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Research Paper

Productivity, resource use efficiency and economics of rice (*Oryza sativa*)-based bio-intensive cropping systems in western Odisha

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ABSTRACT

A field experiment was conducted at Chiplima, Odisha, under irrigated medium-land condition during 2013–14 to 2016–17, to evaluate the production potential and economics of 10 rice (*Oryza sativa* L.)-based bio-intensive cropping systems. Rice–potato (*Solanum tubersum* L.) + radish [*Raphanus raphanistrum subsp. sativus* (L.) Domin]–pumpkin (*Cucurbita pepo* L.) + amaranth (*Amaranthus viridis* L.), rice–maize (*Zea mays* L.) + coriander (*Coriandrum sativum* L.)–cowpea (*Vigna unguiculata* L.) + amaranth and rice–maize + radish–okra (*Abelmoschus esculentus* L.) + amaranth cropping systems recorded significantly higher average rice-equivalent yields (REY) (22.72, 20.73 and 19.65 t/ha respectively) than the other rice-based cropping systems, the increase being 143, 122 and 110% over the existing rice–groundnut (*Arachis hypogaea*) system. Rice–tomato (Solanum l*ycopersicum* L.) + amaranth–watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] + amaranth system had the highest land-use efficiency (97%). Rice–potato + radish–pumpkin + amaranth revealed the highest irrigation water-use efficiency of 239 kg REY/ha-cm. The highest apparent nutrient-use productivity was realized with the rice–maize + coriander–cowpea + amaranth (46.6 kg REY/kg NPK applied). This system also recorded the highest energy-use efficiency (5.04) and energy productivity (0.41 kg REY/MJ). Rice–tomato + fenugreek (*Trigonella foenum-graecum* L.)–cowpea + amaranth (635 man-days) and rice–maize + radish–okra + amaranth (625 man-days) created higher employment opportunity. Rice–maize + coriander–cowpea + amaranth recorded the highest net returns (₹136,544) followed by rice–maize + radish–okra + amaranth (₹116,803) and rice–potato + radish–pumpkin + amaranth (₹111,890). These 3 cropping systems also recorded the highest system profitability and crop profitability with higher benefit: cost ratio.

Key words : Crop diversification, Economics, Energy-use efficiency, Production efficiency, Rice-based bio-intensive cropping system, System productivity

Rice–groundnut is the predominant cropping system in the west central table land zone of Odisha under irrigated ecosystem. However, farmers grow various field crops and short-duration vegetables after the rainy season (*kharif*) rice with limited irrigations in small patches. Crop diversification has been recognized as an effective strategy for achieving the objectives of food and nutritional security, sustainable management of land and water resources, income growth, employment generation and environmental benefit (Ray *et al.,* 2016). Rice being the base crop in *kharif*, crop diversification during the winter season (*rabi*) and summer seasons plays a significant role in augmenting the farm income per unit area by integrating small-duration, high-value crops with high water and nutrient-use efficiency. Inclusion of vegetables in a cereal-based cropping system is remunerative and this changes the economics of the crop sequences (Kachroo *et al.,* 2014; Patra *et al.,* 2017). Keeping this in mind, an experiment was designed to study the overall productivity and profitability, and land, nutrient, water and energy-use efficiency of various possible rice-based bio-intensive cropping systems by integrating various vegetable crops with leafy vegetables as their companion crops during *rabi* and summer seasons which can replace the existing predominant rice–groundnut system in west central table land zone of Odisha under irrigated conditions.

MATERIALS AND METHODS

A field experiment was conducted from 2003–14 to 2016–17 at Regional Research and Technology Transfer Station, Odisha University of Agriculture and Technology, Chiplima, Odisha (21° 38' N, 83° 90' E, 144 m above mean

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sea-level) under irrigated medium-land condition on the same site and lay-out. Chiplima comes under west central table land zone of the state and belongs to Typic Haplustalfs. It has a hot humid climate with mean annual rainfall of 1,496 mm. The mean maximum and minimum temperature were 33.8 and 22.0°C respectively. The soil was sandy loam, having *p*H 6.1, organic carbon 0.71%, available N, P and K of 315.4, 16.2 and 210.4 kg/ha respectively. The experiment was laid out in a randomized block design with 10 treatments of rice-based cropping systems, as detailed in Table 2 and replicated thrice. The varieties and hybrids were used which were locally popular with respect to their yield potential and insect-pest resistance. The varieties of different crops and their duration in the field, recommended fertilizer dose applied and planting spacing are given in Table 1. Rainy-season (*kharif*) rice was sown in the last week of June in the nursery, and after its harvesting in the last week of October, subsequent crops were sown as per optimum sowing time recommended for the region. In winter (*rabi*) season, maize was harvested for green cob purpose, and radish, amaranth, coriander and fenugreek for vegetable purpose. In summer season, cowpea was harvested for vegetable purpose. All the crops were grown successfully with recommended packages of practices.The crops were irrigated optimally and plant-protection measures were taken as and when required.

Crop yields were recorded at the end of each season and rice-equivalent yield (REY) was worked out. System yield was obtained by adding REY of component crops and prices were used from 4th (2016–17) cycle for all the years. Total field duration of a cropping system expressed in percentage of 365 days was taken as the land-use efficiency (LUE) of the system. Apparent nutrient-use productivity (ANUP) was calculated by dividing the rice-equivalent yield of the system with the total quantity of the nutrients (N-P-K) applied to the system. Irrigation water-use efficiency was worked out by dividing the rice-equivalent yield of the system with the total quantity of water applied through irrigation in that cropping system. System productivity of different rice-based cropping systems was obtained by dividing the system yield by 365 and was expressed in kg REY/ha/day. Production efficiency was cal-

Table 1. Crop variety and their average duration in the field, recommended fertilizer dose applied and planting geometry

	Crop	Variety	Duration (days)	Fertilizer dose (kg/ha) N	P	K	Planting geometry (cm × cm)
Rainy season	Rice	'Naveen'	135	80	18	33	20 × 10
Winter season	Groundnut	'Smruti'	121	20	18	33	30 × 10
	Maize	'Kamal'	98	80	18	33	50 × 30
	Tomato	'BT 2'	133	80	18	33	50 × 30
	Potato	'Kufri Alankar'	98	120	36	82	50 × 20
	Knolkohol	'Viena'	98	80	18	33	50 × 30
	Sunflower	'MSF 17'	78		No additional fertilizer		One row after each 2 rows of main crop at 25 cm spacing from plant to plant (additive intercropping)
	Radish	'Pusa Chetki'	60		No additional fertilizer		One row in between 2 rows of main crop at 10 cm spacing from plant to plant
	Coriander	'Natha'	43		No additional fertilizer		Broadcasted in the interspaces of 2 rows of main crops
	Fenugreek	Local	45		No additional fertilizer		Broadcasted in the interspaces of 2 rows of main crops
	Amaranth/ spinach	Local	30		No additional fertilizer		Broadcasted in the interspaces of 2 rows of main crops
Summer	Bottle gourd	'US 15'	84	50	14	41	Pits at 120 cm × 120 cm spacing, in each pit 4 plants were allowed
	Cowpea	'YB 7'	74	25	22	41	30 × 15
	Okra	'S 152'	75	80	18	33	50 × 25
	Ridgegourd	'Saloni 5"	75	80	18	33	Pits at 100 cm × 100 cm spacing, 4 plants were allowed in each pit
	Pumpkin	'Arka Chandan'	81	100	22	41	Pits at 120 cm × 120 cm spacing, 3 plants were allowed in each pit
	Watermelon	'Sugar Baby'	86	100	22	41	Pits at 120 cm × 120 cm spacing, 4 plants were allowed in each pit
	Greengram	'K 85-1'	73	20	18	33	25 × 7.5
	Amaranth	Local	30		No additional fertilizer		Broadcasted in the interspaces of two rows of main crops

culated by dividing the system yield by total duration of the system and expressed in kg REY/ha/day. For economic analysis cost of inputs and price of outputs were used from 4th cycle (2016–17) for all the years. Crop profitability in term of ₹/ha/day was calculated by dividing net monetary returns of the rotation by total duration of the crops and the profitability of the system was calculated by dividing the net returns (₹/ha) in a system by 365 days (Kachroo *et al.*, 2014). The relative productivity efficiency and relative economics efficiency were calculated as per Urkurkar *et al.* (2008). Employment-generation efficiency was determined by dividing the total man days employed for the system with the calendar year of 365 days and expressed in percentage.

The equivalent-energy values of various inputs and outputs as suggested by Singh and Mittal (1992) and Devasenapathy *et al.* (2009) were used for computing total energy input and energy output of a cropping system. The energy input and output were computed as Mega Joule (MJ). The energy input for a particular cropping system was calculated as the summation of energy requirement for a human, animal, machineries, diesel, seed, herbicide, FYM, chemical fertilizers and pesticides used in that system. Similarly, the energy output for a particular cropping system was calculated as the summation of energy output from the main product and by-products in that system. The energy-use efficiency, energy-output efficiency (MJ/ha/day) and energy productivity (kg REY/MJ) were calculated as:

$$\text{Energy-use efficiency} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Energy-output efficiency} = \frac{\text{Energy output (MJ/ha)}}{\text{Duration of the system (days)}}$$

$$\text{Energy productivity} = \frac{\text{Rice equivalent yield (kg/ha)}}{\text{Energy input (MJ/ha)}}$$

Statistical analyses were carried out using standard methodology of randomized block design. Soil samples were drawn at initial and at the end of 4th cropping system cycle from a depth of 0–15 cm from each treatment and soil organic carbon, N, P and K contents were analysed using standard procedures (Jackson, 1973).

RESULTS AND DISCUSSION

System yield and productivity

Rice–potato + radish–pumpkin + amaranth recorded significantly higher 4-year average rice-equivalent yield (REY) of 22.72 t/ha than all other rice-based cropping systems evaluated (Table 2). The next best cropping systems were rice–maize + coriander–cowpea + amaranth and rice–maize + coriander–cowpea + amaranth with REY of 20.73 and 19.65 t/ha respectively, and these 2 cropping systems were at par with respect to system REY. Higher REY in these systems were owing to the contribution of winter and summer crops to the system REY. These three systems also recorded higher system productivity and production efficiency (Table 3). Kachroo *et al*. (2014) and Bastia *et al*. (2008) also reported higher system yields with vegetables as winter season or summer crops and maize for green cobs as a winter season crop in the rice-based crop rotation. The existing rice–groundnut system recorded the lowest REY (9.34 t/ha) with lowest system productivity and production efficiency.

Land-use efficiency

Land-use efficiency (LUE) of rice–tomato + amaranth–watermelon + amaranth system was the highest (97.0%),

Table 2. Average crop yields (t/ha) and year-wise rice-equivalent yields (t/ha) of diversified rice-based bio-intensive cropping systems

Cropping system	Crop yields (t/ha) (4 years mean)						System rice-equivalent yield (t/ha)				
	Rainy season (rice)		*Winter season*		Summer crop		2013–14	2014–15	2015–16	2016–17	Mean
	Grain	Straw	Main crop	Inter crop	Main crop	Inter crop					
Rice–groundnut	3.41	4.86	2.15	0	0	0	8.79	10.26	9.61	8.69	9.34
Rice–groundnut + sunflower–bottlegourd + amaranth	3.40	4.73	1.54	0.44	10.27	1.11	15.99	17.55	13.37	14.22	15.28
Rice–groundnut + amaranth–cowpea + amaranth	3.84	5.01	2.09	1.92	3.45	1.12	15.51	16.25	17.21	16.86	16.46
Rice–maize + radish–okra + amaranth	3.46	5.07	31102*	13.75	3.10	1.07	20.09	20.03	19.22	19.27	19.65
Rice–maize + coriander–cowpea + amaranth	3.93	5.52	44672*	0.74	2.99	0.91	20.14	23.42	19.57	19.79	20.73
Rice–tomato + amaranth–watermelon + amaranth	3.40	4.43	9.22	1.55	10.25	0.85	17.58	20.12	17.64	18.56	18.47
Rice-tomato + fenugreek–cowpea + amaranth	3.90	5.32	10.19	0.43	3.75	0.93	15.74	16.62	17.31	20.22	17.47
Rice–potato + radish–pumpkin + amaranth	3.50	4.93	16.06	9.89	9.16	0.91	23.70	26.81	18.75	21.61	22.72
Rice–potato + amaranth–greengram + amaranth	3.97	5.68	17.58	1.31	1.02	0.96	18.30	18.86	19.18	18.72	18.76
Rice–knolkhol + spinach–ridgegourd	3.46	5.17	7.57	1.62	3.27	0	11.41	13.41	14.96	13.82	13.40
SEm±							0.42	0.52	0.93	1.19	0.49
CD (P=0.05)							1.26	1.53	2.75	3.53	1.46

*Number of green cobs/ha

followed by that of rice–groundnut + sunflower–bottlegourd + amaranth system (93.2%). Rice–groundnut system had the lowest LUE (70.1%). Other sequences showed LUE in the range of 80.8 to 91.2% (Table 3). As rice is the common rainy season crop in all the systems, the LUE was governed mostly by duration of the winter and summer crops. Among the winter season crops, tomato occupied the field for maximum period (133 days), followed by groundnut (121 days) and among the summer crops, watermelon occupied the field maximum period (86 days); followed by bottlegourd (84 days), hence the LUE of the systems having these crops were high. Gangwar *et al*. (2003) reported the highest LUE of 84% in rice–groundnut–cowpea sequence.

Irrigation water and nutrient-use efficiency

Rice–potato + radish–pumpkin + amaranth had the highest irrigation water-use efficiency (IWUE) of 239 kg REY/ha-cm followed by rice–maize + coriander–cowpea + amaranth (218 kg REY/ha-cm) and rice–potato+amaranth–greengram + amaranth (208 kg REY/ha-cm). Rice–groundnut cropping system recorded the least IWUE of 124 (Table 3). The other cropping systems recorded IWUE in the range of 153 to 194 kg REY/ha-cm. Potato and maize being the high yielders, the systems having these crops in the sequence recorded higher irrigation water-use efficiency. On the other hand, groundnut being a long-duration crop among the winter season crops, it required highest number of irrigations and thus the systems having groundnut in the sequence registered lower irrigation water-use efficiency.

Higher apparent nutrient-use productivity (ANUP) was realized with the rice–maize + coriander–cowpea + amaranth (59.2 kg REY/kg NPK applied) and rice–groundnut + amaranth–cowpea + amaranth (56.8 kg REY/kg NPK applied). Rice–knolkhol (*Brassica oleracea* L.) + spinach (*Spinacia oleracea* L.)–ridgegourd [Luffa acutangula (L.) Roxb.] recorded the lowest ANUP (34.1 kg REY/kg NPK applied) (Table 3).

Energy-use efficiency

Total energy inputs in different cropping systems were in the range from 40,350 to 160,498 MJ/ha (Table 4). The highest energy input was recorded in rice–potato + radish–pumpkin + amaranth (160,498 MJ/ha) followed by rice–potato + amaranth–greengram + amaranth (152,013 MJ/ha) and it was mainly due to higher seed requirement of potato (2,000 kg/ha). The existing rice–groundnut cropping system required the lowest energy. Total energy output was computed from main products and by-products of different cropping systems and it ranged from 1,56,974 (rice–knolkhol + amaranth–ridgegourd) to 2,74,799 MJ/ha (rice–tomato + fenugreek–cowpea + amaranth). Rice–maize + coriander–cowpea + amaranth system recorded the highest energy-use efficiency (5.04) followed by rice–tomato + fenugreek–cowpea + amaranth (5.02), with respective energy output efficiency of 870 and 835 MJ/ha/day and this was mainly owing to high energy output of the system. Average maximum energy productivity was obtained in rice–maize + coriander–cowpea + amaranth (0.41 kg REY/MJ) followed by rice–maize + radish–okra + amaranth (0.35 kg REY/MJ) and it was mainly owing to higher REY. Similar results were also recorded by Patra *et al.* (2017).

Employment-generation efficiency

Crop diversification through intensification not only

Table 3. Production and resource-use efficiency of rice-based bio-intensive cropping systems (mean data of 4 years)

Cropping system	Crop duration (days)	Land-use efficiency (%)	System productivity (kg REY/ ha/day)	Production efficiency (kg REY/ ha/day)	Employment-generation efficiency (%)	Irrigation water-use efficiency (kg REY/ha-cm)	ANUP (kg REY/ha/kg nutrient applied)
Rice–groundnut	256	70.1	25.6	36.5	86	124	46.2
Rice–groundnut + sunflower–bottlegourd + amaranth	340	93.2	41.9	45.0	119	153	49.8
Rice–groundnut + amaranth–cowpea + amaranth	328	89.9	45.1	50.2	130	165	56.8
Rice–maize + radish–okra + amaranth	308	84.4	53.8	63.8	171	187	50.0
Rice–maize + coriander–cowpea + amaranth	295	80.8	56.8	70.3	133	218	59.2
Rice–tomato + amaranth–watermelon + amaranth	354	97.0	50.6	52.2	167	194	43.5
Rice-tomato + fenugreek–cowpea + amaranth	333	91.2	47.9	52.5	174	194	49.9
Rice–potato + radish–pumpkin + amaranth	314	86.0	62.2	72.3	147	239	42.7
Rice–potato + amaranth–greengram + amaranth	304	83.3	51.4	61.7	125	208	42.6
Rice–knolkhol + spinach–ridgegourd	299	81.9	36.7	44.8	112	149	34.1
SEm±			2.58	3.12		14.2	2.86
CD (P=0.05)			7.69	9.31		42.3	8.52

ANUP, Apparent nutrient-use productivity; REY, rice-equivalent yield enhances the productivity and the profitability of the farmers but also generates the employment to the farming community for the longer periods which helps in minimizing the problem of the migration during lean periods. Employment-generation efficiency of any diversified system is a direct measure of its profitability in an area (Thakur *et al*., 2009). Rice–tomato + fenugreek–cowpea + amaranth had the highest engagement of man-days (635 days), followed by rice–maize + radish–okra + amaranth (625 days) and rice–tomato + amaranth–watermelon + amaranth (610 days) owing to involvement of more number of human labour for harvesting, grading and marketing of vegetables. These 3 systems had employment-generation efficiency of 174, 171 and 167% respectively (Table 3). Rice–groundnut cropping system recorded the least employment-generation efficiency of 86%. Similarly, Kachroo *et al.* (2014) and Patra *et al.* (2017) also reported that cropping systems with vegetables having high productivity had higher employment-generation efficiency.

Monetary returns and economic viability

Rice–potato + radish–pumpkin + amaranth system gave the highest gross return (₹334,300/ha) followed by rice–maize + coriander–cowpea + amaranth (₹306,166/ha) and rice–maize + radish–okra + amaranth (₹290,022/ha). However, rice–maize + coriander–cowpea + amaranth recorded the highest net returns (₹136,544/ha) followed by rice–maize + radish–okra + amaranth (₹116,803/ha) and rice–potato + radish–pumpkin + amaranth (₹111,890/ha) (Table 5). These 3 cropping systems also recorded the highest

Table 4. Energy input-output relationship of different rice-based bio-intensive cropping systems (pooled data of 4 years)

Cropping system	Energy input ($\times 10^3$ MJ/ha)	Energy output ($\times 10^3$ MJ/ha)	Energy-use efficiency	Energy-output efficiency ($\times 10^3$ MJ/ha/day)	Energy productivity (kg REY/MJ)
Rice–groundnut	40.4	186.6	4.63	0.73	0.23
Rice–groundnut + sunflower–bottlegourd + amaranth	56.3	265.0	4.70	0.81	0.27
Rice–groundnut + amaranth–cowpea + amaranth	54.9	255.2	4.65	0.74	0.30
Rice–maize + radish–okra + amaranth	56.5	260.6	4.61	0.84	0.35
Rice–maize + coriander–cowpea + amaranth	50.0	252.0	5.04	0.82	0.41
Rice–tomato + amaranth–watermelon + amaranth	58.5	191.7	3.28	0.61	0.32
Rice–tomato + fenugreek–cowpea + amaranth	54.8	274.8	5.02	0.87	0.32
Rice–potato + radish–pumpkin + amaranth	160.5	268.9	1.68	0.82	0.14
Rice–potato + amaranth–greengram + amaranth	152.0	231.0	1.52	0.71	0.12
Rice–knolkhol + spinach–ridgegourd	50.1	157.0	3.13	0.50	0.27
SEm±		8.24	0.11		
CD (P=0.05)		24.58	0.33		

Table 5. Economics of rice-based bio-intensive cropping systems (pooled data of 4 years)

Cropping system	Cost of cultivation ($\times 10^3$₹/ha)	Gross returns ($\times 10^3$₹/ha)	Net returns ($\times 10^3$₹/ha)	Benefit: cost	Crop profitability (₹/ha/day)	System profitability (₹/ha/day)
Rice–groundnut	97.1	140.2	43.1	1.44	169	118
Rice–groundnut + sunflower–bottlegourd + amaranth	146.1	226.3	80.2	1.55	236	220
Rice–groundnut + amaranth–cowpea + amaranth	168.5	243.7	75.2	1.45	229	206
Rice–maize + radish–okra + amaranth	173.2	290.0	116.8	1.67	379	320
Rice–maize + coriander–cowpea + amaranth	169.6	306.2	136.5	1.81	463	374
Rice–tomato + amaranth–watermelon+amaranth	164.1	272.3	108.2	1.66	306	296
Rice–tomato + fenugreek–cowpea + amaranth	186.3	258.7	72.4	1.39	217	198
Rice–potato + radish–pumpkin + amaranth	222.4	334.3	111.9	1.50	356	307
Rice–potato + amaranth–greengram + amaranth	195.8	277.8	82.0	1.42	270	225
Rice–knolkhol + spinach–ridgegourd	111.3	199.5	88.2	1.79	295	242
SEm±			3.36		14.1	12.3
CD (P=0.05)			10.03		42.1	36.6

Sale price (₹/t): Rice grain, 14,500; rice straw, 1,000; groundnut pod, 40,000; sunflower, 40,000; bottlegourd, 8,000; okra, 15,000; amaranth, 10,000; cowpea, 20,000; radish, 5,000; coriander, 25,000; tomato, 10,000; watermelon, 10,000; ridgegourd, 15,000; fenugreek, 25,000; potato, 8,000; pumpkin, 10,000; greengram, 50,000; knolkhol, 10,000; spinach, 12,000; maize, ₹3.50/green cob

Table 6. Changes in soil physico-chemical properties after 4 years of cropping cycle under rice-based bio-intensive cropping systems

Cropping system	*p*H	Organic carbon (%)	Available nutrient (kg/ha)		
			N	P	K
Rice–groundnut	5.33	0.85	294	13.0	144
Rice–groundnut + sunflower–bottlegourd + amaranth	5.28	0.89	293	13.0	140
Rice–groundnut + amaranth–cowpea + amaranth	5.39	0.82	296	14.2	149
Rice–maize + radish–okra + amaranth	5.57	0.74	277	12.8	133
Rice–maize + coriander–cowpea + amaranth	5.35	0.84	293	13.1	137
Rice–tomato + amaranth–watermelon + amaranth	5.52	0.75	273	12.1	133
Rice–tomato + fenugreek–cowpea + amaranth	5.57	0.83	286	13.1	136
Rice–potato + radish–pumpkin + amaranth	5.44	0.78	272	12.5	133
Rice–potato + amaranth–greengram + amaranth	5.41	0.86	292	13.4	144
Rice–knolkhol + spinach–ridgegourd	5.42	0.84	293	13.6	146
Initial	5.72	0.71	315	16.2	210

system profitability and crop profitability with higher benefit: cost ratio. Maize sold as green cobs and vegetables like okra and cowpea fetched better market price, besides being high yielders, which has contributed to higher net returns of the systems comprising these crops. The rice–groundnut system recorded the least gross and net returns (₹1,40,230 and ₹43,149/ha respectively). Bastia *et al*. (2008) and Patra *et al.* (2017) also concluded that, inclusion of vegetables and maize (for green cob purpose) as a winter season crop in the rice-based cropping system were remunerative.

Soil fertility and health

The soil *p*H in all the cropping systems decreased from the initial *p*H value after 4 cropping system cycles; however, there was not much difference of treatments. The initial soil organic carbon content was 0.71% and after 4 years of cropping it varied from 0.73 to 0.89% in different rice-based cropping systems (Table 6). After 4 years of experimentation, the available N content decreased in the range of 19–42 kg/ha in the systems from the initial value of 315 kg/ha. The systems having maize or having no legume lost more N from soil than systems having legumes. The symbiotic fixation of atmospheric N in the soil by cowpea and groundnut compensated the removal of N by the crops to some extent. These crops also left huge quantity of crop residue in the form of roots and leaves in the soil. The available P and K content in soil also decreased after completion of 4 cropping cycles, though the depletion in K was more pronounced than that of P. The available P content decreased by 12 to 25% from the initial value of 16.2 kg/ha, and available K content decreased by 29 to 37% from the initial value of 210 kg/ha.

Thus, it can be concluded that rice–maize + amaranth–cowpea + amaranth and rice–maize + radish–okra + amaranth were the most productive and remunerative cropping systems under irrigated condition in coastal Odisha, and can be followed in place of existing rice–groundnut system.

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