Plant Archives Vol. 26, No. 2, 2026 pp. 3292-3300 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.2.457

SUSTAINABLE INTENSIFICATION OF RICE-BASED CROPPING SYSTEMS THROUGH DIVERSIFICATION: PRODUCTIVITY AND ECONOMIC EVALUATION

Bibhuti Bhusan Behera[1], Sayantani Purkait[1], Alok Kumar Patra[1], Sayani Das[2*], Manas Ranjan Nayak[1] and Amaresh Khuntia[1]

[1]Odisha University of Agriculture and Technology, Bhubaneswar - 751 003, Odisha, India.

[2]Bidhan Chandra Krishi Viswavidyalaya, West Bengal - 741 252, India.

*Corresponding author E-mail : sdasagron@gmail.com

(Date of Receiving-01-06-2026; Date of Revision-22-07-2026; Date of Acceptance-06-08-2026)

ABSTRACT

A field experiment was conducted during 2023–24 under irrigated medium land conditions of Eastern India to evaluate the productivity, resource use efficiency and profitability of diversified rice (*Oryza sativa* L.)-based cropping systems. Twelve rice-based cropping systems comprising cereals, legumes, fodders and vegetable crops were evaluated in a randomized block design with three replications. The cropping systems significantly influenced system productivity, efficiency and economics. Among the cropping systems, scented rice–sweet corn–cowpea (vegetable) recorded the highest rice equivalent yield (16.38 t ha^{-1}) followed by scented rice–broccoli–okra (16.30 t ha^{-1}) and rice–groundnut–okra (15.99 t ha^{-1}). The highest system productivity (44.9 kg REY ha^{-1} day^{-1}) and production efficiency (57.5 kg REY ha^{-1} day^{-1}) were recorded under scented rice–sweet corn–cowpea (vegetable). Land use efficiency was highest in rice–groundnut–okra (85%), whereas maximum irrigation water use efficiency (218 kg REY ha^{-1} cm^{-1}) was recorded in GM-rice–cowpea (vegetable)–greengram. The highest apparent nutrient use productivity was obtained under rice–groundnut–blackgram (39.4 kg REY kg^{-1} nutrient applied).

Economic analysis revealed that scented rice–sweet corn–cowpea (vegetable) recorded the highest gross return (Rs.392756 ha^{-1}), net return (Rs.178032 ha^{-1}), system profitability (Rs.487.8 ha^{-1} day^{-1}) and benefit:cost ratio (1.83). The scented rice–sweet corn–cowpea (vegetable) system resulted in 18.6% higher net return over the existing rice–groundnut–okra system. The study indicated that diversification of rice-based systems with high-value vegetables enhanced productivity, profitability and resource use efficiency and can be a viable option for sustainable intensification of rice-based production systems under irrigated conditions of Eastern India.

Key words : Rice-based cropping system, Diversification, Rice equivalent yield, Resource use efficiency, Profitability, Vegetables.

Introduction

Rice (*Oryza sativa* L.)-based cropping systems are the major production systems in eastern India, where rice is traditionally cultivated as the main *kharif* crop under irrigated ecosystems. However, continuous rice cultivation with limited diversification often leads to inefficient utilization of land, water and other production resources (Rosenberg *et al*., 2025; Upadhaya *et al*., 2022). The profitability of rice-based systems mainly depends on the choice and performance of succeeding crops, particularly during rabi and summer seasons, as the contribution of these crops determines the overall productivity and economic return of the system.

Crop diversification through inclusion of legumes, oilseeds, fodders and high-value vegetables in rice-based systems has emerged as an important approach for enhancing system productivity, profitability and sustainability (Alam *et al*., 2021; Jat *et al*., 2012; Singh, 2010). Integration of short-duration and high-value crops such as sweet corn, broccoli, okra and vegetable cowpea

provides better economic returns and improves resource use efficiency by utilizing residual soil moisture, nutrients and available growing period (Sharma *et al*., 2007; Kachroo *et al*., 2014). Moreover, inclusion of legumes in cropping sequences helps in improving nutrient cycling and maintaining soil fertility through biological nitrogen fixation (Foyer *et al*., 2016; Hazra *et al*., 2020; Liu *et al*., 2022).

Rice equivalent yield (REY) is an important indicator for comparing the productivity of different cropping systems involving crops with varying economic values. The overall performance of a cropping system depends not only on yield but also on production efficiency, land utilization, water use efficiency and economic profitability. Therefore, selection of suitable crop combinations is essential for sustainable intensification of rice-based systems.

Although, farmers in eastern India adopt diverse rice-based cropping sequences, information on the comparative productivity, resource use efficiency and profitability of diversified rice-based systems involving vegetables under irrigated conditions is limited. Therefore, the present investigation was undertaken to evaluate the productivity, resource use efficiency and economic performance of different diversified rice-based cropping systems under irrigated conditions of Eastern India.

Materials and Methods

Experimental site and soil characteristics

A field experiment was conducted during 2023–24 under irrigated conditions at the experimental farm of Bhubaneswar, Odisha, India to evaluate the productivity, resource use efficiency and profitability of diversified rice-based cropping systems. The experimental site is situated in the Eastern coastal plain agro-climatic zone of Odisha. It is located at latitude of 20º 15′ N and a longitude of 85º 52′ E, with an elevation of 25.9 meters above mean sea level. It is situated approximately 64 kilometers from the Bay of Bengal and is classified within the East and South Eastern Coastal Plain Agro-climatic Zone of Odisha. The soil of the experimental field was an Inceptisol with suitable fertility status for crop production.

Experimental design and treatments

The experiment was laid out in a randomized block design (RBD) with three replications. Twelve rice-based cropping systems comprising cereals, legumes, fodder crops and vegetables were evaluated. All crops were grown following the recommended package of practices for the respective crops.

Observations recorded

Rice equivalent yield (REY) : The value of the produce per hectare of each crop was calculated as per the prevailing market price. It was divided by the value of rice kg^{-1} to get the rice- equivalent yield in kg ha^{-1}. Sum total REY of component crops of a system was the REY of the system.

$$\text{REY (t ha}^{-1}) = \frac{\text{Yield of crop (t ha}^{-1}) \times \text{Price of crop (Rs. kg}^{-1})}{\text{Price of rice (Rs. kg}^{-1})}$$

System productivity (SP) : System productivity of different rice-based cropping systems was obtained by

Table 1 : Treatment details.

	Cropping system	***Kharif***	***Rabi***	**Summer**
T_1	Pre- dominate cropping system of the region	Rice	Groundnut	Okra
T_2		Rice	Greangram	Okra
T_3	Ecological cropping system involving pulses/ green manures and other crops for improving soil health	Green manuring - rice	Greengram	Cowpea (vegetable)
T_4		Green manuring - rice	Cowpea (vegetable)	Greengram
T_5	Cropping system involving cereals/ pulses/oilseeds to meet the household nutritional security	Rice	Rapeseed	Greengram
T_6		Rice	Sunflower	Blackgram
T_7	Cropping system for round the year green/ dry fodder production	Rice	Oat	Fodder cowpea
T_8		Rice	Fodder maize	Fodder cowpea
T_9	Cropping system for livestock and nutrition:concentrate feed production	Rice	Groundnut	Blackgram
T_{10}		Rice	Ricebean	Maize
T_{11}	Cropping system involving vegetables and other high value crops for income enhancement	Scented rice	Broccoli	Okra
T_{12}		Scented rice	Sweet corn	Cowpea (Vegetable)

dividing the system yield with 365 and was expressed in kg REY $ha^{-1}day^{-1}$.

$$SP = \frac{\text{Total productivity of the system (kg ha}^{-1})}{\text{365 day}}$$

Production efficiency (PE) : Production efficiency was calculated by dividing the system yield by total duration of the system and was expressed in kg REY $ha^{-1}day^{-1}$.

$$PE = \frac{\text{Total productivity of the system (kg ha}^{-1})}{\text{Duration of the system (day)}}$$

Land use efficiency (LUE): Land use efficiency was calculated as total duration of a cropping system in the field expressed as percentage of number of days in a year.

Irrigation water use efficiency (IWUE): Irrigation water use efficiency is the system yield per unit depth of irrigation water required in a system and is expressed in kg REY $ha\text{-}cm^{-1}$. It 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.

$$IWUE = \frac{\text{System yield (kg REY ha}^{-1})}{\text{Irrigation water applied to the system (cm)}}$$

Apparent nutrient use productivity : Apparent nutrient use productivity (ANUP) was calculated by dividing the rice equivalent yield of the system with the total quantity of the nutrients applied to the system. This was calculated as per the formula given by Moll *et al.* (1982).

$$ANUP = \frac{\text{System productivity (kg REY ha}^{-1})}{\text{Total addition of a fertilizer nutrient to the system (kg ha}^{-1})}$$

Economics: The economics of production for different systems were calculated on the basis of prevailing market price for the cost of the inputs and value of the produce. Gross and net returns and benefit: cost ratio were calculated. Crop profitability in terms of Rs. ha^{-1} day^{-1} 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 the net returns (Rs. ha^{-1}) in a system by 365 days.

Statistical analysis : The experimental data were analysed using analysis of variance (ANOVA) appropriate for randomized block design. The significance of treatment effects was tested at 5% probability level and critical difference (CD) values were calculated wherever applicable.

Results and Discussion

Yield performance of crops under different rice-based cropping systems

The yield performance of individual crops in the different rice-based farming systems is presented in Table 2. Variation in crop yield was mainly due to differences in crop choice, crop duration, nutrient requirement and better utilisation of available growth resources under diverse cropping sequences.

In *kharif* season, the productivity of kharif rice ranged from 4743 to 5333 kg ha^{-1}. The highest grain and straw production of rice was obtained under GM-rice–greengram–cowpea (vegetable) (5333 kg ha^{-1}) followed by GM-rice–cowpea (vegetable)–greengram (5324 kg ha^{-1}) and rice–rapeseed–greengram (5038 kg ha^{-1}). The higher yield under green manure-based systems might be attributed to the beneficial effect of green manure incorporation on soil nutrient availability and improved crop growth. Similar results were reported by Nie *et al.* (2025) and Wei *et al.* (2025).

The *rabi* crop yield showed wide variation among the cropping systems depending on the nature of component crops. The highest yield was recorded under rice–oat (fodder)–cowpea (fodder) (43019 kg ha^{-1}) followed by scented rice–sweetcorn–cowpea (41217 kg ha^{-1}).

During summer, the highest yield was recorded under Rice-maize (fodder)-cowpea (fodder) (35067 kg ha^{-1}) followed by Rice-oat(fodder)-cowpea (fodder) (32857 kg ha^{-1}). The variation in summer crop productivity indicated the influence of crop suitability and environmental conditions during the growing period.

System productivity in terms of rice equivalent yield (REY)

The rice equivalent yield (REY) of different rice-based cropping systems varied significantly due to differences in crop productivity, economic value and market price of component crops (Table 3). The system productivity is influenced by the combined effect of crop yield, duration and economic returns of individual crops in a sequence.

Among the evaluated cropping systems, scented rice–sweetcorn–cowpea (vegetable) recorded the highest system REY (16382 kg ha^{-1}) and remained statistically at par with scented rice–broccoli–okra (16297 kg ha^{-1}). The higher system productivity in these systems was mainly attributed to the inclusion of high-value vegetable crops, which contributed greater economic yield compared to conventional cereal and pulse-based

Table 2 : Effect of rice-based cropping systems on yield of *kharif*, *rabi* and *summer* crops.

Cropping system	Yield (kg ha^{-1})					
	Kharif		*Rabi*		Summer	
	Main product	By-product	Main product	By-product	Main product	By-product
Rice-groundnut-okra	4943	4996	1914	2392	6486	3150
Rice-greengram-okra	4952	4962	695	1659	6752	3064
GM-rice-greengram-cowpea (veg)	5333	5238	810	1761	5686	1610
GM-rice-cowpea (veg)-greengram	5324	5248	6143	2716	895	1539
Rice-rapeseed-greengram	5038	5065	800	2401	810	1590
Rice-sunflower-blackgram	4971	5019	1067	3209	899	1783
Rice-oat(fodder)-cowpea (fodder)	5019	4990	43019	-	32857	-
Rice-maize (fodder)-cowpea (fodder)	4810	4857	40038	-	35067	-
Rice-groundnut-blackgram	5095	5151	1864	2962	931	1864
Rice-ricebean-maize	4981	5019	1029	2905	7257	2648
Scented rice-broccoli-okra	4743	4819	7791	3346	6733	3229
Scented rice-sweetcorn-cowpea (veg)	4752	4886	41217	6950	5448	1670

Table 3 : Effect of rice-based cropping systems on system rice equivalent yield (REY).

Cropping system	REY (kg ha^{-1})			
	Kharif	*Rabi*	Summer	Total
Rice-groundnut-okra	4943	5410	5640	15993
Rice-greengram-okra	4952	2720	5872	13545
GM-rice-greengram-cowpea (veg)	5333	3168	4944	13445
GM-rice-cowpea (veg)-greengram	5324	5342	3503	14169
Rice-rapeseed-greengram	5038	2087	3168	10293
Rice-sunflower-blackgram	4971	3248	2933	11152
Rice-oat(fodder)-cowpea (fodder)	5019	2806	2500	10325
Rice-maize (fodder)-cowpea (fodder)	4810	2611	2668	10089
Rice-groundnut-blackgram	5095	5266	3037	13399
Rice-ricebean-maize	4981	1343	6311	12634
Scented rice-broccoli-okra	5361	5081	5855	16297
Scented rice-sweetcorn-cowpea (veg)	5372	6272	4737	16382
SEm (±)				187
CD (0.05)				548

Sale price (Rs.kg^{-1}): Rice grain: 23, scented rice grain: 26, groundnut: 65, okra: 20, greengram: 90, cowpea (vegetable): 20, rapeseed :60, sunflower: 70, blackgram: 75, oat (fodder): 1.50, maize (fodder): 1.50, cowpea (fodder): 1.75, ricebean: 30, maize: 20, broccoli: 15 and sweet corn: 3.50 cob^{-1}.

sequences.

The lowest system REY was recorded under rice–maize (fodder)–cowpea (fodder) (10089 kg ha^{-1}) followed by rice–rapeseed–greengram (10293 kg ha^{-1}) and rice–oat (fodder)–cowpea (fodder) (10325 kg ha^{-1}), which may be due to lower economic value of fodder and oilseed crops compared with vegetable-based systems.

The present findings indicate that inclusion of vegetables in rice-based cropping systems improves system productivity and economic efficiency. Similar enhancement in productivity of diversified rice-based systems has been reported by Bastia *et al*. (2008), Patra *et al*. (2017), Patra *et al*. (2019a) and Singh *et al*. (2017).

System duration, system productivity and production efficiency under different rice-based cropping systems

The system duration, productivity and production efficiency of different rice-based cropping systems varied considerably due to differences in crop combination, crop duration and productivity of individual components (Table 4). The duration of cropping systems ranged from 235 to 311 days. The maximum system duration was recorded under rice–groundnut–okra (311 days) followed by rice–groundnut–blackgram (302 days) and scented rice–broccoli–okra (297 days). The longer duration in these systems was mainly due to the inclusion of crops with longer field occupancy. The minimum system duration was recorded under rice–maize (fodder)–cowpea (fodder) (235 days).

System productivity expressed as rice equivalent yield per day varied significantly among different cropping

Table 4 : Effect of rice-based cropping systems on system duration, system productivity and production efficiency.

Cropping system	System duration (days)	System productivity (kg REY ha^{-1} day^{-1})	Production efficiency (kg REY ha^{-1} day^{-1})
Rice-groundnut-okra	311	43.8	51.4
Rice-greengram-okra	277	37.1	48.9
GM-rice-greengram-cowpea (veg)	265	36.8	50.7
GM-rice-cowpea (veg)-greengram	260	38.8	54.5
Rice-rapeseed-greengram	263	28.2	39.1
Rice-sunflower-blackgram	282	30.6	39.5
Rice-oat(fodder)-cowpea (fodder)	270	28.3	38.2
Rice-maize (fodder)-cowpea (fodder)	235	27.6	42.9
Rice-groundnut-blackgram	302	36.7	44.4
Rice-ricebean-maize	280	34.6	45.1
Scented rice-broccoli-okra	297	44.7	54.9
Scented rice-sweetcorn-cowpea (veg)	285	44.9	57.5

Table 5 : Effect of rice-based cropping systems on land use efficiency, irrigation water use efficiency and apparent nutrient use productivity.

Cropping system	Land use efficiency (%)	Irrigation water use efficiency (kg REY ha^{-1} cm^{-1})	Apparent nutrient use productivity (kg REY kg^{-1} nutrient applied)
Rice-groundnut-okra	85	160	38.1
Rice-greengram-okra	76	181	33.9
GM-rice-greengram-cowpea (veg)	73	192	36.8
GM-rice-cowpea (veg)-greengram	71	218	38.8
Rice-rapeseed-greengram	72	158	28.6
Rice-sunflower-blackgram	77	172	27.9
Rice-oat(fodder)-cowpea (fodder)	74	159	28.7
Rice-maize (fodder)-cowpea (fodder)	64	168	28.0
Rice-groundnut-blackgram	83	158	39.4
Rice-ricebean-maize	77	180	24.3
Scented rice-broccoli-okra	81	181	34.0
Scented rice-sweetcorn-cowpea (veg)	78	193	36.8

systems. The highest system productivity was recorded under scented rice–sweetcorn–cowpea (vegetable) (44.9 kg REY ha^{-1} day^{-1}) followed by scented rice–broccoli–okra (44.7 kg REY ha^{-1} day^{-1}) and rice–groundnut–okra (43.8 kg REY ha^{-1} day^{-1}). Higher system productivity in these systems was mainly associated with greater economic yield obtained from high-value vegetable crops and efficient utilization of available time and resources. The lowest system productivity was recorded under rice–maize (fodder)–cowpea (fodder) (27.6 kg REY ha^{-1} day^{-1}) followed by rice–rapeseed–greengram (28.2 kg REY ha^{-1} day^{-1}), mainly due to comparatively lower economic return of component crops.

Production efficiency followed a similar trend among cropping systems. The highest production efficiency was recorded in scented rice–sweetcorn–cowpea (vegetable) (57.5 kg REY ha^{-1} day^{-1}) followed by scented rice–broccoli–okra (54.9 kg REY ha^{-1} day^{-1}) and GM-rice–cowpea (vegetable)–greengram (54.5 kg REY ha^{-1} day^{-1}). The lowest production efficiency was observed under rice–oat (fodder)–cowpea (fodder) (38.2 kg REY ha^{-1} day^{-1}). The higher production efficiency in diversified vegetable-based systems indicated better conversion of land, time and production inputs into economic yield.

The results suggest that inclusion of high-value vegetable crops in rice-based systems enhanced productivity per unit time and improved overall system performance. Similar findings on higher productivity and efficiency of diversified rice-based cropping systems have been reported by Kachroo *et al*. (2014), Patra *et al*. (2017), Upadhaya *et al*. (2022).

Table 6 : Cost of cultivation of rice-based cropping system (Rs. ha^{-1}).

Cropping system	*Kharif*	*Rabi*	Summer	Total (Rs. ha^{-1})
Rice-groundnut-okra	79254	78795	78777	236826
Rice-greengram-okra	79254	38431	78777	196462
GM-rice-greengram-cowpea (veg)	84258	38431	66987	189676
GM-rice-cowpea (veg)-greengram	84258	66987	38431	189676
Rice-rapeseed-greengram	79254	37143	38431	154828
Rice-sunflower-blackgram	79254	41011	38181	158445
Rice-oat(fodder)-cowpea (fodder)	79254	34208	34561	148023
Rice-maize (fodder)-cowpea (fodder)	79254	33933	34561	147748
Rice-groundnut-blackgram	79254	78795	38181	196230
Rice-ricebean-maize	79254	24447	80517	184218
Scented rice-broccoli-okra	79434	54384	78777	212595
Scented rice-sweetcorn-cowpea (veg)	79434	68303	66987	214724
SEm (±)				1271
CD (0.05)				3738

Table 7 : Gross return of rice-based cropping system (Rs. ha^{-1}).

Cropping system	*Kharif*	*Rabi*	Summer	Total (Rs. ha^{-1})
Rice-groundnut-okra	118682	126821	132864	378367
Rice-greengram-okra	118867	64230	138111	321209
GM-rice-greengram-cowpea (veg)	127905	74618	115324	317847
GM-rice-cowpea (veg)-greengram	127695	125573	82110	335379
Rice-rapeseed-greengram	120941	50401	74448	245790
Rice-sunflower-blackgram	119362	77922	69233	266517
Rice-oat(fodder)-cowpea (fodder)	120429	64529	57500	242457
Rice-maize (fodder)-cowpea (fodder)	115476	60057	61367	236900
Rice-groundnut-blackgram	122341	124091	71714	318146
Rice-ricebean-maize	119581	33785	147794	301160
Scented rice-broccoli-okra	128133	120206	137895	386234
Scented rice-sweetcorn-cowpea (veg)	128448	151210	113098	392756
SEm (±)				4344
CD (0.05)				12740

Resource use efficiency under different rice-based cropping systems

Resource use efficiency varied considerably among different rice-based cropping systems (Table 5). Land use efficiency was highest in rice–groundnut–okra (85%) followed by rice–groundnut–blackgram (83%) and scented rice–broccoli–okra (81%), while the lowest was recorded in rice–maize (fodder)–cowpea (fodder) system (64%). Higher land use efficiency in diversified systems was mainly attributed to the inclusion of high-duration and high-yielding crops, which ensured better utilization of land throughout the year. Similar results were reported by Kachroo *et al*. (2014) and Patra *et al*. (2017).

Irrigation water use efficiency ranged from 158 to 218 kg REY ha^{-1} cm^{-1} among the cropping systems. The maximum water use efficiency was observed in GM–rice–cowpea (vegetable)–greengram (218 kg REY ha^{-1} cm^{-1}) followed by scented rice–sweetcorn–cowpea (vegetable) (193 kg REY ha^{-1} cm^{-1}). The lowest water use efficiency was recorded in rice–rapeseed–greengram and rice–groundnut–blackgram (158 kg REY ha^{-1} cm^{-1}). Higher water use efficiency in vegetable-based systems was due to higher system productivity with efficient utilization of irrigation water. These findings were in agreement with Patra *et al*. (2017).

Apparent nutrient use productivity varied from 24.3 to 39.4 kg REY kg^{-1} nutrient applied. The highest apparent nutrient use productivity was obtained in rice–groundnut–blackgram (39.4 kg REY kg^{-1} nutrient applied) followed by GM–rice–cowpea (vegetable)–greengram (38.8 kg REY kg^{-1} nutrient applied), whereas the lowest was recorded in rice–ricebean–maize (24.3 kg REY kg^{-1} nutrient applied). The higher nutrient use productivity in diversified systems might be due to better nutrient recycling, inclusion of legumes and improved nutrient utilization by component crops. Similar findings were reported by Singh *et al*. (2012), Kachroo *et al*. (2014) and Patra *et al*. (2019b).

Economics of rice-based cropping systems

The economics of different rice-based cropping systems varied significantly due to differences in cost of cultivation, productivity and market value of component crops (Tables 6-8). The cost of cultivation ranged from Rs. 147748 to Rs.236826 ha^{-1}. The maximum cost of cultivation was recorded under rice–groundnut–okra (Rs.

Table 8 : Net return of rice-based cropping system (Rs. ha$^{-1)}$.

Cropping system	*Kharif*	*Rabi*	Summer	Total (Rs. ha^{-1})
Rice-groundnut-okra	39428	48026	54087	141541
Rice-greengram-okra	39613	25800	59335	124747
GM-rice-greengram-cowpea (veg)	43647	36187	48337	128171
GM-rice-cowpea (veg)-greengram	43437	58586	43680	145703
Rice-rapeseed-greengram	41687	13258	36017	90962
Rice-sunflower-blackgram	40108	36911	31052	108071
Rice-oat(fodder)-cowpea (fodder)	41175	30320	22939	94434
Rice-maize (fodder)-cowpea (fodder)	36222	26124	26806	89152
Rice-groundnut-blackgram	43087	45296	33533	121916
Rice-ricebean-maize	40327	9338	67277	116943
Scented rice-broccoli-okra	48699	65822	59118	173639
Scented rice-sweetcorn-cowpea (veg)	49014	82907	46111	178032
SEm (±)				4041
CD (0.05)				11851

was mainly due to higher input requirement and labour involvement.

The gross return varied significantly among the cropping systems. The highest gross return was obtained from scented rice–sweetcorn–cowpea (vegetable) (Rs. 392756 ha^{-1}) followed by scented rice–broccoli–okra (Rs. 386234 ha^{-1}). The higher gross return in these systems was mainly due to greater economic value of vegetable crops and higher system productivity. The lowest gross return was recorded under rice–maize (fodder)–cowpea (fodder) (Rs. 236900 ha^{-1}).

The net return was also influenced significantly by cropping system. The maximum net return was obtained under scented rice–sweetcorn–cowpea (vegetable) (Rs. 178032 ha^{-1}) followed by scented rice–broccoli–okra (Rs. 173639 ha^{-1}). The higher profitability of these systems was associated with higher gross returns obtained from high-value crops. The lowest net return was recorded under rice–maize (fodder)–cowpea (fodder) (Rs. 89152 ha^{-1}).

Overall, inclusion of vegetable crops in rice-based systems improved economic efficiency by enhancing productivity and returns (Srinivasan, 2025). The results indicate that scented rice–sweetcorn–cowpea (vegetable) and scented rice–broccoli–okra were the most profitable cropping systems under the experimental conditions.

Table 9 : Effect of rice-based cropping systems on economics.

Cropping system	Benefit: cost ratio	System profitability (Rs. ha^{-1} day^{-1})	Crop profitability (Rs. ha^{-1} day^{-1})
Rice-groundnut-okra	1.60	387.8	455.1
Rice-greengram-okra	1.63	341.8	450.4
GM-rice-greengram-cowpea (veg)	1.68	351.2	483.7
GM-rice-cowpea (veg)-greengram	1.77	399.2	560.4
Rice-rapeseed-greengram	1.59	249.2	345.9
Rice-sunflower-blackgram	1.68	296.1	383.2
Rice-oat(fodder)-cowpea (fodder)	1.64	258.7	349.8
Rice-maize (fodder)-cowpea (fodder)	1.60	244.3	379.4
Rice-groundnut-blackgram	1.62	334.0	403.7
Rice-ricebean-maize	1.63	320.4	417.7
Scented rice-broccoli-okra	1.82	475.7	584.6
Scented rice-sweetcorn-cowpea (veg)	1.83	487.8	624.7

Sale price (Rs.kg^{-1}): Rice grain: 23, scented rice grain: 26, groundnut: 65, okra: 20, greengram: 90, cowpea (vegetable): 20, rapeseed :60, sunflower: 70, blackgram: 75, oat (fodder): 1.50, maize (fodder): 1.50, cowpea (fodder): 1.75, ricebean: 30, maize: 20, broccoli: 15 and sweet corn: 3.50 cob^{-1}.

236826 ha^{-1}) followed by scented rice–sweetcorn–cowpea (vegetable) (Rs. 214724 ha^{-1}), whereas the minimum cost was recorded under rice–maize (fodder)–cowpea (fodder) (Rs. 147748 ha^{-1}). The higher cultivation cost in vegetable-based and groundnut-based systems

System profitability and crop profitability under different rice-based cropping systems

The economic performance of different rice-based cropping systems varied significantly (Table 9). The

benefit: cost ratio ranged from 1.59 to 1.83 among the cropping systems. The highest B:C ratio was recorded under scented rice–sweetcorn–cowpea (vegetable) (1.83) followed by scented rice–broccoli–okra (1.82), indicating better economic efficiency of vegetable-based cropping systems Similar result was reported by Kumar, 2015. The lowest B:C ratio was observed under rice–rapeseed–greengram (1.59).

System profitability was significantly influenced by cropping systems. The maximum system profitability was recorded under scented rice–sweetcorn–cowpea (vegetable) (Rs. 487.8 ha^{-1} day^{-1}) followed by scented rice–broccoli–okra (Rs.475.7 ha^{-1} day^{-1}). The higher profitability in these systems was mainly due to higher economic return from high-value vegetable crops. The lowest system profitability was recorded under rice–maize (fodder)–cowpea (fodder) (Rs. 244.3 ha^{-1} day^{-1}).

Similarly, crop profitability was highest under scented rice–sweetcorn–cowpea (vegetable) (Rs. 624.7 ha^{-1} day^{-1}) followed by scented rice–broccoli–okra (Rs. 584.6 ha^{-1} day^{-1}), whereas the lowest crop profitability was recorded under rice–rapeseed–greengram (Rs. 345.9 ha^{-1} day^{-1}).

Conclusion

The present experiment revealed that diversification of rice-based cropping systems with high-value vegetables and legumes significantly improved system productivity, resource use efficiency and profitability under irrigated conditions. Among the twelve cropping systems evaluated, scented rice–sweet corn–cowpea (vegetable) was found to be the most productive and profitable system, recording the highest system rice equivalent yield (16382 kg ha^{-1}), system productivity (44.9 kg REY ha^{-1} day^{-1}), production efficiency (57.5 kg REY ha^{-1} day^{-1}), net return (Rs. 178032 ha^{-1}) and benefit: cost ratio (1.83). The next best performing system was scented rice–broccoli–okra. The inclusion of vegetable crops enhanced economic returns due to higher market value and efficient utilization of available resources. Legume-based systems also showed better nutrient use efficiency, indicating their potential for sustainable intensification of rice-based cropping systems. Therefore, adoption of diversified rice-based cropping systems involving vegetables and legumes can improve productivity, profitability and sustainability in irrigated agroecosystems of eastern India.

Funding : The research was conducted with the kind and supports from Odisha University of Agriculture and Technology.

Conflict of interests : The authors have declared no conflict of interests exist.

References

Alam, M.J., Al-Mahmud A., Islam M.A., Hossain M.F., Ali M.A., Dessoky E.S., El-Hallous E.I., Hassan M.M., Begum N. and Hossain A. (2021). Crop Diversification in Rice—based Cropping Systems Improves the System Productivity, Profitability and Sustainability. *Sustainability*, **13(11)**, 6288. https://doi.org/10.3390/su13116288

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 J. Agron.*, **53(1)**, 22–26.

Foyer, C.H., Lam H.M., Nguyen H.T., Siddique K.H.M., Varshney R.K., Colmer T.D., Cowling W., Bramley H., Mori T.A., Hodgson J.M., Cooper J.W., Miller A.J., Kunert K., Vorster J., Cullis C., Ozga J.A., Wahlqvist M.L., Liang Y., Shou H. and Considine M.J. (2016). Neglecting legumes has compromised human health and sustainable food production. *Nature Plants*, **2**, 16112. https://doi.org/10.1038/nplants.2016.112

Hazra, K.K., Nath C.P., Ghosh P.K. and Swain D.K. (2020). Inclusion of legumes in rice–wheat cropping system for enhancing carbon sequestration. In : Ghosh, P., Mahanta S., Mandal D., Mandal B. and Ramakrishnan S. (Eds.), *Carbon management in tropical and sub-tropical terrestrial systems*. Springer, Singapore. https://doi.org/10.1007/978-981-13-9628-1_2

Jat, R.A., Dungrani R.A., Arvadia M.K. and Sahrawat K.L. (2012). Diversification of rice (*Oryza sativa* L.)-based cropping systems for higher productivity, resource-use efficiency and economic returns in South Gujarat, India. *Arch. Agron. Soil Sci.*, **58(6)**, 561–572. https://doi.org/10.1080/03650340.2010.533172

Kachroo, D., Thakur N.P., Kaur M., Kumar P., Sharma R. and Khajuria V. (2014). Diversification of rice (*Oryza sativa*)-based cropping system for enhancing productivity and employment. *Indian J. Agron.*, **59(1)**, 21–25.

Kumar, R. (2015). Productivity, profitability and nutrient uptake of maize (*Zea mays*) as influenced by management practices in North-East India. *Indian J. Agron.*, **60**, 273–278.

Liu, X., Tan S., Song X., Wu X., Zhao G., Li S. and Liang G. (2022). Response of soil organic carbon content to crop rotation and its controls: A global synthesis. *Agricult., Ecosyst. Environ.*, **335**, 108017. https://doi.org/10.1016/j.agee.2022.108017Moll, R. H., Kamprath, E. J., and Jackson, W. A. (1982). Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. Agronomy Journal, 74(3), 562–564. https://doi.org/10.2134/agronj1982.00021962007400030037x

Nie, J., Xie Q., Zhou Y., He F., Yousaf M., Zhu B. and Liu Z. (2025). Long-term legume green manure residue incorporation is more beneficial to improving bacterial richness, soil quality and rice yield than mowing under

double-rice cropping system in Dongting Lake Plain, China. *Front. Plant Sci.*, **16**, 1603434. https://doi.org/10.3389/fpls.2025.1603434

Patra, A.K., Garnayak L.M., Mishra K.N., Paikaray R.K. and Bastia D.K. (2019a). Productivity, resource-use efficiency and economics of rice (*Oryza sativa*)–based bio-intensive cropping systems in coastal Odisha. *Indian J. Agron.*, **64(2)**, 165–171.

Patra, A.K., Garnayak L.M., Mishra K.N., Paikaray R.K. and Bastia D.K. (2019b). Productivity, resource-use efficiency and economics of rice (*Oryza sativa*)-based bio-intensive cropping systems in coastal Odisha. *Indian J. Agron.*, **64(2)**, 165–171.

Patra, A.K., Mishra K.N., Garnayak L.M. and Halder J. (2017). Productivity and energy-efficiency indices for diversified rice (*Oryza sativa*)–based cropping systems in West Central Table Land Zone of Odisha. *Indian J. Agron.*, **62(4)**, 387–393.

Rosenberg, S., Gaudin A.C.M., Fenster T.L.D., Brim-DeForest W., Linquist B., Leinfelder-Miles M.M., Espino L., Al-Khatib K. and Pittelkow C.M. (2025). Benefits and tradeoffs of diversifying rice-based cropping systems: Impacts on soil health, productivity, and agroecosystem multifunctionality. *Agricult., Ecosyst. Environ.*, **391**, 109691. https://doi.org/10.1016/j.agee.2025.109691

Sharma, A.K., Thakur N.P., Kour M. and Kumar P. (2007). Profitable and energy efficient rice-based cropping system under subtropical irrigated conditions of Jammu. *J. Farm. Syst. Res. Develop.*, **13(1)**, 128–130.

Singh, D.K., Singh R., Singh G.D., Singh A.P., Chaturvedi S., Singh J., Rathi A. and Singh M. (2017). Diversification of rice (Oryza sativa)–wheat (*Triticum aestivum*) system and its influence on productivity, profitability and energetics under on-farm situation. *Indian J. Agron.*, **62(3)**, 255–259.

Singh, R.D. (2010). Food security for increasing rural livelihood under limited water supply through adoption of diversified crops and crop sequences. In : Khan, A.R., Singh S. S., Bharti R.C., Srivastava T.K. and Khan M.A. (Eds.), *Resource conservation technologies for food security and rural livelihood* (pp. 342–355). Agrotech Publishing Academy

Srinivasan, R. (2025). Diversification of Rice-Based Cropping Systems with Vegetables and Legumes in Asia and Africa. *Crops*, **5(4)**, 43. https://doi.org/10.3390/crops5040043

Upadhaya, B., Kishor K., Kumar V., Kumar N., Kumar S., Yadav V.K., Kumar R., Gaber A., Laing A.M., Brestic M. and Hossain A. (2022). Diversification of rice-based cropping system for improving system productivity and soil health in Eastern Gangetic Plains of India. *Agronomy*, **12(10)**, 2393.

Wei, C., Cao B., Gao S. and Liang H. (2025). Co-incorporation of green manure and rice straw increases ice yield and nutrient utilization. *Plants*, **14(11)**, 1678.