

## On-farm evaluation of rice (*Oryza sativa*)-based cropping systems for increasing system productivity, profitability, resource-use efficiency and energy productivity in mid-central table land zone of Odisha

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### ABSTRACT

A field experiment was conducted during 2011–12 and 2012–13 at farmers' field of Angul district under mid-central table land zone of Odisha, to assess productivity, profitability and resource-use efficiency of 5 different rice (*Oryza sativa* L.)-based cropping systems, viz. rice–groundnut (*Arachis hypogaea* L.), rice–greengram [*Vigna radiata* (L.) R. Wilczek], rice–cowpea [*Vigna unguiculata* (L.) Walp.], rice–okra [*Abelmoschus esculentus* (L.) Moench] and rice–onion (*Allium cepa* L.). Rice–onion and rice–okra cropping systems recorded significantly higher average rice-equivalent yields (15.47 and 14.67 t/ha respectively) than the other systems evaluated, the relative production efficiency being 104 and 94% over the existing rice–groundnut system (7.57 t/ha). The highest land-use efficiency was exhibited with rice–onion (73.7%). Rice–greengram exhibited the highest irrigation water-use efficiency (427 kg REY/ha), whereas rice–cowpea recorded the highest apparent nutrient-use productivity (56 kg REY/kg NPK applied). Rice–okra and rice–onion had higher employment-generation efficiency (116 and 108% respectively). Rice–cowpea showed the highest energy-use efficiency (6.30) and energy-output efficiency (844 MJ/ha/day). Rice–okra registered the highest net returns of ₹97,740/ha followed by rice–onion system (₹96,974/ha). These 2 systems revealed higher system profitability (₹268 and ₹266/ha/day) and crop profitability (₹386 and ₹360/ha/day). Rice–okra and rice–onion systems recorded higher benefit: cost ratio of 2.43 and 2.25 with higher relative production efficiency (94 and 104%) and relative economic efficiency (291 and 288%) compared to rice–groundnut system. Rice–okra and rice–onion cropping systems were the most productive and remunerative cropping systems and can be followed in place of existing rice–groundnut system under mid-central table land of Odisha with 8–9 irrigations to *rabi*/summer crops.

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

Rice–groundnut is the predominant cropping system in mid-central table land zone of Odisha, covering about 10,830 ha area with an average system rice-equivalent yield of 8.1 t/ha (Govt. of Odisha, 2015). This system is mostly grown under limited water availability where dug-well is the only source of irrigation during dry period since farmers prefer rice–rice system where assured irrigation is available. 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). Crop diversification during the winter (*rabi*) seasons plays significant role in augmenting the farm income per unit area with high water- and nutrient-use efficiency. Thus, diversification of rice-based systems to increase productivity per unit resource is very pertinent and the selection of the second crop is most important, as it decides the overall productivity and profitability of the system. Inclusion of vegetables in the rice-based cropping systems has been suggested for higher productivity and profitability in various agroclimatic zones (Sharma *et al.*, 2007; Bastia *et al.*, 2008; Kachroo *et al.*, 2014). Keeping this in mind, the present study was undertaken to study the overall productivity and profitability, land-, water-, nutrient- and energy-use efficiency of various possible rice-based cropping systems by incorporating pulse and veg-

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etable crops that can replace groundnut in *rabi* season.

## MATERIALS AND METHODS

The field experiment was conducted at farmers' field with 5 rice-based cropping systems, viz. rice–groundnut, rice–greengram, rice–cowpea, rice–okra and rice–onion, to evaluate the system productivity, economics, resource-use efficiency and energetics during 2011–12 and 2012–13. Twenty-four farmers were selected from 24 different villages, spread over in 6 blocks of Angul district of Odisha adopted by All India Coordinated Research Project on Integrated Farming Systems, Orissa University of Agriculture and Technology, Bhubaneswar. Angul and neighbouring Dhenkanal districts come under mid-central table land zone. All the households selected were either marginal or small farmers. The experimental fields had limited irrigation facility with dug-wells as the only source of irrigation. The detailed location of experimental site with latitude, longitude and altitude are given in Table 1. The existing predominant cropping system in the region is rice–groundnut and the predominant farming system is crop + horticulture + livestock. The soils were characterized as sandy loam with average pH 5.7 (5.6–6.1), electrical conductivity 0.26 dS/m (0.21–0.31 dS/m), organic carbon 0.57% (0.54–0.62%), available N 268.3 kg/ha (252.6–285.2 kg/ha), P 16.3 kg/ha (16.6–17.6 kg/ha), available K 155.1 kg/ha (147.2–162.8 kg/ha) and annual rainfall of 1,388 cm and 1,493 cm was received in the year 2011–12 and 2012–13 respectively. Crop sowing and harvesting window period, recommended fertilizer doses and variety of different crops under all cropping systems are given in Table 2. Recommended doses of N, P and K were applied to different crops through urea, single superphosphate and muriate of potash respectively. In every system, rainy season (*kharif*) rice was grown under rainfed condition and the dry season (*rabi/summer*) crops were given irrigation only at critical growth stages. Need-based intercultural and plant-protection measures were adopted for different crops. All the 5 cropping systems were allotted in each of the farmer's field taking a block of 500 m<sup>2</sup> area, i.e. the area of each cropping system at every farmer's plot was 100 m<sup>2</sup>. The trials were conducted at the same site during both the years of study.

As a researcher designed farmer-managed experiment, recommended package of practices were followed for all the crops in different cropping systems. The experiment was laid out in a randomized block design taking every farmer as a replication. For comparison between different cropping systems, the yields of all the crops in the sequences were converted into rice-equivalent yield. The economics (cost of cultivation and gross return) and the rice-equivalent yield were computed using the farm gate

prices of the produce of 2012–13 for both the years. Benefit: cost ratio (B:C) of a system was expressed as gross returns per rupee invested.

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 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 expressed in kg REY/ha/day. Production efficiency was calculated by dividing the system yield by total duration of the system and expressed in kg REY/ha/day. Crop profitability in term of ₹/ha/day was calculated by net monetary return of the rotation divided by total duration of the crops in that rotation. The profitability of the system in term of ₹/ha/day was calculated by dividing the net return in a system by 365 days. Profit margin was calculated by dividing the net return by gross return and expressed in percentage. The relative production efficiency, relative economics efficiency and employment-generation efficiency were calculated using formula as suggested by Urkurkar *et al.* (2008). Employment-generation efficiency was determined by dividing the total mandays employed for the system with the calendar year of 365 days and expressed in percentage.

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

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

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 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 by the following formula.

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

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

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

## RESULTS AND DISCUSSION

### System yield and productivity

Rice–onion and rice–okra cropping systems gave significantly higher average rice-equivalent yield (REY) (15.47 and 14.67 t/ha respectively) than the other 3 rice-based cropping systems evaluated (Table 3) and this was mainly owing to the contribution of *rabi* crops to the system REY. These 2 systems realized 104 and 94% increase in system REY, respectively, over rice–groundnut system. Higher system yields with vegetables as *rabi* crops in the rice-based crop rotation were also recorded by Bastia *et al.* (2008) and Kachroo *et al.* (2014). The rice–greengram and existing rice–groundnut systems recorded lower REY (6.40 and 7.57 t/ha respectively).

Higher system productivity was recorded with rice–onion (42.4 kg REY/ha/day) and rice–okra (40.2 kg REY/ha/day) systems (Table 4). These 2 cropping systems also

registered higher production efficiency (57.5 and 58.0 kg REY/ha/day respectively). Rice–greengram and rice–groundnut cropping systems showed lower system productivity (17.5 and 20.8 kg REY/ha/day respectively) and production efficiency (31.5 and 29.7 kg REY/ha/day respectively).

### Resource-use efficiency

Land-use efficiency (LUE) of rice–onion system was the highest 73.7%, followed by that of rice–groundnut (69.9%), rice–okra (69.3%) and rice–cowpea (60%) systems (Table 4). It was the lowest for rice–greengram system (55.6%). As rice is the common *kharif* crop in all the systems, the LUE was governed by duration of *rabi* crops. Onion occupied the field for maximum period (142 days) and hence the LUE of the rice–onion system was high. Cropping system not only illustrates the current land-use but also reflects how the land pattern has changed over the time (Gangwar and Ram, 2005).

Requirement of irrigation water was higher in rice–onion cropping system, followed by rice–okra and rice–groundnut. Rice–greengram cropping system demanded the lowest irrigation water. But this system revealed the highest irrigation water-use efficiency (IWUE) of 427 kg REY/ha-cm, followed by rice–okra (367 kg REY/ha-cm) and rice–cowpea (359 kg REY/ha-cm). Rice–groundnut

**Table 1.** List of farmers with the GPS data of the experimental site

Name of farmer	Latitude	Longitude	Altitude	Block name	Village name	Holding size (ha)
Mr Narayan Sahoo	N21°02.500'	E84°50.389'	214.3±5 m		Chhendipada	1.2
Mr Muralidhar Sahoo	N21°02.422'	E84°50.626'	218.2±5 m		Handiguda	1.0
Mr Jameswar Majhi	N21°02.712'	E84°50.219'	215.0±5 m		Jamunalui	2.0
Mr Trailokya Pradhan	N21°02.280'	E84°50.670'	219.0±5 m		Deurian Jharana	1.5
Mr Brajamohan Garnayk	N21°05.389'	E84°50.785'	170.0±5 m	Koshola	Podopada	2.0
Mr Bipin Majhi	N21°04.580'	E84°50.339'	167.0±4 m		Machakutta	2.6
Mr Raghunath Sahoo	N20°59.549'	E84°55.691'	174.6±5 m		Koshola	1.2
Mr Suresh ch Behera	N21°01.505'	E84°51.577'	170.8±5 m		Tentuloi	2.0
Mr Kastu Sethi	N20°58.604'	E84°47.265'	248.0±4 m	Kishorenagar	Anandamunda	1.2
Mr Kumar Behera	N20°55.255'	E84°46.368'	253.8±4 m		Jamunali	1.0
Mr Hemanta Behera	N20°58.240'	E84°47.125'	246.0±4 m		Gularsar	1.2
Mr Anil Pradhan	N20°58.412'	E84°47.691'	240.5±6 m		Madhupur	1.2
Mr Sunil Sahu	N20°47.210'	E84°45.250'	187.6±6 m	Atthamallik	Dinabandhupur	1.4
Mr Ranjan Biswal	N20°47.608'	E84°39.112'	190.4±4 m		Hatasimilia	1.4
Mr Arjuna Sahu	N20°47.318'	E84°39.450'	187.5±5 m		Ranibandha	1.0
Mr Dhruvachran Biswal	N20°47.608'	E84°39.522'	192.0±4 m		Sadanandapur	1.5
Mr Dasarathi Dehury	N20°47.168'	E85°04.255'	164.0±3 m	Angul	Shyamsundarpur	0.8
Mr Aviram Sahoo	N20°67.901'	E85°04.455'	170.0±5 m		Karadabani	0.8
Mr Subash Sahoo	N20°47.510'	E85°06.326'	166.0±3 m		Chheliapada	0.6
Mr Kartik Pradhan	N20°47.122'	E85°06.520'	171.0±34m		Nuagoan	1.2
Mr Suresh Pradhan	N20°49.453'	E84°59.595'	182.0±5 m	Banarpal	Tubey	0.8
Mr Pratap Pradhan	N20°50.339'	E84°59.696'	176.5±6 m		Ghotosahi	1.0
Mr. Dibakar Pradhan	N20°51.113'	E84°56.304'	170.6±3 m		Bimalbeda	1.2
Mr. Benudhar Pradhan	N20°50.001'	E84°59.588'	178.5±4 m		Dhipasahi	1.2

cropping system showed the least IWUE of 216 kg REY/ha-cm (Table 4). Groundnut, being a long-duration crop (128 days) among the *rabi* crops, required higher number of irrigations and thus the system having groundnut in the sequence registered the lowest irrigation water-use efficiency. On the other hand, greengram occupied the field only for 76 days as compared to 142 days in case of onion in *rabi* season rice–greengram system demanded the minimum irrigation.

Higher apparent nutrient-use productivity (ANUP) was noted with the rice–okra (56 kg REY/kg NPK applied), followed by rice–cowpea (47.2 kg REY/kg NPK applied) (Table 4). The lower ANUP was recorded with rice–greengram and rice–groundnut cropping systems (34.4 and 37.5 kg REY/kg NPK applied).

Crop diversification through intensification not only enhances the productivity and the profitability of the farmers but also generates the employment to the farming com-

**Table 2.** Agronomic practices of the crops in the cropping systems

Cropping system	Parameter	First crop ( <i>kharif</i> )	Second crop ( <i>rabi/summer</i> )
Rice–groundnut	Sowing window	Last week of June	Second fortnight of December
	Harvesting window	First week of November	Last week of April
	Nutrient dose (N-P-K kg/ha)	80–18–33	20–18–33
	Spacing (cm × cm)	20 × 10	30 × 10
	Variety	‘Naveen’	‘Devi’
	Irrigation no.	0	7
Rice–greengram	Sowing window	Last week of June	Last week of January
	Harvesting window	First week of November	Second week of April
	Nutrient dose (N-P-K kg/ha)	80–18–33	20–18–17
	Spacing (cm × cm)	20 × 10	25 × 8
	Variety	‘Naveen’	‘Devi’
	Irrigation no.	0	3
Rice–cowpea	Sowing window	Last week of June	Last week of December
	Harvesting window	First week of November	First week of April
	Nutrient dose (N-P-K kg/ha)	80–18–33	25–22–50
	Spacing (cm × cm)	20 × 10	45 × 30
	Variety	‘Naveen’	‘Utkal Manika’
	Irrigation no.	0	6
Rice–okra	Sowing window	Last week of June	Second fortnight of December
	Harvesting window	First week of November	Last week of April
	Nutrient dose (N-P-K kg/ha)	80–18–33	80–18–33
	Spacing (cm × cm)	20 × 10	30 × 30
	Variety	‘Naveen’	‘Super Green’
	Irrigation no.	0	8
Rice–onion	Sowing window	Last week of June	Second fortnight of December
	Harvesting window	First week of November	Second fortnight of May
	Nutrient dose (N-P-K kg/ha)	80–18–33	120–26–83
	Spacing (cm × cm)	20 × 10	15 × 10
	Variety	‘Naveen’	‘Nasik Red 53’
	Irrigation no.	0	9

**Table 3.** Crop yields and system rice-equivalent yield (t/ha)

Cropping system	First crop ( <i>kharif</i> )				Second crop ( <i>rabi/summer</i> )		Rice-equivalent yield		
	Grain		Straw		2011–12	2012–13	2011–12	2012–13	Pooled
	2011–12	2012–13	2011–12	2012–13					
Rice–groundnut	4.15	4.33	4.26	4.03	1.43	1.29	7.66	7.49	7.57
Rice–greengram	3.82	4.22	4.23	4.62	0.69	0.81	6.01	6.78	6.40
Rice–cowpea	4.23	4.09	4.40	4.79	6.42	5.68	11.24	10.28	10.76
Rice–okra	4.52	4.29	4.61	4.36	10.18	8.64	15.63	13.72	14.67
Rice–onion	4.43	4.32	4.59	4.52	11.26	10.93	15.69	15.25	15.47
S <sub>Em</sub> ±	–	–	–	–	–	–	0.54	0.65	0.45
CD (P=0.05)	–	–	–	–	–	–	1.50	1.82	1.25

munity for the longer periods which help in minimizing the problem of the 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-okra showed the highest engagement of mandays (425 days/ha), followed by rice-onion (395 mandays/ha) owing to involvement of more number of human labour for harvesting, grading and packaging of okra and onion. These 2 systems had employment-generation efficiency of 116 and 108% respectively (Table 4). Rice-greengram cropping system recorded the least employment-generation efficiency of 67%. Rice-groundnut and rice-cowpea also recorded employment generation efficiency less than 100%. Kachroo *et al.* (2014) and Ray *et al.* (2016) reported that, cropping systems with vegetables like onion and okra respectively having high productivity had higher employment-generation efficiency.

#### Energy-use efficiency

Total energy inputs in different cropping systems was in the range from 24,261 to 41,563 MJ/ha (Table 5). The highest energy input was recorded in rice-onion (41,563 MJ/ha), followed by rice-okra (37,606 MJ/ha), whereas in the existing rice-groundnut cropping system required

35,498 MJ/ha. The lowest energy input was required for rice-greengram (24,261 MJ/ha) (Table 5). The higher energy inputs required for cropping systems with onion and okra might be owing to the use of higher energy-rich inputs like fertilizer and human labour. Total energy output was computed from main product and by-product of different cropping systems and it ranged from 142,858 to 199,489 MJ/ha (Table 5). The highest total energy output was obtained from rice-okra, followed by rice-cowpea and rice-groundnut and this was mainly because of higher by-product energy-equivalent from okra, cowpea and groundnut. The lowest energy output was obtained from rice-greengram system. Rice-onion system produced relatively low energy output mainly owing to low production of onion by-product.

Rice-onion system recorded the lowest energy-use efficiency of 3.98 (Table 5). The energy-use efficiency values for all other cropping systems ranged from 4.74 to 6.30 (rice-cowpea). Average maximum energy productivity was obtained in rice-okra (0.39 kg REY/MJ) and it was owing to its higher total energy output. The other systems having high energy productivity were rice-onion and rice-cowpea, both the systems having energy productivity of 0.37 kg REY/MJ. Inclusion of vegetables like okra, cowpea and onion in a cropping system increased the en-

**Table 4.** Production and resource-use efficiency of rice-based cropping systems (pooled data of 2 years)

Cropping system	Crop duration (days)	Land-use efficiency (%)	System productivity (kg REY/ha/day)	Production efficiency (kg REY/ha/day)	Relative production efficiency (%)	Employment-generation (mandays/ha)	Employment-generation efficiency (%)	Irrigation water-use efficiency (kg REY/ha-cm)	Apparent nutrient use productivity (kg REY/kg nutrient applied)
Rice-groundnut	255	69.9	20.8	29.7		245	86	216	37.5
Rice-greengram	203	55.6	17.5	31.5	-16	283	67	427	34.4
Rice-cowpea	219	60.0	29.5	49.1	42	425	78	359	47.2
Rice-okra	253	69.3	40.2	58.0	94	395	116	367	56.0
Rice-onion	269	73.7	42.4	57.5	104	245	108	344	43.0
SEM±	—	—	1.23	1.32	—	—	—	19.8	3.76
CD (P=0.05)	—	—	3.43	3.68	—	—	—	55.2	10.49

**Table 5.** Energy input-output relationship of different rice-based cropping systems (pooled data of 2 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	35.5	168.2	4.74	0.66	0.21
Rice-greengram	24.3	142.9	5.89	0.70	0.26
Rice-cowpea	29.3	184.8	6.30	0.84	0.37
Rice-okra	37.6	199.5	5.30	0.79	0.39
Rice-onion	41.6	165.4	3.98	0.61	0.37
SEM±	—	3.35	0.18	—	—
CD (P=0.05)	—	9.32	0.50	—	—

**Table 6.** Economics of rice-based cropping systems (pooled data of 2 years)

Cropping system	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 (%)	Profit margin (%)
Rice-groundnut	62.5	25.0	1.40	98	68		29
Rice-greengram	48.9	25.9	1.53	127	71	4	35
Rice-cowpea	57.0	65.9	2.16	301	181	164	54
Rice-okra	68.1	97.7	2.43	386	268	291	59
Rice-onion	77.8	97.0	2.25	360	266	288	56
S <sub>Em</sub> ±	–	4.92	–	16.2	13.5	–	–
CD (P=0.05)	–	13.71	–	45.1	37.6	–	–

Sale price (₹/t): rice, 11,000; rice straw, 1,000; groundnut, 2,700; greengram, 35,000; cowpea, 12,000; okra, 12,000; onion, 11,000

ergy productivity by 76–85% as compared to rice-groundnut (0.21 kg REY/MJ) cropping system. The highest average value of energy output efficiency was recorded in rice-cowpea system (844 MJ/ha/day), followed by rice-okra (789 MJ/ha/day). Similar results were reported by Kachroo *et al.* (2012)

#### Monetary returns and economic viability

Among the 5 cropping systems evaluated, rice-okra and rice-onion systems gave higher returns. Rice-okra registered the highest net returns of ₹97,740/ha, closely followed by rice-onion (₹96,974/ha) (Table 6). Rice-cowpea was the next best cropping system with net returns of ₹65,939. Vegetables like okra, onion 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 as a *rabi* crop in the rice-based cropping systems were remunerative. Rice-okra system showed the highest net return at Kakdweep in West Bengal (Ray *et al.* 2016). The existing rice-groundnut system recorded the least net returns (₹24,977/ha). Rice-greengram system also recorded lower net return (₹25,871/ha).

Rice-okra system showed the highest system profitability (₹268/ha/day) and crop profitability (₹386/ha/day). Rice-onion also registered higher system profitability and crop profitability than the other systems. Highest profit margin was also recorded with rice-okra (59%), followed by rice-onion (56%) system. These 2 systems also recorded higher benefit: cost ratio (Table 6). Rice-groundnut system recorded the least system profitability and crop profitability of ₹68 and ₹98/ha/day, respectively, with the lowest benefit: cost ratio and profit margin (Table 6).

#### Relative production and economic efficiency

Relative efficiency of different cropping systems was worked out with respect to the total productivity and eco-

nomics over the existing rice-groundnut cropping system. Relative production efficiency for rice-greengram system was negative (Table 4). The highest positive relative production efficiency (104%) was found in rice-onion, followed by rice-okra (94%). Rice-okra and rice-onion systems also registered higher relative economic efficiency (291 and 288% respectively) (Table 6), which indicated their efficient productivity and profitability over the existing rice-groundnut system.

Thus, it can be concluded that rice-okra and rice-onion, were the most productive and remunerative cropping systems in mid-central table land zone of Odisha, and can be followed in place of existing rice-groundnut system with 8–9 irrigations to *rabi*/summer crops based on critical stages and rainfall during the cropping period.

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