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Research Paper

Diversification of rice (*Oryza sativa*)-based cropping systems for higher productivity, profitability and resource-use efficiency under irrigated ecosystem of Jharkhand

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ABSTRACT

A field experiment was conducted at Kanke, Ranchi under irrigated condition in 2008–09 and 2009–10 to evaluate the production potential, nutrient uptake, resource use efficiency and economics of eight rice (*Oryza sativa* L.)-based cropping systems. Eight cropping systems *viz.* rice–fallow, rice–wheat {*Triticum aestivum* (L.) emend. Fiori & Paol}, rice–mustard {*Brassica juncea* (L.) Czernj & Cosson}–greengram {*Vigna radiata* (L.) Wilczek}, rice–rajmash (*Phaseolus vulgaris* L.)–greengram, rice–potato (*Solanum tuberosum* L.)–greengram, rice–wheat + mustard (5:1)–greengram, rice–wheat + rajmash (5:1)–greengram, and rice–potato + wheat (1:1)–greengram were evaluated in the study. Among the cropping systems, rice–potato + wheat (1:1)–greengram cropping system recorded highest system productivity (20.39 t REGY/ha), land use efficiency (95.89), production efficiency (55.58 kg REGY/ha/day) and employment generation (293 man days/ha) as compared to other cropping systems. Crop sequences with potato as *rabi* crop resulted in significantly higher N, P and K uptake, while S uptake was significantly higher in rice–mustard–greengram sequence. Economic analysis revealed that the maximum net profit (125 × 10^3 ₹/ha), benefit:cost ratio (1.61) and monetary efficiency (342.7 ₹/ha/day) were recorded in rice–potato–greengram crop sequence closely followed by rice–potato + wheat (1:1)–greengram, which were significantly superior over other cropping systems. Based on study, rice–potato + wheat (1:1)–greengram and rice–potato–greengram were found to be the most productive, resource-use efficient and remunerative cropping system under irrigated conditions and can be followed in place of rice–wheat or rice–fallow systems for higher profitability.

Key words : Cropping systems, Production efficiency, Resource-use efficiency, Rice equivalent yield, Systems productivity

Indian agriculture is increasingly getting influenced more and more by economic factors after initiation of economic reforms in 1991. Since then, a number of policy initiatives have been undertaken to liberalize markets and improve agriculture–industry linkages. This need not be surprising because irrigation expansion, infrastructure development, penetration of rural markets, development and spread of short duration and drought resistant crop technologies have all contributed to minimizing the role of non-economic factors in crop choice of even small farmers. The ongoing agricultural liberalization and globalization policies are also going to further strengthen the role of price related economic incentives in determining crop composition as globalization has created new opportunities for the export of high-value products. Most high-value food commodities are labor-intensive, have low gestation periods and generate quick returns. Hence, they offer a perfect opportunity for smallholders to utilize surplus labor and augment their incomes. This price related economic incentives play in crop choice can also pave the way for the next stage of agricultural revolution, where growth originates more and more from value-added production. Hence, choice of the component crops needs to be suitably maneuvered to harvest the synergism among them towards efficient utilization of resource-base and to increase overall productivity (Anderson, 2005). Agricultural diversification towards high-value crops can potentially increase farm incomes, especially in a country like India, where demand for high-value food products has been increasing more quickly than that for staple crops. So, diversification has been envisaged as a new strategy for enhancing and stabilizing productivity, making Indian

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agriculture export competitive and increasing net farm income and economic security and toward achieving the sustainable agricultural development. Keeping this in view, the present investigation was undertaken to select productive, resource use efficient and remunerative rice-based cropping systems for irrigated ecosystem of Jharkhand.

MATERIALS AND METHODS

A field experiment was undertaken at Agronomy Research farm, Birsa Agricultural University at Kanke, Ranchi under irrigated condition during 2008–09 and 2009–10. The soil (*Alfisol*) of the experimental site was poor in fertility, acidic in reaction (pH 6.0), sandy-clay-loam in texture, low in organic carbon (3.8 g/kg), available nitrogen (225.0 kg/ha), available sulphur (13.5 kg/ha), medium in available phosphorus (20.0 kg/ha), available potassium (115.0 kg/ha) and sufficiency level of zinc (0.650 ppm). The experiment was laid out in randomized block design with three replications on a fixed site. Eight rice-based cropping systems *viz.* rice–fallow, rice–wheat, rice–Indian mustard–greengram, rice–rajmash–greengram, rice–potato–greengram, rice–wheat + mustard (5:1)–greengram, rice–wheat + rajmash (5:1)–greengram and rice–potato + wheat (1:1)–greengram were evaluated for their production potential, nutrient uptake, resource use efficiency and economics. All the crops were grown with recommended package and practices. Certified seeds of different crops were used in the experiment. Before sowing, seeds of all the crops were treated with SAAF (Carbendazim + Mancozeb) @ 3 g/kg seed to protect the crops from seed borne diseases. The seeds of greengram were also treated with *rhizobium* culture to improve the nitrogen fixation capacity. Details of crop variety used, recommended seed rate and spacing are given in table 1. However, the amount of seed sown in intercropping *i.e.* wheat + mustard (5:1), wheat + rajmash (5:1) and potato + wheat (1:1) was according to the respective population of intercrops. In rainy season, rice was sown in the last week of June and after harvest in the last week of October, the subsequent crops were sown in *rabi* season at optimum sowing time recommended for the region except in case of intercropping of wheat in potato sowing was done late (at 25 DAS) at the time of earthing up. In summer season, greengram was plucked three times to harvest its yield potential and the remains were incorporated into the soil. Nutrient requirement of all the crops was met through urea (46% N), DAP (18% N and 46% P_2O_5) and muriate of potash (60% K_2O). In wheat + mustard (5:1), wheat + rajmash (5:1) and potato + wheat (1:1) fertilizers were applied according to the main crop in respective intercropping. Full doses of phosphorus and potassium along with 50% nitrogen were applied as basal to all the *kharif* and *rabi* crops. Remaining nitrogen was given in two equal splits to rice, wheat and potato and in single split to mustard and rajmash. During *kharif* irrigation was given as and when required depending upon intensity of rains to keep the soil in saturated condition throughout the crop growth period. The *rabi* and summer crops were irrigated optimally as and when required. All together, 3 irrigations were applied to mustard and rajmash, 6 irrigations to potato and wheat and 4 irrigations to greengram to meet out their irrigation requirement. In potato + wheat intercropping 2 extra irrigation was given in addition to 6 irrigation applied to potato crop. The plant samples collected at harvest were dried at 70ºC, powdered in Willey mill and digested to analyze the various nutrient compositions. The nitrogen, phosphorus, potassium and sulphur content in plant parts were estimated by Kessler's reagent method (Nicholas and Nason, 1957), HNO_3:$HClO_4$ (9:4) digestion, colour development by Vandomolybdate solution followed by spectrophotometer determination (Jackson, 1973), flame photometric determination after digestion in HNO_3:$HClO_4$ (9:4) (Jackson, 1973) and turbidimetric method (Chesnin and Yien, 1951) respectively. The nutrient uptake was estimated by multiplying the nutrient concentration with the grain and straw yield. The data were subjected to statistical analysis as prescribed by Gomez and Gomez (1984) and significant effects were presented and discussed in this paper. The economics of different crops and crops combinations were computed on the basis of prevailing market rates of produce and agro-inputs. To compare the crop sequences, the yield of all crops were converted to rice–equivalent grain yield (REGY) on prevailing market price of produce.

System productivity was calculated by adding the rice-equivalent grain yield of each component crops. Production efficiency values in terms of kg REGY/ha/day was worked out by dividing the total production of a sequence by total duration of crops in that sequence (Tomar and Tiwari, 1990). Land use efficiency (LUE) was obtained by taking the total duration of crops in individual cropping system divided by 365 days. Net returns were the difference between the gross returns of a system and total cost of cultivation of the component crops. The monetary efficiency values in terms of ₹/ha/day were calculated by net returns of a sequence divided by total duration of the crops in that sequence. The benefit: cost ratio for different cropping sequences was calculated by dividing the net returns by the cost of cultivation in a system.

RESULTS AND DISCUSSION

Productivity of crops

Rice–potato–greengram system produced higher grain and straw yield of rice (table 2), which may be attributed to residual effect of nutrients by growing potato during *rabi* and the beneficial effect of legumes grown in summer season (Quayyam and Maniruzzaman, 1996). Rice–fallow system produced the lowest rice yield of 3.41 t/ha. As keeping the land fallow improves compaction, reduces pore space and aeration and increase the temperature of the soil profile. This might have deteriorated the biological activities of soil and ultimately reduced the yield of rice. Rajmash, being a shy nodulating crop, might not have expressed the desired advantage of legumes in the systems. The yield of the component crops varied with the systems. In general, lower yield of *rabi* season crops were obtained in 2008–09 as compared to 2009–10 in all the sequences (Table 2). Among the crop sequences, potato grown as sole as well as intercropped with wheat in winter season out yielded all the other crops during both the years. Among grain crops, wheat yield was considerably higher than mustard and rajmash. Yield of rajmash and mustard was lower during both years. Impaired soil structure, poor aeration, excess moisture retention for extended periods in the plough layer due to puddling and continuous submergence of rice might have resulted in poor crop stand, restricted root growth and yield of rajmash (Prasadini *et al*. 1993) and mustard. Sole rajmash performed better than its intercrop as wheat + rajmash (5:1), because of more number of irrigation in wheat suppressed the performance of rajmash, while it did better in sole cropping, where less irrigation was applied. On the other hand, sole mustard produced lowest yield than wheat + mustard (5:1) intercropping. It might be due to the fact that nutrients supplied in wheat caused better harvest of wheat as well as the intercrop, mustard.

Among the eight cropping sequences, greengram grown as summer crop performed better when grown after sole potato followed by rice–potato + wheat (1:1)–greengram cropping sequence (Table 2). This was mainly due to timely sowing of greengram after sole potato that provided favorable weather conditions for initial growth and development. The other crops like wheat, rajmash and mustard vacated the field 20–25 days later resulting in poorer grain and straw yield. This variation in the yield of crops might be attributed to the biological and environmental complexities and interaction in the cropping systems (Francis, 1989).

System productivity

The results revealed that there is sufficient scope to replace rice–wheat cropping system with other cropping systems without any decline in economic yield rather it improved substantially. The system productivity in terms of rice–equivalent grain yield (REGY) of rice–potato + wheat (1:1)–greengram was highest (18.97 and 21.61 t/ha/annum in 2008–09 and 2009–10, respectively) followed by that of rice–potato–greengram (19.99 and 20.47 t/ha/annum in 2008–09 and 2009–10, respectively) as against 8.36 and 8.81 t/ha/annum of rice equivalent yield in 2008–09 and 2009–10 in rice–wheat system (Table 3). The winter crops mostly governed the REGY of the systems, because rice was the base crop and contribution of summer crops was only marginal. The higher production potential of potato and better market price of potato were instrumental for attaining higher REGY, besides, the bonus yield of wheat in potato + wheat (1:1) enhanced REGY of the system. These results corroborate with Khaurb *et al.*, (2003). Intensification of rice–wheat system by inclusion of greengram grown in summer also intensified the system to add yield and consequently resulted in significantly higher REGY than that of rice–wheat sequence. Soni and Kaur (1984) were also of the opinion that addition of third crop as legume in the sequence resulted in higher yield and profitability. These results are in close conformity with the results of Sharma *et al*. (2004). But, wheat substituted by mustard or wheat + mustard (5:1) resulted in very poor performance of the system. It was apparent that poor yield of the mustard was responsible for lower REGY than rice–wheat sequence during both the years. Crop sequences having 200 and 300% cropping intensity produced significantly more rice equivalent grain yield than the traditional practice of rice–fallow, which registered the minimum REGY of 3.35 and 3.47 t/ha/annum in 2008–09 and 2009–10, respectively.

Nutrient uptake

Among the different cropping sequences, rice–potato + wheat (1:1)–greengram registered the highest N, P, K uptake followed by rice–potato–greengram and it was remained superior than rest of the sequences. Potato is heavy feeder of nutrients, so inclusion of potato as *rabi* crop improved the uptake of N, P and K as compared to other crop sequences (Table 3). This result is in conformity with the findings of Sharma *et al.* (2004). The intercropping of mustard and rajmash with wheat resulted in higher N, P and K uptake than sequences having sole crop of mustard and rajmash and rice–wheat system due to higher removal of nutrients in intercropping system. Crop sequences *viz.* rice–wheat, rice–rajmash–greengram and rice–mustard–greengram showed comparatively similar N, P and K uptake due to lower production of oilseeds and pulses in cropping sequences resulting in lower nutrient uptake. Rice–mustard–greengram sequence resulted in significantly higher S uptake (Table 3) than other sequences, which could be due to greater requirement of oilseeds crops to sulphur. The cropping sequence rice–potato +

Table 1. Agronomic practices followed in different crops

Agronomic practices	Crops								
	Rice	Wheat	Mustard	Rajmash	Potato	Wheat + Mustard (5:1)	Wheat + Rajmash (5:1)	Potato + Wheat (1:1)	Greengram
Seed rate (kg/ha)	50	125	7	120	2000	104 (1.2)	104 (20)	2000 (50)	30
Fertilizer (N:P:K kg/ha)	120:60:40	120:60:40	80:40:20	120:60:40	120:80:100	120:60:40	120:60:40	120:80:100	0:0:0
Spacing (cm x cm)	20 × 10	20	30	40 × 10	50 × 20	20 (1 row of mustard after 5 row)	20(1 row of rajmash after 5 row)	50 × 20(1 row of wheat in furrow)	30
Genotypes	Lalat	K 9107	Pusa Bold	HUR 137	Kufri Ashoka	K 9107 (Pusa Bold)	K 9107 (HUR 137)	Kufri Ashoka (K 9107)	SML 668
Sowing/ transplanting time	03/07/08 & 13/07/09	03/11/08 & 10/11/09	03/11/08 & 10/11/09	02/11/08 & 10/11/09	02/11/08 & 10/11/09	03/11/08 & 10/11/09	03/11/08 & 10/11/09	02/11/08 (4/12/08) & 10/11/09 (12/12/09)	T5 – 15/02/09 & 15/02/10 T4 – 01/03/09 & 08/03/10 T3 – 06/03/09 & 14/03/10 T6&T7 – 16/03/09 & 22/03/10 T8 – 04/04/09 & 10/04/10
Date of harvesting	17/10/08 & 27/10/09	12/03/09 & 18/03/10	02/03/09 & 10/03/10	25/02/09 & 04/03/10	26/01/09 & 03/02/10	12/03/09 (02/03/09) & 18/03/10 (10/03/10)	12/03/09 (25/02/09) & 18/03/10 (04/03/10)	26/01/09 (02/04/09) & 03/02/10 (09/04/10)	T5 – 01/05/09 & 02/05/10 T4 – 12/05/09 & 19/05/10 T3 – 18/05/09 & 26/05/10 T6, T7 – 30/05/09 & 04/06/10 T8 – 15/06/09 & 21/06/10

Data in paranthesis represent the intercrop value

T_3: Rice–mustard–greengram, T_4: Rice–rajmash–greengram, T_5: Rice–potato–greengram, T_6: Rice–wheat + mustard (5:1)–greengram, T_7: Rice–wheat + rajmash (5:1)–greengram and T_8: Rice–potato + wheat (1:1)–greengram

Table 2. Rice equivalent yield of *kharif*, *rabi* and summer crops of different rice-based cropping system.

Treatment	Rice equivalent yield (t/ha)						Straw/Stover/ haulm yield (t/ha)					
	Kharif		*Rabi*		Summer		*Kharif*		*Rabi*		Summer	
	2008–09	2009–10	2008–09	2009–10	2008–09	2009–10	2008–09	2009–10	2008–09	2009–10	2008–09	2009–10
Rice–Fallow	3.35	3.47	–	–	–	–	5.05	5.34	–	–	–	–
Rice–Wheat	3.71	3.72	4.66	5.09	–	–	5.23	5.35	5.02	5.53	–	–
Rice–Mustard–Greengram	3.62	3.67	2.28	2.66	2.04	2.15	5.06	5.43	4.27	4.48	1.28	1.39
Rice–Rajmash–Greengram	3.67	3.83	4.62	4.69	2.23	2.32	5.10	5.44	1.65	1.85	1.50	1.57
Rice–Potato–Greengram	3.97	4.25	12.97	13.08	2.95	3.14	5.27	5.38	18.96	17.04	2.48	2.54
Rice–Wheat + Mustard (5:1)–Greengram	3.65	3.65	3.88	5.02	1.84	2.08	5.16	5.34	3.61 (1.56)	4.85 (1.64)	1.19	1.37
Rice–Wheat + Rajmash (5:1)–Greengram	3.75	3.77	4.85	5.99	1.86	1.97	4.77	5.27	3.76 (0.66)	5.07 (0.68)	1.30	1.42
Rice–Potato + Wheat (1:1)–Greengram	3.82	4.18	12.37	14.60	2.70	2.83	4.87	5.23	15.38 (2.85)	15.71 (2.96)	2.17	2.22
SEm±	0.24	0.14	0.40	0.26	0.14	0.10	0.25	0.25			0.10	0.08
CD (P = 0.05)	NS	0.43	1.25	0.81	0.44	0.32	NS	NS			0.31	0.24

Data in parenthesis indicate the intercrop yield

wheat (1:1)–greengram, rice–potato–greengram and rice–wheat + mustard–greengram have comparatively similar S uptake but superior than rest of the sequences. Rice–rajmash–greengram and rice–wheat + rajmash (5:1)–greengram also registered higher S uptake than rice–wheat sequence due to higher cropping intensity. Similarly, rice–fallow has significantly lower S uptake than rice–wheat cropping sequence.

Resource-use efficiency

The highest land use efficiency (LUE) was observed in rice–potato + wheat (1:1)–greengram (95.9%). Other crop sequences having 300% cropping intensity, showed LUE in the range of 76.7% to 89.0% (Table 4). As rice is the common *kharif* crop in all the systems and summer crops also having similar duration, the LUE was governed mostly by duration of *rabi* crops. Potato + wheat intercropping occupied the field for a maximum period of 325 days and hence the LUE of the systems having potato + wheat was maximum. Intensification of rice based cropping sequence by growing summer greengram recorded markedly higher land use efficiency than crop sequences without summer crops *viz.* rice–wheat sequence (69.9%). Rice–fallow registered minimum LUE (34.3%) among the crop sequences as the land remain unutilized after cultivation of rice. Sequences having 300% cropping intensity consumed more number and quantity of irrigation water (cm) as compared to sequences at 200% cropping intensity. This is mainly due to inclusion of summer crop which utilized 4 additional irrigations and contributed to higher water use of sequences with 300% cropping intensity. The highest water use was recorded in rice–potato + wheat (1:1)–greengram (174 cm), then in rice–potato–greengram (162 cm), rice–wheat + rajmash (5:1)–greengram (162 cm) and rice–wheat + mustard (5:1)–greengram (162 cm). The highest water use in rice–potato + wheat (1:1)–greengram sequence was mainly due to 2 more number of irrigation was utlilized by wheat crop in addition to water used by potato crop in *rabi* season. Employment generation was also found highest in rice–potato + wheat–greengram cropping sequence (293 man days/ha) due to more involvement of labour in harvesting of potato. Round the year cultivation with three crops in a year recorded higher employment generation than cultivation of two crops in a year due to intensification of cropping systems. The lowest employment generation was found with rice–fallow system (107 man days/ha) as the land remained vacant for larger period of time.

Production efficiency refers to per day productivity of entire cropping system under a particular treatment. Thus, production depend on the quantum of total production as well as duration of total crop period under a particular treatment. The rice–potato + wheat (1:1)–greengram had the highest production efficiency (55.6 kg REGY/ha/day) followed by rice–potato–greengram (55.4 kg REGY/ha/day) and these two sequences had significantly higher production efficiency than other sequences (Table 4). Potato is a short duration, labour intensive crop which when intercropped with wheat produced the highest rice equivalent grain yield of 20.29 kg/ha amongst all the *rabi* crops resulting in the highest production efficiency. In general, inclusion of greengram in summer season improved the production efficiency over crop sequences having 200% cropping intensity (rice–wheat). Rice–fallow system showed the lowest production efficiency (9.34 kg REGY/ha/day) mainly because of the lowest rice equivalent grain yield (3.41 t/ha) of the system.

Economics

Among all the system, rice was the common *kharif* crop and summer crop was also common, so economic parameters were mostly governed by the *rabi* crops. The highest cost of cultivation (82.5 × 10^3 ₹/ha/annum) was incurred on rice–potato + wheat (1:1)–greengram followed by rice–potato–greengram (77.7 × 10^3 ₹/ha/annum) (Table 4). The inclusion of potato in the cropping system increased the total variable cost due to more fertilization and human labour requirement. The gross returns were also higher in these systems because of higher value of produce. The rice–potato + wheat (1:1)–greengram fetched a gross return of 202.9 × 10^3 ₹/ha/annum closely followed by rice–potato–wheat cropping system with a gross return of 202.8 × 10^3 ₹/ha/annum were at par to each other but significantly higher gross return when compared with that of other cropping systems. The net profitability was highest in rice–potato–greengram (125.1 × 10^3 ₹/ha), being at par with rice–potato + wheat (1:1)–greengram (120.4 × 10^3 ₹/ha) but significantly higher over other cropping systems. The inclusion of potato in crop sequences can boost the profitability of the sequences because of its higher production fetching better return (Sharma, *et al.*, 2004). In general, cropping sequences of 300% cropping intensity gave significantly higher net returns than rice–wheat (49.4 × 10^3 ₹/ha) except rice–mustard–greengram (37.7 × 10^3 ₹/ha) which gave net returns lower than rice–wheat sequence due to poor performance of mustard in the cropping se-

Table 3. System productivity and nutrient uptake of different rice-based cropping systems

Treatments	System productivity (t REGY/ha)		Nutrient uptake (kg/ha)							
			Nitrogen		Phosphorus		Potassium		Sulphur	
	2008–09	2009–10	2008–09	2009–10	2008–09	2009–10	2008–09	2009–10	2008–09	2009–10
Rice–Fallow	3.35	3.47	69.2	70.5	13.2	13.1	60.2	57.2	9.6	10.6
Rice–Wheat	8.36	8.81	160.1	170.3	31.4	34.0	150.0	161.6	21.2	22.4
Rice–Mustard–Greengram	8.00	8.48	170.1	184.6	32.9	35.8	140.0	152.0	38.7	42.2
Rice–Rajmash–Greengram	10.58	10.84	170.2	182.1	28.3	31.9	133.4	141.3	25.4	26.9
Rice–Potato–Greengram	19.99	20.47	267.3	282.4	59.0	66.5	323.7	245.0	32.7	32.6
Rice–Wheat + Mustard (5:1)–Greengram	9.43	10.76	184.3	212.4	33.1	39.9	160.3	188.5	29.1	32.7
Rice–Wheat + Rajmash (5:1)–Greengram	10.52	11.73	185.8	216.0	31.9	38.9	154.8	188.9	23.4	26.6
Rice–Potato + Wheat (1:1)–Greengram	18.97	21.61	272.3	294.0	57.7	78.9	330.4	276.1	32.7	33.6
SEm±	0.49	0.33	10.4	4.5	1.8	1.0	11.6	4.9	1.1	0.7

Table 4. Indices of resource-use efficiency and economics of different rice-based cropping systems (Pooled data of two years)

Treatment	Land use efficiency (%)	Production efficiency (kg REGY/ha/day)	Irrigation water requirement (cm)	Employment generation (days/ha)	Total Variable cost (×10^3 ₹/ha)	Net returns (× 10^3 ₹/ha)	B:C ratio	Monetary efficiency (₹/ha/day)
Rice–Fallow	34.3	9.3	102	107	19.9	22.2	1.12	61.0
Rice–Wheat	69.9	23.5	138 (6)	212	42.9	49.4	1.15	135.3
Rice–Mustard–Greengram	87.7	22.6	144 (7)	283	51.4	37.7	0.73	103.3
Rice–Rajmash–Greengram	84.9	29.4	144 (7)	239	54.3	58.1	1.07	159.1
Rice–Potato–Greengram	76.7	55.4	162 (10)	275	77.7	125.1	1.61	342.7
Rice–Wheat + Mustard (5:1)–Greengram	89.0	27.7	162 (10)	286	55.3	51.4	0.93	140.8
Rice–Wheat + Rajmash (5:1)–Greengram	89.0	30.5	162 (10)	282	56.0	59.8	1.07	163.9
Rice–Potato + Wheat (1:1)–Greengram	95.9	55.6	174 (12)	293	82.5	120.4	1.46	329.8
SEm±	–	0.8	–	–	–	3.0	0.05	8.3
CD (P=0.05)	–	2.4		–	–	8.8	0.16	24.1

quence. Rice–fallow (22.2 × 10^3 ₹/ha) resulted in lowest net returns amongst all sequences. The benefit : cost ratio was highest in rice–potato–greengram (1.61) followed by rice–potato + wheat (1:1)–greengram system (1.46). This was due to higher gross returns of the above systems. The other cropping systems having 300% cropping intensity gave comparatively lower benefit: cost ratio than rice–wheat cropping sequence. It was owing to higher cost of cultivation and poor yield of crops. Further, monetary efficiency in terms of ₹/ha/day was also maximum (342.7) in rice–potato–greengram followed by rice–potato + wheat (1:1)–greengram (329.8). The lowest monetary efficiency was noted with rice–fallow system (61.0), which may be due to lower net returns of the system. Similar results were also reported by Yadav *et al.* (2005) and Walia *et al.* (2011).

Thus, rice–potato + wheat (1:1)–greengram and rice–potato–greengram are biologically efficient, resource conservative, highly profitable crop sequences under irrigated ecosystem of Chhotanagpur plateau region, which has the potential to serve as a viable and better alternative to the existing rice–fallow and rice–wheat system. However, the farmer still prefer rice–wheat sequence because of better stability and assured government procurement policy with greater remunerative profit margins than other less assured crop sequences.

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