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Evaluation of various rice (*Oryza sativa*) based crop sequences for enhanced productivity, profitability and energy efficiency in eastern plateau and hills zone of India

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ABSTRACT

A field experiment was conducted consecutively for four years (2004-05 to 2007-08) at Regional Research Station, Chiplima (Sambalpur), Odisha on sandy loam soil with pH 6.0 and organic carbon content of 0.56%. The available N, P and K were 212, 15.7 and 89 kg/ha respectively. The experiment was laid out in randomized block design involving 10 rice based crop sequences with three replications. Among various cropping sequences evaluated, rice (*Oryza sativa* L.)-frenchbean (*Phaseolus vulgaris*)-greengram (*Vigna radiata* L.) produced the highest rice equivalent yield (17.31 tonnes/ha/year), net return (₹ 39 899/ha), benefit: cost ratio (2.25) and monetary advantage (140.48 ₹/ha/day). This system was the most sustainable with sustainable yield index of 0.40 and sustainable value index of 0.84 with higher energy productivity (0.854 kg/MJ) and energy intensiveness (0.078 MJ/Re). However, the rice- groundnut-sesame system had highest land use efficiency of 87.14% whereas rice-radish-greengram registered the highest production efficiency (61.54 kg/ha/day). Rice- groundnut - greengram sequence was found to be the most efficient user of N (138.8 kg yield/ha N applied) whereas rice - groundnut - fallow used P (388.3 kg yield/ha N applied) and K (202.6 kg yield/ha N applied) more efficiently than that of other cropping sequences. The study further revealed that rice productivity could be enhanced by 19.1 and 17.7% due to inclusion of oilseeds and pulses, respectively than that of its monocropping..

Key words: Energy productivity, Equivalent yield, Monetary advantage, Nutrient use efficiency, Production efficiency, Rice based crop sequences, Sustainable Yield Index

Rice (*Oryza sativa* L.) is the staple food crop of 63 to 65 percent people of India. The crop at present is grown in 43 million hectares of land with production of 96.7 million tonnes. Its production has to be raised to 160 million tonnes by 2030 with a minimum annual growth rate of 2.35 percent (Venkatramani 2005). The spread and extent of rice based cropping systems across the country and more specially in Odisha state of Eastern India, is predominant. Rapid spread of rice-wheat in north and rice-rice systems in east parts of the country in the post-green revolution era has caused an eclipse on productivity and sustainability of the system (Rattan and Singh 1997). The main reason behind yield stagnation and declining soil productivity of the rice-rice system is attributed mainly to the monotony of the system as well as the over exhaustive nature of the cereal-cereal crop sequence and huge exploitation of soil resource base coupled with imbalanced use of inputs. Moreover, continuance of rice-rice system has also led to the development of several biotic and abiotic stresses (Ali *et al.* 2006). A diversified cropping pattern has been advocated and suggested by many workers in eastern part of the country (Samui *et al.* 2004). Odisha is not exceptional as rice-rice sequence occupies about 2.23 million hectare which is 36 percent of the total cropped area (6.16 mha) of the state. Earlier workers (Newaj and Yadav 1992, Satyasai and Viswanath 1996) have suggested substitution of *rabi* rice with that of vegetables and pulses to realize higher productivity and profitability by efficient utilization of labour force and other inputs used in crop production. Further, inclusion of high value and high volume crops like oilseeds, pulses and vegetables in the rice-based cropping systems may improve the economic condition of farmers especially small and marginal types owing to higher productivity and net returns per unit area and time. In view

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of this, it would be advantageous if a more profitable and economically viable sequence could be introduced in the zone under the prevalent rice-based cropping system for long-term productivity and profitability in a sustainable manner. In order to provide a viable option to the farmers of this region it becomes imperative to go for an extensive field study to evaluate production potential of various rice based cropping systems. Hence, the study on productivity, profitability and energy efficiency of rice based cropping systems was planned.

MATERIALS AND METHODS

A field experiment was carried out consecutively for four years (2004-05 to 2007-08) at Regional Research Station, Chiplima (Sambalpur) under Odisha University of Agriculture & Technology, Bhubaneswar.The experimental site was located in Eastern Plateau and Hills, i.e. zone-7 of the 15 agro-climatic zones of India having red and yellow to mixed red and black soil with mean annual rainfall- 1335 mm, mean maximum temperature- 39°C, mean minimum temperature- 16°C with 85% and 48% maximum and minimum relative humidity, respectively. The experiment was laid out in randomized block design involving 10 rice based crop sequences [rice (*Oryza sativa*)-groundnut (*Arachis hypogaea*) fallow, rice-mustard (*Brassica juncea*)-fallow, rice-groundnut-greengram (*Vigna radiata*), rice-groundnut-cowpea (*Vigna unguiculata*), rice-groundnut-sesame (*Sesamum indicum*), rice-mustard-greengram, rice – radish (*Raphanus sativus*) - cowpea, rice–radish-greengram, rice-French bean (*Phaseolus vulgaris*)-greengram and rice-maize (*Zea mays*)-cowpea] replicated thrice on sandy loam soil (80.44% sand, 13.96% clay and 5.6% silt). The soil of the experimental site was slightly acidic in reaction (pH 6.0) with medium in organic carbon content (0.56%), low in available N, (212 kg/ha) and K (89 kg/ha) and medium in available P (15.7 kg/ha). Before planting/sowing of experimental crops in different cop sequences, soil samples from 0-15 centimeter depth were collected by core sampler of 8 mm diameter from 5 plots in the field. The samples were pooled together and represented a homogenous sample drawn for determination of organic carbon (Walkley and Black method) available N ($KMnO_4$ method), 0.5 m sodium bicarbonate-extractable P and 1 N NH_4OAC- extractable K following Jackson (1973). This process was carried out before the start of the experiment and at the end of experiment after completion of four crop cycles in each of the annual cropping systems. The crops of rice, groundnut, mustard, greengram, cowpea, maize, radish, sesame and French bean were sown/ transplanted and harvested in July and November, November and March, November and February, March and May, March and May, November and February, November and January, March and June and November and February, respectively during all the four years of experimentation. The crops were raised using standard package of practices recommended for respective crops of the zone. The test varieties and fertilizer doses (kg N, P_2O_5 and K_2O/ha) of each crop used were Lalata/80:40:40 (rice), Aswini/120:60:60 (maize), SEB II/ 25:50:50 (cowpea), K 851/20:40:40 (greengram), DD Red/ 50:80:80 (frenchbean), Smruti/20:40:40 (groundnut), M 27 and Pusa bold/60:30:30 (mustard), S 14/60:30:30 (sesame) and Pusa Chetki/50:50:75 (radish). Data on yield was recorded from net plot size of 6.2 m × 5.0 m for rice, 6.0 m × 5.0 m for maize and 5.8 m × 5.0 m for cowpea, greengram, frenchbean, groundnut, mustard, sesame and radish.

Economic yields of component crops were converted into rice-equivalent yield (REY), taking into account the prevailing market prices of different crops in the cropping sequences. The above values were computed as per the following formula given by Verma and Modgal (1983).

$$\text{Rice-equivalent yield (REY) of a component crop} = \frac{\text{Yield of component crop} \times \text{market of a component crop}}{\text{Price of rice}} = a$$

Total REY = a + yield of rice in the particular system

Production-efficiency values in terms of kg/ha/day were worked out by total production by means of rice equivalent yield in a crop sequence divided by total duration of crop in that sequence. Land-use efficiency was obtained by taking total duration of crops in individual crop sequence divided by 365 days. The values of production efficiency and monetary advantage in terms of ₹/ha/day were calculated by net monetary returns of the sequence divided by total duration of the crop in that sequence (Tomar and Tiwari 1990).

Nutrient use efficiency was calculated using the formula as suggested by Moll *et al.*(1982) .

$$\text{Nutrient use efficiency} = \frac{\text{System productivity (REY Kg /ha)}}{\text{Total addition of fertilizer nutrient to the system (kg/ha)}}$$

The total energy input and output values were calculated as per the details (Tawnega *et al*. 1997). The sustainable yield index (SYI) and sustainable value index (SVI) were calculated using the formula given by Singh *et al*. (1990).

$$\text{Sustainable Yield Index} = \frac{\text{Mean yield - Standard deviation}}{\text{Maximum Yield}}$$

$$\text{Sustainable Value Index} = \frac{\text{Mean economic return - Standard deviation}}{\text{Maximum economic return}}$$

The data of each crop season were statistically analyzed separately. The homogeneity of error variance was tested using Bartlett's χ^2 test. As the error variance was homogeneous, pooled analysis was done according to Cochran and Cox (1957). Since the variation between the two seasons was not significant, the mean data of two crop seasons are presented here for discussion. Various treatments were compared under randomized block design. The critical difference (CD) was computed to determine statistically significant treatment differences.

$$CD = (\sqrt{2\ VEr^{-1}})t_{5\%}$$

where VE is the error variance, r is the number of replications; $t_{5\%}$ is the table of t at 5% level of significance at error degree of freedom.

RESULTS AND DISCUSSION

Rice equivalent yield of the system (REY)

Data pertaining to system productivity in terms of rice equivalent yield of different rice- based cropping sequences are presented in Table 1. It was observed that the cropping sequence of rice-french bean-greengram produced the highest REY of 17.31 tonnes/ha/year. It was significantly superior to rice- groundnut- fallow (13.51 tonnes/ha / year), rice- mustard-greengram (12.50 tonnes/ha/year) and rice-mustard-fallow (9.32 tonnes/ha/year). It was statistically at par with remaining cropping sequences evaluated in the experiment. The next cropping sequences in order were rice-groundnut-greengram and rice-groundnut-sesame, both of them having statistically significant over rice-mustard-fallow and rice-mustard-greengram. Francis (1989) opined that biological complexities present in different cropping systems and the inter play among them can alter and integrate the efficiency of the applied inputs which, in turn, enhances the crop productivity provided the appropriate crops are chosen. In this study rice-french bean-greengram appears to have synergistic effect on the system productivity that resulted in the highest REY among different rice based cropping sequences. Further, the legumes are known to increase the soil fertility status and reportedly to have a yield advantage to the tune of 30 to 35% than the system when only cereals are followed (Peoples and Craswell 1992). This might be the cause that the sequence rice-french bean-greengram produced the highest REY among the various sequences evaluated.

Data on year wise rice yield as influenced by last crop grown in the sequence, revealed that the sequences where oil seeds (groundnut, mustard and sesame) and pulses (cowpea and greengram) were taken as last crop produced an enhanced rice yield to the tune of 19.1 and 17.7%, respectively, over the base year yield of rice (Table 3). However, the sustainable yield index was more (0.882) in the sequences involving pulses compared to sustainable yield index involving oilseed (0.870). The legumes are known to offer special advantage with regards to the stability of the system as they not only improve but maintain the fertility status of the soil. The system wise data on SYI presented in Table 2 revealed that the cropping sequence of rice-french bean-greengram produced the highest SYI (0.86) followed by rice-groundnut-greengram (0.82) and rice-groundnut-sesame (0.81). The lowest SYI (0.40) was observed in the cropping sequence of rice-mustard- fallow. This also confirms the legume effects and the results corroborated with the findings of Ghosh (1987) who observed that inclusion of legume crop in rice based cropping sequence helped in stabilizing the crop yield by improving soil fertility in long run.

Economics

Data on net returns (Table 1) showed that rice-french bean-greengram cropping sequence was the most remunerative and recorded significantly the highest net returns (₹ 39 899/ha) along with highest benefit: cost ratio (2.25),

Table 1 Productivity and profitability of rice based cropping sequences (mean of 4 years, 2004-05 to 2007-08)

Cropping systems	Economic yield (tonnes/ha)				Rice Equivalent Yield of the system (tonnes/ ha/yr)	Cost of cultivation (Rs/ha/yr)	Net return (Rs/ha/yr)	Benefit cost ratio	Monetary advantage (Rs/ha /day)	Susta-inable value index
	Kharif		*Rabi*	Summer						
	Grain	Straw								
Rice-groundnut-fallow	5.96	7.42	2.36		13.51	30 500	28 116	1.92	117.15	0.55
Rice-mustard-fallow	6.09	7.66	0.98		9.32	23 000	17 772	1.77	78.63	0.29
Rice-groundnut-greengram	6.07	7.53	2.31	0.87	16.65	38 500	34 256	1.88	114.18	0.70
Rice-groundnut-cowpea	6.19	7.86	2.44	1.89	15.44	39 000	28 484	1.73	98.90	0.56
Rice-groundnut-sesame	6.13	7.60	2.39	0.65	16.46	38 500	33 382	1.86	105.00	0.68
Rice-mustard-greengram	6.23	7.74	0.82	0.83	12.50	31 000	24 101	1.77	84.26	0.45
Rice-radish-cowpea	6.05	7.88	14.16	2.64	15.45	34 500	31 369	1.90	124.97	0.63
Rice-radish- greengram	6.18	7.67	14.69	0.88	14.05	34 000	29 777	1.87	113.22	0.59
Rice-French bean-greengram	6.11	7.62	5.51	0.83	17..31	31 900	39 899	2.25	140.48	0.84
Rice-maize-cowpea	5.86	7.58	5.08	2.63	14.47	36 500	26 775	1.73	98.43	0.52
SEm(±)					0.792		3 484.22			
CD(P = 0.05)					3.350		10 383			

Cost of cultivation (₹/ha):Rice-15000, maize-13000, cowpea-8500, greengram-8000, mustard-8000, groundnut-15500, french bean-8900, sesame-8000, radish-11000.

Table 2 Sustainability and efficiency of rice based cropping systems (mean of 4 years, 2004-05 to 2007-08)

Cropping systems	Land use efficiency (%)	Production efficiency (kg/ha/day)	Sustainable yield index	Nutrient use efficiency (kg REY/ha N applied)		
				N	P	K
Rice-groundnut-fallow	65.75	56.27	0.64	135.1	388.3	202.6
Rice-mustard-fallow	61.91	41.23	0.40	66.6	306.2	159.7
Rice-groundnut-greengram	82.19	55.51	0.82	138.8	319.2	166.5
Rice-groundnut-cowpea	78.90	53.61	0.75	123.5	273.1	142.5
Rice-groundnut-sesame	87.12	51.77	0.81	102.9	344.3	179.6
Rice-mustard-greengram	78.35	43.69	0.58	78.1	261.3	136.3
Rice-radish-cowpea	68.76	61.54	0.75	99.7	253.8	112.3
Rice-radish-greengram	72.05	53.44	0.67	93.7	248.7	108.8
Rice-French bean-greengram	77.80	60.93	0.86	115.4	248.7	129.8
Rice-maize-cowpea	74.52	53.20	0.69	64.3	221.9	115.8

monetary advantage (₹ 140.48/ha/day) and sustainable value index (0.84). Further, the net return from rice-french bean-greengram was statistically on par with rice-groundnut-greengram (₹ 34 256/ha), rice-groundnut-sesame (₹ 33 342/ha) and rice-radish-cowpea (₹ 31 369/ha). French bean used in the system was sold as green pods that fetched high rate and ultimately contributed to higher net returns of the system. Further, Kaumpawat (2001) also reported the benefit of pulses and oilseeds towards the net return of cropping systems.

Efficiency indices

The efficiency of different rice based cropping sequences was assessed through land use efficiency (LUE), production efficiency (PE) and nutrient use efficiency (NUE). The data are presented in Table 4. It was observed that the cropping sequence of rice-groundnut-sesame has the highest LUE (87.12 %) followed by rice-groundnut-greengram (82.19 %). Involving two crops in either of the sequence, i.e. rice-groundnut-fallow and rice-mustard-fallow recorded the lowest LUE of 65.75 and 75.91 %, respectively. Rice being the common *kharif* crop in all the sequences, the LUE was mostly governed by the duration of *rabi* and summer crops. Almost similar LUE was also reported by Gangwar *et al.* (2003) where groundnut was included during winter.

From the data on production efficiency (PE) (Table 2) it was observed that rice-radish-greengram crop sequence recorded the highest production efficiency of 61.54 kg/ha/day closely followed by rice-french bean-greengram with a production efficiency of 60.93 kg/ha/day. The lowest PE of 41.23 and 43.69 kg/ha/day were observed in rice-mustard-fallow and rice-mustard-greengram systems, respectively. Cowpea, radish and French bean being vegetable crops, and when included in the sequence, registered higher productivity than the other cropping sequences. The lowest PE in rice-mustard-fallow has also been reported by Samui *et al.* (2004). The low productivity of the system might be due to low yield from mustard.

Nutrient use efficiency

Nitrogen use efficiency was the highest (138.8) in the

Table 3 Year wise mean (over sequences) rice yield (tonnes/ha) as influenced by last crop grown in the system

Last crop of the system	Cropping systems	Yield of rice(tonnes/ha)				Mean (Excluding base year) year	% increase in rice yield over base (SYI)	Sustainable yield index
		Base year 2004-05	2005-06	2006-07	2007-08			
Groundnut	Rice- groundnut-fallow	5.41	6.47	5.74	6.23	6.15	13.67	0.826
Mustard	Rice-mustard-fallow	5.49	6.59	6.20	6.12	6.30	14.75	0.878
Greengram	Rice- groundnut-greengram Rice-radish-greengram Rice- French bean-greengram Rice-mustard-greengram	5.24	6.63	6.50	6.23	6.45	23.09	0.900
Cowpea	Rice-radish-cowpea Rice-maize-cowpea Rice-groundnut-cowpea	5.53	6.25	6.27	6.10	6.21	12.30	0.864
Sesame	Rice-groundnut-sesame	5.04	6.62	6.51	6.37	6.50	28.97	0.908

Table 4 Energy Use Efficiency of different rice -based crop sequences

Cropping systems	Total energy input (MJ/ha)	Total energy output (MJ/ha)	Energy output efficiency (MJ/ha/day)	Energy productivity (kg/MJ)	Energy intensiveness (MJ/Re)
Rice-groundnut-fallow	17735	1961	8.17	0.762	0.064
Rice-mustard-fallow	17597	1353	5.98	0.530	0.058
Rice-groundnut-greengram	20573	2418	8.06	0.810	0.062
Rice-groundnut-cowpea	21407	2242	7.78	0.721	0.057
Rice-groundnut-sesame	23059	2391	7.51	0.715	0.062
Rice-mustard-greengram	20534	1814	6.34	0.609	0.058
Rice-radish-cowpea	21022	2243	8.93	0.735	0.065
Rice-radish-greengram	20188	2041	7.75	0.696	0.060
Rice-French bean-greengram	20272	2513	8.84	0.854	0.078
Rice-maize-cowpea	25743	2101	7.72	0.562	0.057

sequence rice-groundnut-greengram closely followed by rice-groundnut-fallow (135.1). It was the lowest in rice-maize-cowpea (64.3) and rice-mustard-fallow (66.6). The cropping sequence of rice-groundnut-fallow also recorded the highest P and K use efficiency of 388.3 and 202.6, respectively. Since the nutrient use efficiency is the ratio of system productivity to the total amount of fertilizer nutrient added, the highest nitrogen use efficiency in rice based cropping sequences involving groundnut and greengram produced proportionately higher system productivity with comparatively less addition of fertilizer nutrient. The results are in conformity with that of Bastia (2005) who also reported a higher nitrogen use efficiency of 115.7 followed by 106.9 in rice-groundnut-greengram and rice-groundnut-fallow, respectively. Similarly, the highest P and K use efficiency observed with rice-groundnut-fallow was also in agreement with the findings of Bastia (2005).

Energy use

The cropping sequence of rice-french bean-greengram emerged as the most efficient in energy use with highest energy productivity of 0.854 kg/MJ and energy intensiveness of 0.078 MJ/Rs (Table 4). Moreover, it also recorded the highest energy output efficiency of 8.84 MJ/ha/day though it was marginally less compared to the sequence of rice-radish-cowpea that recorded energy output efficiency of 8.93 MJ/ha/day. Since, energy productivity is the ratio of rice equivalent yield (kg/ha) to total energy input (MJ/ha), the corresponding values relating to the system will determine the energy productivity. In this experiment the sequence of rice-french bean-greengram recorded the highest REY that might have also contributed towards higher energy indices. Bastia (2005) too has reported higher energy indices utilization when greengram was included in the system.

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