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Research Paper

Productivity and energy-efficiency indices for diversified rice (*Oryza sativa*)-based cropping systems in West Central Table Land Zone of Odisha

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ABSTRACT

A long-term field experiment was conducted at Chiplima, Odisha, under irrigated medium land condition during 2006–07 to 2012–13, to evaluate the production potential and economics of 10 rice (*Oryza sativa* L.)-based cropping systems. Rice–maize (*Zea mays* L.)–cowpea [*Vigna unguiculata* (L.) Walp.] and rice–groundnut (*Arachis hypogaea* L.)–bottle gourd [*Lagenaria siceraria* (Molina) Standl.] cropping systems recorded significantly higher average rice equivalent yield (19.55 and 18.57 t/ha, respectively) than the other systems evaluated, the relative production efficiency being 85.8 and 76.5% over the rice–groundnut system. Rice-based 3-cropping systems having groundnut as winter (*rabi*) crop had higher land-use efficiency (83%). Rice–maize–cowpea recorded the highest irrigation water-use efficiency (230 kg REY/ha), whereas rice–groundnut–bottle gourd recorded the highest apparent nutrient use efficiency (60.8 kg REY/kg NPK applied). Rice–maize–cowpea also recorded the highest energy-use efficiency (5.89), energy-output efficiency (1,240 MJ/ha/day) and energy productivity (0.34 kg REY/MJ). Rice–maize–cowpea had the highest employment generation efficiency (124.7%), followed by rice–groundnut–bottle gourd (120.5%) and rice–groundnut–cowpea (120.0%). Rice–maize–cowpea gave the highest net returns of ₹135,087/ha, followed by rice–groundnut–bottle gourd system (₹111,777/ha). Rice–maize–cowpea system showed the highest system profitability (₹370/ha/day) and crop profitability (₹500/ha/day). This system also gave the highest benefit: cost ratio (2.56), with highest relative production efficiency (85.8%) and relative economic efficiency (168.5%) compared to rice–groundnut system.

Key words : Diversification, Economics, Energy-use efficiency, Production efficiency, Rice-based cropping system, System productivity

Rice–groundnut and rice–toria are two predominant cropping systems in the West Central Table Land zone of Odisha under irrigated ecosystem. However, 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 enhance productivity per unit resource is very pertinent. Hence choice of component crops needs to be suitably manoeuvred in order to harvest the synergism among them towards efficient utilization of resource base and to increase overall productivity (Anderson, 2005). Inclusion of pulses, oilseeds and vegetables in a system is remunerative and such inclusion in the sequence changes the economics of the crop sequences (Gangwar *et al.,* 2004; Kachroo *et al*., 2014). Higher productivity and profitability with sustainability remains the major concern of any crop planning. Any system which requires less input and contributes more is considered to be the efficient. Hence an experiment was designed to study the overall productivity and profitability, and land, nutrient, water and energy use efficiency under different rice-based diversified cropping systems for irrigated ecosystems**.**

MATERIALS AND METHODS

A long-term field experiment was conducted from 2006–07 to 2012–13 at Regional Research and Technology Transfer Station, Orissa University of Agriculture and Technology, Chiplima, Odisha (21° 38' N, 83° 90' E, 144 m above mean 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

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mean annual rainfall of 1,496 mm. The mean maximum and minimum temperature was 33.8 and 22.0°C respectively. The soil was sandy loam, having *p*H 5.6, organic carbon 0.63%, available N, P and K of 305.4, 16.2 and 190.4 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 which were popular among local farmers with respect to their yield potential and insect-pest resistance were used. The varieties of different crops and their duration in the field, recommended fertilizer dose applied and planting spacing are given in Table 1. In the rainy season (*kharif*), rice was sown in the nursery in the last week of June, and after its harvesting in the last week of October subsequent crops were sown as per optimum sowing time recommended for the region. In the winter (*rabi*) season, maize was harvested for green cob purpose and *rajma* or red kidney bean (*Phaseolus vulgaris*) was grown for grain and radish for vegetable purpose. In summer season, cowpea and bottle gourd were harvested for vegetable purpose. All the crops were grown successfully with recommended packages of practices. The crops were irrigated and plant protection measures were applied as and when required.

Crop yields were recorded at the end of each season and rice-equivalent yield (REY) was computed at the end of each cropping cycle. System yield was obtained by adding REY of component crops and prices were used from seventh cycle for all the years. Total field duration of a cropping system expressed in percentage of 365 days was taken as land-use efficiency (LUE) of the system. Apparent nutrient-use efficiency (ANUE) was calculated by dividing the REY of the system with the total quantity of nutrients applied to the system. Irrigation water-use efficiency was worked out by dividing the REY 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 calculated by dividing the system yield by total duration of the system and was expressed in kg REY₹/ha/day (Tomar and Tiwari, 1990). Crop profitability in term of ₹/ha/day was calculated by net monetary returns of the rotation divided by total duration of the crops in that rotation. The profitability of the system was calculated by dividing net returns (₹/ha) in a system with by 365 days. The relative productivity efficiency, relative economics efficiency and employment-generation efficiency were calculated as per Urkurkar *et al.* (2008). Employment-generation efficiency was determined by dividing the total man-days employment for the system with the calendar year of 365 days and expressed in percentage.

$$\text{Relative productivity efficiency} = \frac{\text{Total yield of diversified cropping system} - \text{total yield of existing cropping system}}{\text{Total yield of existing cropping system}} \times 100$$

$$\text{Relative economics efficiency} = \frac{\text{Net return of diversified cropping system} - \text{net return of existing cropping system}}{\text{Net return of existing cropping sytem}} \times 100$$

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:

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

Table 1. Crop variety and their average duration in the field, crop-wise recommended fertilizer dose applied and planting spacing

Season	Crop	Variety	Duration (days)	Fertilizer dose (kg/ha) N	P	K	Planting spacing (cm × cm)
Rainy season	Rice	'Khandagiri'	127	80	17.5	33	20 × 10
Winter season	Maize	'Kamal'	90	120	26.5	50	50 × 25
	Toria	'Keshari 101'	69	60	13.2	25	30 × 10
	Groundnut	'Smruti'	117	20	17.5	33	30 × 10
	Radish	'Pusa Chetki'	61	50	23	62	30 × 10
	Rajma	'Chitra'	74	50	35	66	30 × 10
Summer	Cowpea	'Gayatri UK 99'	73	25	23	41	50 × 15
	Greengram	'K 85 1'	72	20	17.5	33	30 × 10
	Bottle gourd	'US 15'	66	50	13.2	41	120 × 120

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

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

For economic analysis (cost of cultivation and gross return), cost of inputs and price of outputs were used from seventh cycle (2012–13) for all the years. Statistical analyses were carried out using standard methodology of randomized block design. Soil samples were drawn at initial and at the end of seventh 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–maize–cowpea and rice–groundnut–bottle gourd cropping systems showed significantly higher rice-equivalent yield (REY) than the other 8 rice-based cropping systems evaluated (Table 2) and this was mainly owing to contribution of winter (*rabi*) and summer crops to the system REY. Kachroo *et al*. (2014) and Bastia *et al*. (2008) also recorded higher system yields with vegetables as winter (*rabi*) or summer crops and maize for green cobs as a winter (*rabi*) crop in the rice-based crop rotation. The existing rice–*toria* and rice–groundnut systems recorded lower REY. Among the 3-crop sequences, rice–*toria*–greengram system yielded the least and it was at par with rice–groundnut system. The REY from other 3-crop sequences ranged between 13.87 (rice–*rajma*–greengram) to 15.04 t/ha (rice–radish–greengram). The highest system productivity was recorded with rice–maize–cowpea and rice–groundnut–bottle gourd systems (Table 3). These 2 cropping systems also showed the highest production efficiency. Rice–*toria* and rice–groundnut cropping systems recorded lower system productivity and production efficiency.

Sustainable yield index

Rice–groundnut–bottle gourd and rice–maize–cowpea cropping systems exhibited higher sustainable yield index (SYI), while rice–*toria* and rice–groundnut cropping systems recorded lower SYI (Table 2). Among 3-crops sequences except rice–*toria*–greengram and rice–groundnut–cowpea, all the other systems revealed SYI above 0.50.

Land-use efficiency

Land-use efficiency (LUE) of rice–groundnut–greengram system was the highest (83.6%), followed by 83% in both rice–groundnut–cowpea and rice–groundnut–bottle gourd systems. Other 3-crops sequences showed LUE in the range of 65.5 to 75.6% (Table 3). It was the lowest for rice–*toria* system (54%). Groundnut occupied the field for maximum period (117 days) and hence the LUE of the systems having groundnut were high. Gangwar *et al*. (2003) reported the highest LUE (84%) in rice–groundnut–cowpea sequence. Cropping system not only illustrates the current land use but also it reflects how the land pattern has changed over the time (Gangwar and Ram, 2005).

Table 2. Average crop yields, year-wise rice-equivalent yields and sustainable yield index of diversified rice-based cropping systems

Crop sequences	Crop yields (t/ha) (7 years mean)				Rice-equivalent yield (t/ha)								Sustainable yield index
	Kharif (rice)		*Rabi*	Summer	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	2012–13	Mean	
	Grain	Straw											
Rice–groundnut	4.73	6.61	2.36	-	11.91	12.51	10.64	10.49	10.04	9.05	8.99	10.52	0.36
Rice–*toria*	4.51	6.33	1.15	-	7.97	8.42	6.47	6.90	6.87	6.68	6.46	7.11	0.25
Rice–groundnut–greengram	4.84	6.50	2.34	1.12	14.48	17.44	15.57	14.72	14.56	13.83	12.05	14.66	0.51
Rice–groundnut–cowpea	4.96	6.75	2.46	3.54	14.09	16.64	14.91	14.80	15.12	12.13	11.80	14.21	0.49
Rice–groundnut–bottle gourd	4.58	6.02	2.33	11.37	17.51	20.98	19.71	16.86	18.59	16.62	19.71	18.57	0.66
Rice–*toria*–greengram	4.66	6.11	1.17	1.09	11.02	13.07	11.81	10.77	10.99	11.54	9.86	11.29	0.40
Rice–radish–cowpea	4.70	6.29	21.88	3.60	13.26	15.93	14.94	13.89	15.14	14.62	16.78	14.94	0.54
Rice–radish–greengram	4.82	6.45	20.70	1.00	13.44	15.50	15.16	14.83	15.12	14.97	16.30	15.04	0.55
Rice–*rajma*–greengram	4.97	6.82	1.84	1.06	13.43	15.19	14.03	12.75	14.15	14.36	13.16	13.87	0.51
Rice–maize–cowpea	4.75	6.58	51181*	3.48	20.74	25.63	19.99	17.83	18.89	16.76	16.98	19.55	0.64
SEm±					0.86	0.46	0.30	0.86	0.53	0.35	1.14	0.46	
CD (P=0.05)					2.57	1.38	0.88	2.56	1.58	1.04	3.41	1.37	

*No. of green cobs/ha

Sales price (₹/t): rice grain, 11,000; rice straw, 1,000; *toria*, 25,000; greengram, 40,000; groundnut, 27,000; radish, 3,500; cowpea, 10,000; bottle gourd, 8,000; *rajma*, 30,000; maize, ₹2.50/green cob

Irrigation water and nutrient-use efficiency

Rice–maize–cowpea had the highest irrigation water-use efficiency (IWUE) of 230 kg REY/ha, followed by rice–radish–greengram (215 kg REY/ha) and rice–radish–cowpea (213 kg REY/ha). Rice–*toria* cropping system showed the least IWUE (Table 3). The other cropping systems recorded IWUE in the range of 140 to 196 kg REY/ha. Groundnut, being a long-duration crop (117 days) among the *rabi* and summer crops, required highest number of irrigations and thus the systems having groundnut in the sequence registered lower irrigation water-use efficiency.

Higher apparent nutrient-use efficiency (ANUE) was realized with the rice–groundnut–bottle gourd (60.8 kg REY/kg NPK applied), followed by rice–groundnut–greengram (Table 3). The lower ANUE was recorded with rice–*toria*, rice–*toria*–greengram and rice–*rajma*–greengram cropping systems.

Energy-use efficiency

Total energy inputs in different cropping systems varied from 36,011 to 58,566 MJ/ha (Table 3). The highest energy input was recorded in rice–groundnut–bottle gourd (58,566 MJ/ha), followed by rice–groundnut–cowpea (57,546 MJ/ha) and rice–maize–cowpea (56,888 MJ/ha), whereas in existing rice–groundnut cropping system total 43,797 MJ/ha energy was required. The lowest energy input was required for rice–*toria*, which was obvious for a two-crop pattern. The higher energy inputs required for cropping systems with groundnut and maize might be due to the use of energy-richer inputs like seed and fertilizer, respectively, in higher quantity. Total energy output was computed from main product and by-product of different cropping systems and it ranged from 210,150 to 334,987 MJ/ha (Table 3). The highest total energy output was obtained from rice–maize–cowpea, followed by rice–groundnut–cowpea and rice–groundnut–greengram and this was mainly owing to higher by-product energy-equivalent from maize and groundnut. The lowest energy output was obtained from rice–*toria* system.

Rice–groundnut–bottle gourd system revealed the lowest energy-use efficiency (4.68). The energy-use efficiency values for all other cropping systems ranged from 5.32 to 5.89 (rice–maize–cowpea). Average maximum energy productivity was obtained in rice–maize–cowpea (0.34 kg REY/MJ) and it was owing to its higher total energy output. The other systems having high energy productivity were rice–radish–greengram, rice–groundnut–bottle gourd and rice–radish–cowpea. Inclusion of vegetables like cowpea, radish and bottle gourd in a cropping system increased the energy productivity by 29–42% as compared to rice–groundnut (0.24 kg REY/MJ) cropping system.

Table 3. Resource-use efficiency, energy-use efficiency, system productivity and production efficiency of rice-based diversified cropping systems (average of 7 years)

Crop sequences	System duration (days)	Land-use efficiency (%)	ANUE (kg REY/ kg NPK applied)	Irrigation water-use efficiency (kg REY/ha/cm)	Energy input ($\times10^3$ MJ/ha)	Energy output ($\times10^3$ MJ/ha)	Energy-use efficiency	Energy-output efficiency ($\times10^3$ MJ/ha/day)	Energy productivity (kg REY/MJ)	System productivity (kg REY/ ha/day)	Production efficiency (kg REY/ ha/day)	Relative production efficiency (%)
Rice–groundnut	238	65.2	52.3	150.3	43.79	248.4	5.67	1.04	0.24	28.8	44.2	-
Rice–*toria*	197	54.0	31.1	74.83	36.01	210.1	5.84	1.07	0.20	19.5	36.1	-32.4
Rice–groundnut–greengram	305	83.6	54.0	154.3	56.01	297.9	5.32	0.98	0.26	40.2	48.1	39.4
Rice–groundnut–cowpea	303	83.0	49.0	149.6	57.54	312.2	5.43	1.03	0.25	38.9	46.9	35.1
Rice–groundnut–bottle gourd	303	83.0	60.8	195.5	58.57	274.0	4.68	0.90	0.32	50.9	61.3	76.5
Rice–*toria*–greengram	264	72.3	37.7	141.2	48.23	258.9	5.37	0.98	0.23	30.9	42.8	7.4
Rice–radish–cowpea	239	65.5	42.1	213.4	47.75	266.2	5.57	1.11	0.31	40.9	62.5	42.0
Rice–radish–greengram	241	66.0	44.8	214.9	46.22	263.6	5.70	1.09	0.33	41.2	62.4	43.0
Rice–*rajma*–greengram	276	75.6	39.4	163.1	50.62	272.7	5.39	0.99	0.27	38.0	50.2	31.8
Rice–maize–cowpea	270	74.0	47.0	230.0	56.88	335.0	5.89	1.24	0.34	53.6	72.4	85.8
SEm±			2.62	10.48		5.92	0.14	0.02	0.01	1.26	2.91	
CD (P=0.05)			7.79	31.28		17.63	0.42	0.05	0.03	3.75	8.68	

ANUE, apparent nutrient-use efficiency; REY, rice-equivalent yield

The highest average value of energy-output efficiency was recorded in rice–maize–cowpea system (1240 MJ/ha/day) followed by rice–radish–cowpea.

Employment-generation efficiency

Crop diversification through intensification not only enhances the productivity and the profitability of the farmers but also generates employment to the farming community for the longer periods which help in minimizing the problem of migration during lean periods (Kachroo *et al*., 2014). Employment-generation efficiency of any diversified system is a direct measure of its profitability in an area (Thakur *et al*., 2009). Rice–maize–cowpea had highest engagement of man-days (455 days), followed by rice–groundnut–bottle gourd (440 days) and rice–groundnut–cowpea (338 days). These 3 systems had employment-generation efficiency of 124.7, 120.5 and 120.0% respectively (Table 4). Rice–*toria* cropping system recorded the least employment-generation efficiency. Rice–groundnut, rice–*rajma*–greengram, rice–radish–greengram and rice–*toria*–greengram also recorded employment-generation efficiency less than 100%. Likewise, Kachroo *et al.* (2011) reported that cropping systems with vegetables having high productivity had higher employment generation efficiency.

Monetary returns and economic viability

Among 10 cropping systems, rice–maize–cowpea and rice–groundnut–bottle gourd systems gave higher returns. Rice–maize–cowpea gave the highest gross and net returns of ₹221,587 and ₹135,087/ha, respectively, followed by rice–groundnut–bottle gourd system with gross and net returns of ₹210,277 and ₹111,777/ha respectively (Table 4). Rice–radish–greengram and rice–radish–cowpea were the next best cropping systems. Maize sold as green cobs and vegetables like bottle gourd and cowpea fetched better market price, besides being high yielders, which has contributed to higher net returns of the systems comprising these crops. Bastia *et al*. (2008) also concluded that, inclusion of vegetables and maize (for green cob purpose) as a *rabi* crop in the rice-based cropping system were remunerative. The rice–*toria* system recorded the least gross and net returns, followed by rice–groundnut system. The other 3-crop systems also recorded lower net returns, in the range of ₹56,843 to ₹78,860/ha.

Rice–maize–cowpea system recorded the highest system profitability (₹370/ha/day) and crop profitability (₹500/ha/day). Rice–groundnut–bottle gourd and rice–radish–greengram also registered higher system profitability and crop profitability as compared to other systems. The rice–*toria* system recorded the least system profitability and crop profitability. Rice–maize–cowpea (2.56), rice–radish–greengram (2.32) and rice–groundnut–bottle gourd (2.13) systems also recorded higher benefit: cost ratio (Table 4).

Relative productivity and economic efficiency

Rice–groundnut and rice–*toria* are the two prevalent cropping systems followed in the region. However, relative efficiency of different cropping systems were worked out with respect to the total productivity and economics over the existing rice–groundnut cropping system. Both relative productivity efficiency and relative economic efficiency for the rice–*toria* system were found negative.

Table 4. Employment-generation efficiency and economics of rice-based diversified cropping systems (average of 7 years)

Crop sequences	Man-days employment of the system (days)	Employment-generation efficiency (%)	Cost of cultivation ($\times 10^3$ ₹/ha)	Net returns ($\times 10^3$ ₹/ha)	Benefit: cost ratio	Crop profitability (₹/ha/day)	System profitability (₹/ha/day)	Relative economic efficiency (%)
Rice–groundnut	320	87.7	72.0	50.3	1.70	211	138	
Rice–*toria*	270	74.0	51.5	33.0	1.64	168	90	-34.4
Rice–groundnut–greengram	385	105.5	94.0	73.8	1.78	242	202	46.6
Rice–groundnut–cowpea	438	120.0	98.5	64.6	1.66	213	177	28.3
Rice–groundnut–bottle gourd	440	120.5	98.5	111.8	2.13	369	306	122.1
Rice–*toria*–greengram	335	91.8	73.5	56.8	1.77	215	156	13.0
Rice–radish–cowpea	391	107.1	78.5	92.1	2.17	385	252	83.0
Rice–radish–greengram	338	92.6	74.0	97.9	2.32	406	268	94.6
Rice–*rajma*–greengram	320	87.7	80.5	78.9	1.98	286	216	56.7
Rice–maize–cowpea	455	124.7	86.5	135.1	2.56	500	370	168.5
SEm±				3.44		14.84	9.42	
CD (P=0.05)				10.28		44.25	28.10	

Sales price (₹/t): rice grain, 11,000; rice straw, 1,000; *toria*, 25,000; green gram, 40,000; groundnut, 27,000; radish, 3,500; cowpea, 10,000; bottle gourd, 8,000; *rajma*, 30000; maize, ₹2.50/ green cob

Table 5. Changes in soil fertility status after 7 years of cropping cycle under rice-based diversified cropping systems

Crop sequence	*p*H	Organic carbon (%)	Available nutrient (kg/ha)		
			N	P	K
Rice–groundnut		0.69	294.5	13.0	140.2
Rice–*toria*	5.43	0.70	296.5	13.8	124.3
Rice–groundnut–greengram	5.30	0.83	336.3	15.3	154.9
Rice–groundnut–cowpea	5.57	0.82	330.3	15.5	151.2
Rice–groundnut–bottle gourd	5.83	0.72	310.2	14.3	134.0
Rice–*toria*–greengram	5.47	0.81	326.1	14.8	145.6
Rice–radish–cowpea	5.73	0.74	316.7	14.7	140.6
Rice–radish–greengram	5.70	0.80	312.6	14.6	136.5
Rice–*rajma*–greengram	5.60	0.80	335.7	14.9	144.9
Rice–maize–cowpea	5.53	0.73	313.5	14.3	133.2
Initial status	5.60	0.63	305.4	16.2	190.4

The highest positive relative production efficiency (85.8%) was noted in rice–maize–cowpea, followed by rice–groundnut–bottle gourd (76.5%) (Table 3). Similarly, the relative economic efficiency was also found highest (168.5%) in rice–maize–cowpea, followed by rice–groundnut–bottle gourd (122.1%) (Table 4), which indicated their efficient productivity relatively over existing rice–groundnut system. On the other hand, rice–*toria*–greengram and rice–groundnut–cowpea systems recorded only 13.0 and 28.3% relative economic efficiency respectively.

Soil fertility and health

The soil *p*H did not show any difference of treatments over the initial *p*H value after 7 cropping system cycles. The initial soil organic carbon content was 0.63% and after seven years of cropping it varied from 0.69 to 0.83% in different rice-based cropping systems (Table 5). The cropping systems which include two legumes like groundnut–cowpea, groundnut–greengram and *rajma*–greengram improved soil organic carbon content by 28.6 to 31.7% over the initial value.

After seven years of experimentation, the available N content increased in all the 3-crop systems over the initial value of 305.4 kg/ha. The cropping systems having 2 legumes in the sequence increased available N content by 8.2 to 10.1% as compared to 1.6 to 3.7% increase in the systems with only 1 legume. This was mainly due to cowpea and greengram symbiotically fixed atmospheric nitrogen in the soil and also left huge quantity of crop residue in the form of roots and leaves in the soil. However, the available P and K content in soil decreased after completion of 7 cropping cycles, though the depletion in K was more pronounced than that of P. The highest decrease (19.8%) in available P content was noticed in rice–groundnut system over the initial value of 16.2 kg/ha, followed by rice–*toria* (14.8%). The available K content decreased by 20.6 to 34.7% from the initial values of 190.4 kg/ha, the highest decrease was recorded with rice–*toria* followed by rice–maize–cowpea cropping system (30%).

Thus, it can be concluded that rice–maize–cowpea and rice–groundnut–bottle gourd cropping systems were the most productive and remunerative under irrigated condition in West Central Table Land zone of Odisha, and can be followed in place of existing rice–groundnut or rice–*toria* systems.

REFERENCES

Anderson, R.I. 2005. Are some crops synergistic to following crops? *Agronomy Journal* **97**(1): 7–10.

Bastia, D.K., Garnayak, L.M. and Barik, T. 2008. Diversification of rice (*Oryza sativa*)-based cropping systems for higher productivity, resource-use efficiency and economics. *Indian Journal of Agronomy* **53**(1): 22–26.

Devasenapathy, P., Senthil Kumar, G. and Shanmugam, P.M. 2009. Energy management in crop production. *Indian Journal of Agronomy* **54**(1): 80–89.

Gangwar, B. and Ram, B. 2005. Diversification opportunities in rice–wheat cropping system, pp. 154–162. (In) *Alternative Farming Systems.* Singh, A.K., Gangwar, B. and Sharma, S.K. (Eds). ICAR-Project Directorate for Farming Systems Research, Modipuram, Meerut, Uttar Pradesh

Gangwar, B., Katyal, V. and Anand, K.V. 2003. Efficient cropping systems for coastal areas in India. *Journal of Indian Society of Coastal Agricultural Research* **21**(1): 21–30.

Gangwar, B., Katyal, V. and Anand, K.V. 2004. Stability and efficiency of cropping systems in Chhattisgarh and Madhya Pradesh. *Indian Journal of Agricultural Sciences* **74**(10): 521–528.

Jackson, M.L. 1973. *Soil Chemical Analysis,* pp. 183–204. Prentice Hall of India Pvt. Ltd, New Delhi.

Kachroo, D., Kour, M., Kumar, P. and Thakur, N.P. 2011. Efficient alternative cropping system under western Himalyan region. pp. 4–11. (In) *Efficient Alternative Cropping System,* Gangwar, B. and Singh, A.K. (Eds). ICAR-Project Directorate for Farming Systems Research, Modipuram, Meerut, Uttar Pradesh

Kachroo, D., Thakur, N.P., Kour, M., Kumar, P., Sharma, R. and

Khajuria, V. 2014. Diversification of rice (*Oryza sativa*)-based cropping system for enhancing productivity and employment. *Indian Journal of Agronomy* **59**(1): 21–25.

Singh, S. and Mittal, J.P. 1992. *Energy in Production Agriculture,* pp. 143. Mittal Publications, New Delhi.

Thakur, N.P., Kachroo, D., Kumar, J., Kour, M. and Kumar, P**.** 2009**.** Diversification of rice–wheat cropping system for enhancing resource use-efficiency and profitability under sub–humid Indo-Gangetic plains of Jammu region. *Oryza* **46**(2): 108–112.

Tomar, S.S. and Tiwari, A.S. 1990. Production potential and economics of different crop sequences. *Indian Journal of Agronomy* **35**(1 & 2): 30–35.

Urkurkar, J.S., Chitale, S., Tiwari, A., Savu, R.M. and Tomar, H.S. 2008. Identification of promising rice (*Oryza sativa*)-based cropping system for increasing productivity and sustainability for Chhattisgarh plains. *Journal of Farming System Research and Development* **14**(1): 50–55.

Yadav, J.S.P. 2002. Agricultural resources management in India: the challenges. *Journal of Agricultural Water Management* **1**(1): 61–69.