statistically similar values of the above yield attributes. Numerically more number of panicles m^{-2} in DS and CT in closer spacing might be the cause for lower number of filled spikelets $panicle^{-1}$ due to more competition for all resources, since; sink is divided between productive tillers and grains per panicle (Bommayasamy et al., 2010). The plants receiving integrated nutrition (INM) recorded the highest number of panicles m^{-2} (258.3 and 276.9 in 2009 and 2010, respectively) and the minimum number of sterile grains whereas the sterility % was the highest with the crop receiving only RDF (Table 1). Further, it was found that the production of spikelets $panicle^{-1}$ and 1000- grain weight did not differ among nutrient management practices of rice.

3.4. Yield

System of rice intensification (SRI) produced the highest grain yields of 6.3 and 7.0 t ha^{-1} in 2009 and 2010, respectively, (Table 2) which were significantly higher than those obtained with conventional method of transplanting i.e. CT (5.4 and 5.9 t ha^{-1} in 2009 and 2010, respectively) and DS (5080 and 5499 kg ha^{-1} in 2009 and 2010, respectively). The latter two treatments produced comparable grain yields during both the years. These findings are in conformity with earlier reports by Geethalaxmi et al. (2011) and Thakur et al. (2011). The roots of rice plants have least competition under wider spacing so that growth is stimulated by sun light and more space for canopy expansion increases the yield attributes and yield in

Table 1: Growth attributes, root dry weight and root volume of rice as influenced by establishment methods and nutrient management practices

Treatments	Plant height (cm)		Tillers m^{-2}		Leaf area index (105 DANS)		Dry matter accumulation (g m^{-2})		Root dry weight (g $hill^{-1}$)		Root volume (cc $hill^{-1}$)	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Crop establishment												
SRI*	125.9	126.8	234	246	4.51	4.67	1203.25	1245.10	24.16	26.85	59.89	66.62
DS	115.1	115.0	247	264	3.84	3.95	1066.51	1101.97	9.43	10.47	23.55	25.76
CT	119.7	120.7	261	280	4.05	4.17	1088.16	1133.03	10.24	11.35	25.43	28.37
CD (p=0.05)	7.3	8.1	NS	NS	0.41	0.39	83.23	106.07	1.21	1.24	3.06	3.25
Nutrient management												
RDF*	121.9	122.5	248	268	3.95	4.10	1110.03	1156.56	14.22	15.80	35.27	39.12
OM	116.1	116.3	225	237	3.95	4.07	1061.95	1094.68	14.01	15.58	34.57	38.74
INM	122.7	123.8	268	284	4.49	4.62	1185.94	1228.86	15.60	17.28	39.04	42.88
CD (p=0.05)	5.6	5.8	28	22	0.24	0.25	44.48	33.46	0.735	0.831	2.306	2.529

*SRI: System of rice intensification; DS: Drum seeding; CT: Conventional transplanting; *RDF: 80 kg N, 40 kg P_2O_5 and 40 kg K_2O ha^{-1}; OM: Organic management (50% N through FYM+25% N through vermicompost+25% N through neem oil cake); INM: Integrated nutrient management (½ RDF+½ OM)

Table 2: Yield attributes and yield of rice influenced by establishment methods and nutrient management practices

Treatments	Panicles m^{-2}		Spikelets $panicle^{-1}$		Sterility (%)		1000-grain weight (g)		Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Harvest Index (%)	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Crop establishment														
SRI*	227.0	239.5	199.3	200.5	13.76	14.00	23.37	24.48	6341	6969	7636	7486	45.30	48.17
DS	241.0	256.9	167.1	165.0	16.38	16.39	21.71	22.40	5080	5499	7344	7286	40.80	42.97
CT	252.9	271.8	169.4	165.9	15.70	15.58	21.80	22.44	5407	5876	7262	7272	42.54	44.56
CD (*p*=0.05)	NS	NS	22.2	18.9	1.868	1.661	1.18	1.57	766	897	NS	NS	0.84	2.99
Nutrient management														
RDF*	242.5	260.0	180.3	178.1	16.51	16.35	21.90	22.56	5506	5997	7387	7427	42.66	44.63
OM	220.1	231.3	173.4	174.6	14.19	14.51	22.70	23.43	5164	5635	7183	7065	41.57	44.12
INM	258.3	276.9	181.9	178.7	15.13	15.11	22.28	23.33	6158	6711	7672	7552	44.42	46.95
CD (*p*=0.05)	26.1	21.4	NS	NS	1.425	1.381	NS	NS	766	897	347	390	0.81	0.45

Table 2a: Interaction effect of crop establishment and nutrient management practices on grain yield (kg ha^{-1}) of rice

Crop establishment	Nutrient management					
	2009			2010		
	RDF*	OM	INM	RDF	OM	INM
SRI*	5793	6271	6960	6348	6920	7638
Drum seeding	5140	4594	5506	5577	4956	5964
Conventional transplanting	5585	4628	6009	6065	5030	6532
	CD (*p*=0.05)			CD (*p*=0.05)		
Main×Sub	903			1057		
Sub×Main	599			700		

SRI (Uphoff, 2001 and Rajesh and Thanunathan, 2003). The crop establishment methods differed for the harvest index parameter with SRI recording the highest harvest index followed by CT and DS. It implied better translocation of photosynthates from source to sink in case of SRI. INM practices produced the highest amount of grain yield (6.2 and 6.7 t ha^{-1}) which was significantly higher than that obtained with RDF (5.5 and 6.0 kg ha^{-1}) and OM (5.2 and 5.6 t ha^{-1}) in 2009 and 2010, respectively. Superior performance of rice crop with supply of 50% RDF+50% RDN through organic manures as exhibited in the present study corroborate the findings of Mandal and Adhikary (2005) and Mankotia (2007). Supply of the required nutrients through inorganic and organic sources comprising of FYM, vermicompost and neem oil cakes facilitated balanced nutrition of the crop, which enhanced grain yield. The straw yield and harvest index were also the highest with INM practices, though the straw yield was comparable with RDF. The increase in straw yield might be due to high N availability to the plants from an optimal combined source of inorganic and organic sources. Among the interactions the highest grain yield (7.0 and 7.6 t ha^{-1} in 2009 and 2010, respectively) was recorded with SRI method coupled with INM and the lowest grain yield (4.6 and 5.0 t ha^{-1} in 2009 and 2010, respectively) was obtained from the treatment DS supplied with sole organic nutrition only (Table 2a).

3.5. Economics

The study on the economic feasibility of different crop estab-

Table 3: Effect of crop establishment methods and nutrient management practices on economice of rice production

Treatments	Cost of cultivation (₹ ha^{-1})		Gross return(₹ ha^{-1})		Net return (₹ ha^{-1})		Return ₹ $^{-1}$ invested	
	2009	2010	2009	2010	2009	2010	2009	2010
Crop establishment								
SRI*	34708	35076	74595	81254	26312	30418	2.19	2.37
DS	34428	34796	60739	65214	29123	33818	1.82	1.94
CT	35088	35456	64210	69274	2263.1	2568.4	1.90	2.03
CD (*p*=0.05)	-	-	8883	10082	8883	10082	0.27	0.30
Nutrient management								
RDF*	27790	27790	65377	70705	37586	42915	2.35	2.54
OM	41601	42338	61520	66514	19919	24176	1.48	1.57
INM	34831	35199	72649	78523	37817	43323	2.09	2.23
CD (*p*=0.05)	-	-	4016	4634	4016	4634	0.12	0.14

Table 3a: Interaction effect of crop establishment and nutrient management practices on gross return (₹ ha^{-1}) of rice

Crop establishment	Nutrient management											
	Gross return						Net return					
	2009			2010			2009			2010		
	RDF*	OM	INM	RDF*	OM	INM	RDF*	OM	INM	RDF*	OM	INM
SRI*	68383	73749	81654	74454	80529	88778	40626	32181	46856	46697	38224	53612
Drum seeding	61384	55346	65488	66049	59273	70321	33907	14058	30970	38572	17248	35435
Conventional transplanting	66363	55464	70804	71612	59740	76469	38226	13516	35626	43475	17055	40923
	CD (p=0.05)			CD (p=0.05)			CD (p=0.05)			CD (p=0.05)		
Main×Sub	10474			11945			10474			11945		
Sub×Main	6956			8026			6956			8026		

Table 4: Effect of crop establishment and nutrient management practices on energetics of rice production

Treatments	Energy input (MJ×10^3)		Energy output (MJ×10^3)		Energy productivity (kg^{-1} MJ×10^3)		Energy ratio	
	2009	2010	2009	2010	2009	2010	2009	2010
Crop establishment								
SRI*	11.28	11.36	188.7	196.0	562.9	614.0	16.74	17.27
DS	11.63	11.71	166.5	171.9	436.6	469.2	14.31	14.67
CT	11.96	12.04	170.3	177.3	451.6	487.5	14.23	14.71
CD (p=0.05)	-	-	NS	NS	65.9	76.0	1.79	1.78
Nutrient management								
RDF*	11.88	11.88	173.3	181.0	463.8	505.1	14.59	15.24
OM	11.34	11.51	165.7	171.2	457.0	491.6	14.65	14.91
INM	11.64	11.72	186.4	193.1	530.2	573.9	16.05	16.50
CD (p=0.05)	-	-	9.4	10.4	29.7	34.5	0.81	0.88

Table 4a: Interaction effect of crop establishment and nutrient management practices on energy productivity (kg^{-1} MJ x 10^3) of rice

Crop establishment	Nutrient management					
	2009			2010		
	RDF*	OM	INM	RDF	OM	INM
SRI*	502.0	570.1	616.5	550.1	620.1	671.8
Drum seeding	432.3	404.7	472.6	469.0	430.2	508.4
Conventional transplanting	457.1	396.3	501.6	496.3	424.5	541.6
	CD (p=0.05)			CD (p=0.05)		
Main×Sub	77.6			89.7		
Sub×Main	51.4			59.7		

lishment methods in rice revealed that the gross returns, net returns and return ₹$^{-1}$ invested were the highest with SRI during both the years (Table 3). SRI could fetch 16.8 and 23.7% higher gross return, 36.7 and 51.7% higher net return and 16.3 and 21.3% higher return re^{-1} invested than conventional transplanting and drum seeding, respectively as per mean yield. This was mainly because of higher yields obtained in SRI as compared to the other two methods during both the years. The results corroborate earlier findings of Singh et al. (2008). Further, it was noticed that CT and DS returned at par values of all the above economic parameters which was reflective of their yields. The crop supplied with sole organics became costlier than that of INM practices and RDF mainly due to higher quantity as well as cost of bulky organic manures such as FYM, vermicompost and neem oil-cake. INM fetched increased gross returns by 11% and 18% over that of RDF and sole organics, respectively. Though the gross returns were the highest with INM; it fetched very similar net return to that of RDF due to high cost of cultivation of the former as stated earlier. The return re^{-1} invested for INM (2.09 and 2.23 in 2009 and 2010, respectively) was lower than RDF (2.35 and 2.54 in respective years). Rice cultivation with sole organics resulted in the lowest gross return, net return and return re^{-1} invested because of lower grain yield and higher cost of cultivation under this treatment as compared to other two nutrient management practices. Similar findings have been reported by Kumari and Reddy (2011).

Interaction studies revealed that SRI method with INM practices realised significantly the highest gross return followed by SRI with sole organics (Table 2a). The lowest gross return was obtained from DS supplied with OM. Further, SRI method of crop establishment with INM fetched significantly the highest net return and the lowest net return was obtained from CT with sole organic nutrition (Table 3a).

3.6. Energetics

The comparison of the crop establishment methods in the scale of energetics (Table 4) revealed that conventional transplanting used the maximum energy (11.96 and 12.04 MJ×10^3 in 2009 and 2010, respectively) followed by DS (11.63 and 11.71 MJ×10^3 in 2009 and 2010, respectively) and the least energy was expended by SRI method of cultivation (11.28 and 11.36 MJ×10^3 in respective years) for production of rice. Among nutrient management practices, use of sole organics became most energy efficient by expending the least energy and the maximum energy was spent by RDF followed by INM practices. Similar findings of higher energy input due to use of chemical fertilizers in rice have been reported by Khan et al. (2009). The data suggested that SRI recorded the maximum energy output being significantly higher than conventional transplanting and drum seeding; while the latter two treatments produced at par energy output. Among nutrient management practices, INM returned the highest energy output as compared to RDF and sole organics during both the years. The energy productivity and the energy ratio were also the highest with SRI during both the years. The other two rice establishment methods recorded statistically comparable values of energy indices. The result was obvious on account of higher grain and straw yield under SRI. The data revealed that application of INM recorded significantly the highest value of energy productivity and energy ratio which was significantly higher than RDF and sole organics. However, RDF and OM recorded comparable values of energy productivity and energy ratio (Table 3). This was due to lower use of energy inputs in OM as compared to RDF.

The interaction effect of crop establishment and nutrient management practices on energy productivity of rice showed that the highest energy productivity (616.5 and 671.8 kg^{-1} MJ×10^3 in 2009 and 2010, respectively) was obtained from SRI method of crop establishment with INM practices, which was at par with SRI method of crop establishment receiving organic nutrition (570.1 and 620.1 kg^{-1} MJ×10^3 in 2009 and 2010, respectively); but the combination was significantly higher than all other treatment combinations (Table 4a).

4. Conclusion

In terms of productivity, profitability and energy use, the establishment of rice by the system of rice intensification (SRI) technique in combination with integrated nutrient management (INM) approach was found to be superior to drum seeding and conventional transplanting among crop establishment methods and sole chemical fertilization and sole organic nutrition among nutrient management options.

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