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Diversification of rice (*Oryza sativa*)–based cropping systems for higher productivity, resource-use efficiency and economics

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ABSTRACT

A field experiment was conducted at Bhubaneshwar under irrigated medium land condition from 2002 to 2005 to evaluate the production potential, resource-use efficiency and economics of 10 cropping systems based on rice (*Oryza sativa* L.). Rice-groundnut-greengram system resulted in maximum number of effective tillers in rice (362/m^2), longest panicles (23.0 cm) and maximum number of grains/panicle (112). However, system productivity of rice-maize-cowpea was the maximum (15.98 t/ha) which was on a par with that of rice-maize-greengram (15.30 t/ha). Rice-sunflower-greengram registered the minimum rice equivalent yield (REY) of 11.66 t/ha among the three-crop sequences and rice-*toria*-fallow (8.36 t/ha) among the two-crop sequences. Sustainable yield index (0.85), production efficiency (50.73 kg REY/ha/day), employment generation (550 man days/ha) and net returns (Rs 40,415/ha) were maximum in rice-maize-cowpea followed by rice-maize-greengram system. Inclusion of two legumes improved the sustainability and that of groundnut increased the land-use efficiency of the systems. Returns per Re invested were the highest for rice-fieldpea-sesame system (Rs 1.94), which were on a par with that of rice-maize-cowpea and rice-maize-greengram systems (Rs 1.85 and 1.83 respectively). Cropping systems having maize as a component crop expressed higher production efficiency (Rs 124 to 128/ha/day), water-use efficiency (Rs 203 to 213/ha-cm) and energy intensiveness (11.23 to 12.56 MJ/Re) in economic terms. Rice-maize-cowpea was the most productive, sustainable, resource-use efficient and remunerative cropping system.

Key words: Economics, Resource-use efficiency, Rice-based cropping system, System productivity

Cropping systems based on rice (*Oryza sativa* L.) are prevalent in the eastern part of India, which covers 43% of rice area of the country. Rice-based systems are intimately connected with development of water resources. In the era of shrinking resource base of land, water and energy, resource-use efficiency is an important aspect for considering the suitability of a cropping system (Yadav, 2002). Diversification and intensification of rice-based systems to increase productivity per unit resource is very pertinent. As rice is synonymous with life of the people of eastern India, any modification to the existing system with a tendency to decline the productivity of rice crop will neither be sustainable nor acceptable to the farming community. Hence, choice of the component crops needs to be suitably manoeuvered to harvest the synergism among them towards efficient utilization of resource base and to increase overall productivity (Anderson, 2005). Keeping this in view, the present investigation was carried out to select productive, resource use efficient and remunerative rice-based cropping systems for irrigated ecosystems.

MATERIALS AND METHODS

A field experiment was conducted at Central Research Station of Orissa University of Agriculture and Technology, Bhubaneshwar (20° 15' N and 85° 52' E) under irrigated medium-land condition during 2002-2005 on the same site and lay-out. A randomized complete block design was followed with 10 treatments and three replications. The soil was sandy loam with pH 6.7, organic C 9,600 mg/kg and the available N, P and K were respectively 106.0, 7.8 and 44.5 mg/kg soil. The treatments were 10 rice-based cropping systems, viz. T_1, rice-*toria*-fallow; T_2, rice-*toria*-greengram; T_3, rice-groundnut-fallow; T_4, rice-groundnut-greengram; T_5, rice-groundnut-cowpea; T_6, rice-maize-greengram; T_7 rice-maize-cowpea; T_8, rice-sunflower-greengram; T_9, rice-rajmash-sesame; and T_{10}, rice-fieldpea-sesame. The varieties of different crops used were: rice 'Lalat' (125-130 days), *toria* 'Parbati' (75-80 days), groundnut 'Smruti' (115-120 days), maize 'Hyb Trupti' (90-95 days), sunflower 'Hyb PAC 36' (90-95 days), rajmash 'Chitra' (85-90 days),

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fieldpea 'Azad' (85-90 days), greengram 'Samrat' (55-65 days), cowpea 'IR 8' (60-70 days) and sesame 'Uma' (65-75 days). Rainy season (*kharif*) rice was sown in the nursery in the last week of June, and after its harvest in the last week of October the subsequent crops were sown as per the optimum sowing time recommended for the region. In winter (*rabi*) season, maize crop was harvested for cob purpose, fieldpea for vegetable in three phases, and the rest of the crops as grains. In summer season cowpea was harvested in three plucking for vegetable purpose. All the crops were grown successfully with recommended packages of practices. The crops were irrigated optimally as and when required and irrigation water was measured through a 7.5 cm Parshal flume.

Economic yields of the component crops were converted to rice-equivalent yield (REY), taking into account the prevailing market price (Rs/kg) of rice (5.50), *toria* (16.00), groundnut (14.00), sunflower (12.50), rajmash (15.00), field pea (6.00), greengram (13.70), cowpea (5.00) and sesame (14.85); and maize (Rs 0.60/cob). System productivity was calculated by adding the rice-equivalent yield of the component crops. Sustainable yield index (SYI) was calculated as per Singh *et al.* (1990). Total field duration of a cropping system expressed in percentage of 365 days was taken as the land use efficiency (LUE) of the system. Production efficiency was expressed as the ratio of system productivity in kg REY/ha to total duration of the system in days. Water-use efficiency (WUE) was computed by dividing system productivity with water requirement of the system and was expressed as kg REY/ha-cm of water uses. Net returns were the difference between the gross returns of a system and total cost of cultivation of the component crops. Returns per Re invested of a system were expressed as net returns (Rs) per Re spent. Production efficiency and water-use efficiency in economic terms were calculated by taking net returns instead of REY. Energy intensiveness was expressed as energy output of a system in MJ per Re invested.

RESULTS AND DISCUSSION

Growth and yield of rice

The cropping systems did not influence the growth parameters like plant height at harvest and leaf-area index at 60 days after transplanting (DAT) of rice (Table 1). On the contrary, the cropping systems expressed significant effect on yield and yield attributes of rice such as effective tillers/m^2, panicle length and number of grains/panicle (Table 1). Pooled data indicated that rice-groundnut-greengram system resulted in maximum number of effective tillers in rice (362/m^2), longest panicles (23.0 cm) and maximum number of grains/panicle (112), but the traits were similar to those of rice-groundnut-cowpea, rice-maize-greengram, rice-maize-cowpea and rice-sunflower-greengram systems. All these systems also produced higher grain and straw yields of rice, which may be attributed to the beneficial effect of legumes grown in summer season (Quayyam and Maniruzzaman, 1996). Rice-*toria*-fallow system produced minimum rice yield of 4.08 t/ha, which was on a par with that of rice-groundnut-fallow and rice-rajmash-sesame systems. Soil is a dynamic medium for plant growth. Keeping the land fallow in summer season improves compaction, reduces pore space and aeration, and increases the temperature of the soil profile. This might have deteriorated the biological activities of soil and ultimately reduced the yield of rice in the succeeding season. Rajmash, being a shy nodulating crop, might not have expressed the desired advantage of legumes in the systems and the crop performed dismally low in sequence with rice and sesame over the years.

Productivity of component crops

Yield of the component crops under the present inves-

Table 1. Effect of rice-based cropping systems on growth, yield attributes and yield of rice (pooled data of 3 years)

Cropping system	Plant height at harvest (cm)	Leaf-area index at 60 DAT	Effective tillers/m^2	Panicle length (cm)	Grains/ panicle	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)
Rice-*toria*-fallow	96.10	4.61	324	21.0	97	22.1	4.08	6.41	38.9
Rice-*toria*-greengram	97.18	4.53	335	21.6	104	22.3	4.43	6.68	39.9
Rice-groundnut-fallow	94.97	4.64	329	21.0	96	22.6	4.26	6.67	39.0
Rice-groundnut-greengram	98.02	4.82	362	23.0	112	22.8	4.84	7.35	39.7
Rice-groundnut-cowpea	96.52	4.75	350	23.0	109	22.7	4.63	7.10	39.5
Rice-maize-greengram	97.33	4.68	353	23.0	111	22.6	4.70	7.07	39.8
Rice-maize-cowpea	97.14	4.70	354	22.7	112	22.7	4.73	7.09	40.0
Rice-sunflower-greengram	96.86	4.74	358	23.0	110	22.7	4.83	7.31	39.7
Rice-rajmash-sesame	96.88	4.69	332	21.1	101	22.1	4.29	6.63	39.3
Rice-field pea-sesame	96.55	4.71	334	21.0	103	22.6	4.41	6.73	39.6
SEm±	1.64	0.08	4	0.2	1	0.1	0.08	0.17	0.6
CD (P=0.05)	NS	NS	12	0.7	4	NS	0.23	0.49	NS

tigation varied with the systems. *Toria* yield was higher in rice-*toria*-greengram than in rice-*toria*-fallow system (Table 2). On the contrary, groundnut yield was more in rice-groundnut-fallow system than in other two three-crop sequences. *Toria* being a non-leguminous crop might have been benefited by the inclusion of greengram as the legume component, which was not reflected in groundnut, a nodulating oilseed crop. Maize yield was more in rice-maize-greengram than in rice-maize-cowpea system. Sunflower and fieldpea yields showed a declining trend in the subsequent years. Yield of rajmash and fieldpea was not up to the mark. Impaired soil structure, poor aeration, excess moisture retention for extended periods in the ploughsole layer due to puddling and continuous submergence of rice might have resulted in low crop stand, restricted root growth, poor nodulation and hence growth and yield of *rabi* pulses like rajmash and fieldpea (Prasadini *et al.* 1993). Further, Anderson (2005) reported that variation in yields of crops in sequences could be attributed to synergism of some crops to the following crops. Greengram yield was the maximum after maize in the first year and after sunflower in the subsequent years, and the yield showed an increasing trend after sunflower. Cowpea yield was more after groundnut in the first year and after maize in the last 2 years. Yield of sesame crop was higher in rice-rajmash-sesame than in rice-fieldpea-sesame system in all the three years. This type of variation in the yield of crops might be attributed to the biological and environmental complexities and interactions in the cropping systems (Francis, 1989).

Table 2. Economic yield of *rabi* and summer crops, rice-equivalent yield (REY) and sustainable yield index (SYI) of different rice-based cropping systems

Cropping system	Economic yield (t/ha)						System productivity (t REY/ha)			SYI
	2002-03		2003-04		2004-05		2002-03	2003-04	2004-05	
	Rabi	Summer	*Rabi*	Summer	*Rabi*	Summer				
Rice-*toria*-fallow	1.67		1.63		1.12		8.81	8.57	7.71	0.49
Rice-*toria*-greengram	1.80	1.27	1.82	1.26	1.18	1.36	12.54	12.82	11.55	0.73
Rice-groundnut-fallow	2.44		2.69		2.44		10.49	10.90	10.67	0.64
Rice-groundnut-greengram	2.32	1.33	2.53	1.05	2.32	1.20	13.99	13.69	13.89	0.83
Rice-groundnut-cowpea	2.33	4.00	2.59	4.05	2.44	3.83	14.07	14.63	14.71	0.83
Rice-maize-greengram	67,582*	1.38	71,104*	1.09	68,547*	1.23	15.44	14.99	15.47	0.83
Rice-maize-cowpea	66,813*	3.70	69,501*	4.27	70,940*	4.28	15.46	16.03	16.44	0.85
Rice-sunflower-greengram	1.75	1.07	1.60	1.27	1.56	1.41	11.31	11.68	11.99	0.67
Rice-rajmash-sesame	1.73	1.36	1.50	1.40	1.57	1.55	12.58	12.08	12.93	0.74
Rice-field pea-sesame	6.04	1.27	5.73	1.33	5.70	1.58	14.15	14.29	15.13	0.78
SEm±							0.28	0.38	0.37	
CD (P=0.05)							0.83	1.14	1.09	

*Number of green cobs

Table 3. Indices of resource-use efficiency and economics of different rice-based cropping systems (pooled data of 3 years)

Cropping system	Land-use efficiency (%)	Production efficiency (kg REY/ ha/day)	WUE (kg REY/ ha-cm)	Man-days/ha	Net returns (x 10^3 Rs/ha)	Returns per Re invested (Rs)	Economic efficiency: Production efficiency (Rs/ha/day)	Economic efficiency: WUE (Rs/ha-cm)	Economic efficiency: Energy intensiveness (MJ/Re)
Rice-*toria*-fallow	64.20	35.72	56.0	340	16.81	1.58	71.7	112.6	7.09
Rice-*toria*-greengram	83.84	40.21	71.5	432	29.28	1.76	95.7	170.3	7.69
Rice-groundnut-fallow	73.33	39.94	63.9	423	20.85	1.55	77.9	124.7	6.74
Rice-groundnut-greengram	90.96	41.86	72.2	515	29.25	1.62	88.1	152.0	7.32
Rice-groundnut-cowpea	91.96	43.12	74.7	523	31.29	1.64	93.2	160.6	5.97
Rice-maize-greengram	84.57	49.60	81.4	542	38.21	1.83	123.8	203.2	12.56
Rice-maize-cowpea	86.30	50.73	84.3	550	40.42	1.85	128.3	213.0	11.23
Rice-sunflower-greengram	84.20	37.93	62.8	442	20.65	1.47	67.2	111.1	7.30
Rice-rajmash-sesame	85.02	40.41	72.3	430	26.62	1.63	85.8	153.4	6.38
Rice-field pea-sesame	85.02	46.83	84.1	430	38.62	1.94	124.4	223.2	5.77
SEm±		0.86			1.45	0.04	2.8	6.8	0.07
CD (P=0.05)		2.57			4.30	0.11	8.2	20.1	0.22

System productivity

Pooled data indicated that system productivity in terms of rice-equivalent yield (REY) of rice-maize-cowpea was the maximum (15.98 t/ha), closely followed by that of rice-maize-greengram (Table 2). Next in order was rice-fieldpea-sesame system. The winter crops mostly governed the REY of the systems, because rice was the base crop and contribution of summer crops was marginal. The contribution of winter crops to REY of rice-maize-cowpea, rice-maize-greengram and rice-fieldpea-sesame was 47, 48 and 44 % respectively. Other crops remaining the same, inclusion of summer cowpea as a vegetable crop increased the productivity of the systems and showed an edge over greengram and sesame. Setty and Gowda (1997) also reported similar results. Rice-sunflower-greengram registered minimum REY (11.66 t/ha) among the three-crop sequences because of relatively lower sale price of sunflower (Rs 12.50/kg) compared with other *rabi* pulses and oilseed crops. Among two-crop sequences, rice-*toria*-fallow produced the lowest REY (8.36 t/ha), which was due to lower yields of both the component crops, i.e. 5% in rice (Table 1) and 42% in *toria* (Table 2) compared with that of rice-groundnut-fallow system.

Sustainability

Rice-maize-cowpea system expressed the highest sustainable yield index (SYI) of 0.85 (Table 2), which might be due to above-average stability of *kharif* and summer crops and highest SYI of *rabi* crop. Kumar *et al.* (2005) also reported higher sustainability of rice-maize cropping sequence in Andhra Pradesh irrespective of variations in weather and price. The systems having two legumes i.e. rice-groundnut-greengram and rice-groundnut-cowpea, also had higher SYI (0.83). Legumes are known to offer special advantage regarding stability of the systems because of their legume effect and wider adaptability to diverse conditions.

Resource-use efficiency

Land use efficiency (LUE) of rice-groundnut-cowpea system was the highest (91.96%), closely followed by that of rice-groundnut-greengram system (90.96%). Other three-crop sequences showed LUE in the range of 83.84 to 86.30 % (Table 3). It was the lowest for rice-*toria*-fallow system (64.20%). As rice is the common *kharif* crop in all the systems and summer crops having almost similar duration, the LUE was governed mostly by duration of *rabi* crops. Groundnut occupied the field for maximum period of 119 to 125 days and hence the LUE of the systems having groundnut was maximum. Gangwar *et al.* (2003) reported highest LUE of 84% in rice-groundnut-cowpea sequence at Bhubaneshwar and Kumar *et al.* (2005) for rice-groundnut sequence (73%) in Andhra Pradesh.

Rice-maize-cowpea system registered the highest production efficiency (PE) of 50.75 kg REY/ha/day and water use efficiency (WUE) of 84.3 kg REY/ha-cm of water use with maximum employment generation of 550 mandays/ha (Table 3). In most of the cases this system was closely followed by that of rice-maize-greengram system, with corresponding values of 49.60, 81.4 and 542. Maize is a short-duration, labour-intensive and C_4 plant, which produced the highest REY of 7.54 t/ha amongst all the *rabi* crops, resulting in the highest PE, WUE and employment generation of the systems. Inclusion of cowpea as a vegetable component in summer season further improved the efficiency. Rice-*toria*-fallow system showed the lowest PE of 35.72 kg REY/ha/day, WUE of 56.0 kg REY/ha-cm water use and the minimum employment generation of 340 mandays/ha, mainly because of the lowest REY (8.36 t/ha) of the system. Inclusion of *toria* has been reported to lower the production efficiency (Singh *et al.*, 2004) and employment generation (Padhi, 1993) of the cropping systems.

Economics

Among the systems, rice-maize-cowpea registered the highest net returns of Rs 40,415/ha, which were on a par with that of rice-fieldpea-sesame and rice-maize-greengram systems (Table 3). Maize sold as green cob and both fieldpea and cowpea as vegetables had higher rice-equivalent yield, which has contributed to higher net returns of the systems comprising of these crops. Net returns of rice-groundnut-cowpea, rice-*toria*-greengram and rice-groundnut-greengram were next in order. Padhi (1993) also reported higher net returns of rice-based cropping systems having cowpea as summer crop under Orissa conditions. Return per rupee invested was the highest for rice-fieldpea-sesame system (Rs 1.94), which was on a par with that of rice-maize-cowpea and rice-maize-greengram systems. This was due to higher gross returns and moderate cost of cultivation of the above systems. From economic efficiency, the cropping systems with maize as a component crop expressed higher production efficiency (Rs 123.8 to 128.3/ha/day), water use efficiency (Rs 203.2 to 213.0/ha-cm) and energy intensiveness (11.23 to 12.56 MJ/Re). However, rice-fieldpea-sesame was on a par with the above systems about PE and WUE in economic terms. This was due to higher rice-equivalent yield, and moderate land use and water-use efficiency of these systems. Rice-sunflower-greengram and rice-*toria*-fallow systems showed the minimum production efficiency and WUE in economic terms because of their lower REY. Kumar *et al.* (2005) reported lower monetary efficiency of rice-based cropping systems with *toria* and sunflower as component crops due to their lower yields and net returns.

Thus rice-maize-cowpea is the most productive, sustainable, resource-use efficient and remunerative cropping system under irrigated condition, and can be followed in place of rice-*toria* or rice-groundnut systems.

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