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Research Paper

Diversification of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system for sustainable production in south Bihar alluvial plains

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ABSTRACT

A field experiment was conducted during 2009–10 to 2011–12 at Sabour, Bhagalpur, Bihar to diversify the existing rice (*Oryza sativa* L.)–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] cropping system. Among the 12 rice-based cropping systems tested, scented rice–potato (*Solanum tuberosum* L.) + radish (*Raphanus sativus* L.)–onion (*Allium cepa* L.) + maize (*Zea mays* L.) relay cropping gave the highest mean rice-equivalent yield (28.10 t/ha/year) and net returns (₹1,14,700/ha/year), followed by hybrid rice–maize + potato–sorghum [*Sorghum bicolour* (L.) Moench] + cowpea [*Vigna unguiculata* (L.) Walp.] both grown for fodder (24.2 t/ha/year and ₹1,12,200/ha/year) and hybrid rice–garlic (*Allium sativum* L.) + coriander (*Coriandrum sativum* L.)–maize for grain purpose + cowpea in-situ incorporation (22.60 t/ha/year and ₹1,11,600/ha/day). However, the benefit: cost ratio was the highest (1.39) in long-duration rice–wheat–mungbean [*Vigna radiata* (L.) Wilczek] both sown by zero till, which was at par with scented rice–wheat + fenugreek (*Trigonella foenum-graecum* L.)–mungbean grown for grain + residue incorporation (1.37). Scented rice–potato + radish–onion + maize relay cropping required higher energy inputs (69.35 MJ × 10^3/ha), whereas energy-use efficiency was the maximum (5.0) in rice–maize (ZT)–clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.] (fodder). Hybrid rice–maize + potato–sorghum + cowpea showed the highest energy output (287.01 MJ × 10^3/ha) and water-use efficiency (36.6 kg rice-equivalent yield/ha-mm). This cropping system removed the maximum quantity of N (448.4 kg/ha), P (130 kg/ha) and K (457.2 kg/ha) which resulted in maximum negative balance of phosphorus (32.8 kg/ha) and potassium (320.2 kg/ha). Potassium was negative in all the cropping systems, indicating that K was the most removable nutrient by the crops, which results in mining of soil K and thus calls for adequate fertilization.

Key words: Diversification, Economics, Nutrient balance, Rice-equivalent yield, Rice–wheat cropping system productivity

Rice–wheat cropping system is the most dominant cropping system in alluvial plains of Bihar. The wide adoption of this system is mainly owing to its high productivity, stability and less risk (Kumar *et al.,* 2001). But continuous adoption of this system has led to the problem of specific weeds, reduced soil fertility and infestation of similar kind of pests, which ultimately resulted in declining the efficiency and productivity of the system (Kumar and Yadav, 2005). Since rice is the stable food of the state, it is difficult to replace rice by any other crop in rainy season due to soil and climatic conditions of the state. Hence the only option left to replace wheat in the winter season for diversification of rice–wheat system. Growing of crops such as pulses and vegetables during the post-rainy period is an alternative approach for realizing overall higher profitability and productivity (Newaj and Yadav, 1992). Crop diversification through such crops and inclusion of fodder crops help to improve the economic situation of small and marginal farmers because of higher income (Sharma *et al.,* 2007). Crop diversication would fullfil the basic needs of cereals, pulses, oilseeds (Kumar *et al.,* 2008) and vegetables, and regulate farm income by better withstanding weather aberrations, controlling price fluctuations, ensuring a balanced food supply, conserving natural resources, reducing chemical fertilizer and pesticide loads, ensuring environmental safety and creating employment opportunities (Gill and Ahlawat, 2006). In view of these facts, the present experiment was conducted to find out the possibility of diversification in existing rice–wheat cropping system for sustainable productivity, profitability and their relative nutrient balance in the soil.

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MATERIALS AND METHODS

A field experiment was conducted during 2009–10 to

2011–12 at Bihar Agricultural College farm, Sabour, Bihar, on sandy-loam soil having pH 8.1, organic C 0.53%, available N 213.3 kg/ha, P 23.6 kg/ha and K 226.0 kg/ha. Twelve rice-based cropping systems were evaluated for their production potential and economics, viz. rice–wheat, rice (direct–seeded)–maize + potato (intercropping)–maize + cowpea (fodder), scented rice–wheat + fenugreek (intercropping)–mungbean (grain + residue incorporation), scented rice–potato + radish (intercropping)–onion + maize (relay cropping), scented rice–cabbage + radish (intercropping)–okra (*Abelmoschus esculantus* L.) + mungbean (intercropping), hybrid rice–maize + potato–sorghum + cowpea (fodder), hybrid rice–maize + *rajmash* (*Phaseolus vulgaris* L.) (intercropping)–maize + cowpea (fodder), hybrid rice–garlic + coriander (green leaf)–maize (grain) + cowpea (incorporation), long- duration rice–zero till wheat–zero till mungbean, long duration rice–zero till maize–clusterbean (as fodder), long duration rice–oat (*Avena sativa* L.) (multi cut)–pearlmillet (*Pennisetum typhoides*) + rice bean (fodder), long-duration rice–chickpea (*Cicer arietinum* L.) + coriander–maize (grain) + cowpea for incorporation. A randomized block design was followed with 3 replications. The crops were raised under irrigated condition with recommended package of practices. Details of package of practices of different crops are given in Table 1. Maize + potato, maize + *rajmash*, maize + cowpea (incorporation), cabbage + radish and maize + cowpea (F) were sown in 1:1in additive series and pearlmillet + rice bean (F) and sorghum + cowpea (F) in 2:2 , garlic + coriander leaf in 10:2 and chickpea + coriander in 4:2, wheat + fenugreek in 6:1 and okra + mungbean in 3:1 were sown in replacement series. Seeds of maize in onion + maize relay cropping were dibbled in 4:1 row proportion, 15 days before onion harvesting. Cowpea raised in maize (grain) + cowpea treatment during summer season was incorporated in the soil after 40 days. The N, P, K and the moisture content in cowpea on dry-weight basis was 2.65, 0.8 and 1.35 and 86% respectively. Nitrogen, phosphorus and potassium were supplied through urea, di-ammonium phosphate and muriate of potash respectively. For comparison between crop sequences, the yields of all the crops were converted into rice-equivalent yield on prevailing market price basis. The mean data of 3 years were analysed for computing economics and efficiencies as influenced by different rice-based cropping systems. Net returns were the difference between the gross returns of a system and total cost of cultivation of the system. The benefit: cost ratios for different cropping sequences were calculated by dividing the net returns by the cost of cultivation in a system. The water-use efficiency of different cropping systems was calculated by dividing the rice-equivalent yield of the system by the total water used by different crops in the cropping system. Similarly, the apparent nutrient-use productivity was calculated by dividing the rice-equivalent yield of the system with the total quantity of nutrients (NPK) used in different crops in the system. Energy inputs, outputs and energy-use efficiency of different cropping systems were calculated using the energy equivalents as reported by Mittal *et al.* (1985). Land-use efficiency (LUE) was calculated by dividing total field duration of a system by 365 days and expressed in percentage (Tomar and Tiwari, 1990). System productivity and system profitability values in terms of kg/ha/day and ₹/ha/day were calculated by rice-equivalent yield and net returns of a sequence divided by 365 days, respectively. The total rainfall received during crop period was 919, 644 and 816 mm in 2009–10, 2010–11 and 2011–12, respectively.

RESULTS AND DISCUSSION

Biomass and N accumulation of cowpea

Cowpea grown as an intercrop in maize during summer, on an average, produced 1.38 t/ha of dry matter (10.25 t/ha of fresh biomass in 40 days) and added 36.3 kg N/ha in rice (H)–garlic + coriander–maize (G) + cowpea and rice (LD) – chickpea + coriander + maize (G) + cowpea (Table 2).

System productivity

The results revealed that the yield of rice varied significantly over different cropping systems. Among different cropping system treatments, the highest yield was obtained under rice (H)–maize + *rajmash*–maize + cowpea (F) cropping system for all the 3 years followed by rice (H)–maize + potato–sorghum + cowpea (F) and rice (H)–garlic + coriander (L)–maize (G) + cowpea (incorporation) cropping sequences having average rice productivity of 6.42 tonnes/ha (Table 2). Three years data revealed that among the rice varieties, hybrid variety 'JKRH 401' gave the highest yield followed by long-duration variety 'Rajendra Mahsuri' and scented variety 'Rajendra Suwasini'. During the second year, the productivity of rice slightly declined irrespective of various cropping sequences, which can be attributed to the seasonal variability and low receipt of monsoon rainfall. On average, rice productivity was the highest during 2011–12 over all the years of experimentation. The lowest mean rice productivity (4.68 tonnes/ha) was obtained under rice (S)–potato + radish–onion + maize relay cropping due to the exhaustive nature of the crops in rotation as well as the low production potential of the scented rice variety. It was observed that among all the combinations, a system that included legume crop in rotation had a prominent impact on rice production. Senaratne *et al.* (1995) reported that cowpea

Table 1. Details of package and practices of different crops

Season	Crop	Variety	Spacing (cm × cm)	Fertilizer dose (kg/ha) N	P_2O_5	K_2O	Date of sowing	Date of harvesting
Rainy season (*Kharif*)	Rice	‘Sita, ‘R. Suwasini’ (scented), ‘JKRH 401’ (Hybrid), ‘R. Mahsuri’	20 x 15	100	40	20	Sita (Direct seeded) – 12–17 June Transplanting 7–13 July	‘Sita’ (DS) ‘Sita’ (TP) ‘JKRH 401’ and ‘R. Suwasini’ 26–30 Oct. ‘Rajendra Mahsuri’ 05–10 Nov.
Winter) season (*Rabi*	Wheat	‘HD 2733’	20 ×	120	60	40	16–23 Nov.	2–3 Apr.
	Maize + potato	‘Shaktiman 3’ ‘K Ashoka’	60 × 25, 60 × 15	60	37.5	25	13–15 Nov.	22–27 Apr.
				150	90	100	13–15 Nov	1–6 Feb.
	Wheat +fenugreek	‘HD 2733’‘Rajendra ‘Kranti’	20 × 20 × 10	120	60	40	14–20 Nov.	1–3 Apr.
				20	30	20	14–20 Nov.	30 Mar. –1 Apr.
	Potato +radish	‘Kufri Ashoka’‘Pusa Chetki’	60 × 15, 60 × 30	150	90	100	13–15 Nov.	1–4 Feb.
				30	20	20	13–15 Nov.	4–10 Jan.
	Cabbage +radish	‘Pusa Mukta’‘Pusa Chetki’	45 × 45, 45 × 15	120	80	80	7–14 Nov.	13–20 Feb.
				30	20	20	7–14 Nov.	1–14 Jan.
	Maize +*rajmash*	‘Shaktiman 3’ ‘PDR 14	60 × 25, 60 × 15	120	75	50	6–16 Nov.	22–26 Apr.
				50	25	15	6–16 Nov.	14–24 March
	Garlic +coriander leaf	‘Yamuna Safed’	15 × 10, 15 × 10	100	80	80	8–10 Nov.	26–30 Mar.
		‘Pant Haritima’		30	20	15	8–10 Nov.	29 Dec.–3 Jan.
	Wheat (ZT)	‘HD 2733’	20 ×	120	60	40	9–14 Nov.	29 Mar.–1 Apr.
	Maize (ZT)	‘Shaktiman 3’	60 × 25	120	75	50	9–18 Nov.	20–26 Apr.
	Oat	‘JHO 822’	20 ×	80	40	20	9–23 Nov.	21 Jan.–30 Jan. (1st) 31 Mar.–2 Apr. (2nd)
	Chick pea + coriander	‘Baibhav’‘Rajendra Swati’	30 × 10	20	50	00	10–19 Nov.	30 Mar.–02 Apr.
			30 × 10	30	20	15	10–19 Nov.	26 Mar.–02 Apr.
Summer season	Maize +cowpea (F)	‘Suwan’	60 × 20	80	40	20	24 Apr.–02 May	14–16 Jun.
		‘Pusa Komal’	60 × 10	10	25	00	24 Apri–2 May	14–16 Jun.
	Mungbean (G + R)	‘SML 668’	30 × 10	20	50	00	4–6 Apr.	Picking up to 20–22 Jun.
	Onion +maize* (RC)	‘Nasik Red’	15 × 10	100	80	80	18–24 Dec.	10–19 May
		‘Suwan’	60 × 20	40	20	10	seedling, 10–11 Feb. (Planting), 13–16 Apr.	29 Jun–1 Jul (Green cob)
	Okra +mungbean	‘Parbhani’ ‘Kranti’	45 × 30	100	60	60	17–24 Feb.	Picking 18–21 Jun.
		‘SML 668’	45 × 10	10	25	00	24 Feb–4 Mar.	27 May–4Jun.
	Sorghum + cowpea	‘SSG 99’	30 × 10	60	30	20	24–28 Apr.	11–20 Jun.
	(fodder)	‘Pusa Komal’	30 × 10	10	25	00	24–28 Apr.	11–20 Jun. (Fodder)
	Mungbean (ZT) (G + R)	‘SML 668’	30 × 10	20	50	00	1–2 Apr.	Picking up to 17 Jun.
	Clusterbean (F)	‘Golden Early 36’	30 × 10	20	50	00	24–26 Apr.	23–25 Jun.
	Pearl millet +	‘GFB 1’	30 × 10	60	30	20	3–6 Apr.	3–12 Jun.
	ricebean (F)	‘Bidhan 1’	30 × 10	10	25	00	3–6 Apr.	3–12 Jun.
	Maize (grain) +	‘Suwan’	60 × 20	60	40	20	28 Mar–4Apr.	30 Jun.–3 Jul
	cowpea (Incorporation)	‘Pusa Komal’	60 × 20	10	25	00	28 Mar–4Apr.	13–21 May

RC, Relay cropping; G+R, Grain + Residue incorporation; Maize*, Maize for cob

Table 2. Effect of different rice-based cropping systems on yields (t/ha) of different crops (mean data of 3 years)

Crop sequence	2009–10			2010–11			2011–12			REY (t/ha)				System Productivity (kg/ha/day)
	K	R	S	K	R	S	K	R	S	2009–10	2010–11	2011–12	Mean	
Rice–wheat	4.89	4.66	-	4.68	4.66	-	5.11	4.74	-	10.74	10.53	11.07	10.78	29.9
Rice (DS + BM)–maize + potato–maize + cow pea (F)	5.05	7.35 +16.41	33.77	4.84	7.31+16.94	32.87	5.34	7.52+17.60	34.23	22.36	22.27	23.39	22.67	60.6
Rice (S)–wheat + fenugreek–mungbean (G+R)	4.71	4.70 +0.32	0.75	4.64	4.62+0.31	0.70	5.05	4.60+0.32	0.91	14.28	13.92	15.04	14.40	39.3
Rice (S)–potato + radish–onion + maize (RC)	4.68	21.78+7.34	11.39+7.82	4.55	22.38+8.06	12.19+8.61	4.82	22.98+7.05	9.75+6.35	28.11	29.33	26.92	28.10	70.2
Rice (S)–cabbage + radish–okra + mungbean	4.76	44.72+7.41	11.48+0.32	4.45	42.52+7.52	11.11+0.22	4.99	43.07+7.13	12.38+0.29	23.01	21.73	23.11	22.60	59.5
Rice (H)–maize + potato–sorghum + cowpea (F)	6.25	7.46+16.01	37.97	6.15	7.28+16.67	35.59	6.85	7.44+17.34	37.40	23.87	23.68	25.00	24.20	66.2
Rice (H)–maize + *rajmash*–maize + cowpea (F)	6.35	8.34+0.40	34.23	6.21	7.89+0.29	32.41	7.06	7.68+0.49	34.00	18.68	17.55	19.14	18.50	49.4
Rice (H)–garlic + coriander–maize (G) + cowpea*	6.25	4.40+6.23	3.85+10.32*	6.09	4.44+5.85	3.54+9.63*	6.94	5.04+5.75	3.42+9.43*	22.39	21.80	23.72	22.60	62.0
Rice (LD)–wheat (ZT)–mung bean (ZT)	5.98	3.84	0.78	5.98	4.45	0.71	6.36	4.47	0.82	13.49	14.02	14.77	14.10	38.5
Rice (LD)–maize (ZT)–cluster bean (F)	6.00	7.15	25.84	5.67	7.38	24.03	6.25	7.76	19.04	15.49	15.17	15.52	15.39	41.9
Rice (LD)–oat (multicut)–pearl millet + rice bean (F)	6.01	47.20	41.03	5.63	48.23	40.35	6.13	46.58	43.52	15.16	14.83	15.43	15.14	40.5
Rice (LD)–chickpea + coriander – maize (G) + cowpea*	5.96	1.64+0.32	3.70+10.20*	5.78	1.54+0.36	3.81+9.86*	6.23	1.61+0.44	3.45+9.54*	16.06	15.74	16.41	16.07	42.1
SEm±	-	-	-	-	-	-	-	-	-	3.9	4.6	5.5	5.0	-
CD (P=0.05)	-	-	-	-	-	-	-	-	-	11.4	13.4	16.1	14.8	-

K, *Kharif*; R, *Rabi*; S, Summer, DS + BM; Direct seeded + brown manuring; S, Scented rice; H, Hybrid rice; LD, Long duration; In, Incorporation; REY, Rice-equivalent yield, RC, Relay cropping
*green biomass added to soil

and mungbean when intercropped with maize could fix 161and 197 mg N/plant, obtaining 81% and 78% of their N content from the atmosphere. Thus the increased productivity of rice crop can be attributed to the cumulative effect of fixed nitrogen from legume crops. Singh and Sharma (2002) also reported the beneficial effect of legumes on the succeeding rice crop.

The rice-equivalent yields of different systems revealed that there was sufficient scope to diversify the rice–wheat cropping system with other crops in system maintaining the productivity level and improved sustainability. Analysis of rice–equivalent yields over the years showed significant variation over different crop sequences. The maximum mean yield (28.10 t/ha) was obtained from rice (S)–potato + radish–onion + maize relay cropping system followed by rice (H)–maize + potato–sorghum + cowpea for fodder (24.2 t/ha). The higher rice-equivalent yield in these cropping systems was owing to replacement of wheat with high-volume and high-priced vegetable crops like potato and onion. Choudhary *et al.* (2001) also reported greater productivity by replacing wheat in rice–wheat system with vegetables like radish and potato. However, rice–maize + potato – maize + cowpea (F), rice (S)–cabbage + radish – okra + mungbean and rice (H)–garlic + coriander–maize (grain) + cowpea *in-situ* incorporation were at par. Inclusion of vegetables along with pulses to diversify existing rice–wheat cropping system as well as incorporation of cowpea as green manure in the field helped in achieving higher rice-equivalent yield than with sequence having cereals and pulse crops. Mishra *et al.* (2007) also reported higher productivity and profitability with the inclusion of vegetables and pulses in rice-based cropping system. The existing rice–wheat system recorded the lowest rice equivalent yield of 10.78 t/ha. The system productivity expressed in kg/ha/day showed that compared to 29.9 kg/ha/day productivity of rice–wheat system; rice (S)–potato + radish–onion + maize relay cropping had a productivity capacity of 70.2 kg/ha/day which was 2.3 times that of the rice–wheat cropping system. Though the productivity of the hybrid rice was the highest in rice (H)–maize + *rajmash*–maize + cowpea (F) cropping sequence, its system productivity was only 49.4 kg/ha/day due to low productivity capacity of intercropped maize. Cropping systems having either high-volume production like cabbage and potato or high market value like garlic, coriander leaves, radish and onion achieved the highest system productivity. Inclusion of potato and onion in the system were observed to be helpful in increasing rice-equivalent yield and system productivity. Growing of 3 crops in all the three seasons, viz. rice (longer duration cv 'Rajendra Mahsuri')–wheat (sowing by zero tillage)–mungbean as well as rice ('Rajendra Mahsuri')–maize sown by zero tillage–clusterbean (fodder purpose) also registered high rice-equivalent yield and system productivity than the double cropping of rice–wheat.

Resource use efficiency

The land-use efficiency (LUE) was the highest in rice (LD)–chickpea + coriander–maize (G) + cowpea incorporation, followed by rice (LD)–wheat (ZT)–mungbean (ZT) and rice (LD)–maize (ZT)–clusterbean (F) systems, as these systems occupied the land for longer period (Table 3). Though, the rice is a common crop in all the system but due to long-duration rice in the rainy season and growing of maize/mungbean for grain purpose in summer occupied the field for a maximum of about 340–355 days and hence the LUE of these systems increased. The higher land-use efficiency indicates longer duration of crops in a calendar year. The results are in conformity with the findings of Prasad *et al.* (2013). The land-use efficiency was lowest in existing rice–wheat system, as the land remained fallow for more than 2 months in a year. The rice (LD)–wheat (ZT)–mungbean (ZT) cropping system recorded LUE 94.4%. This indicates that the existing rice–wheat system has a scope to include one more crop like mungbean. The variation in land-use efficiency among different cropping system was mainly due to the variation in duration of crops in the cropping systems. Sharma *et al.* (2004) also reported that crop intensification through the inclusion of vegetables and leguminous crops increased the production and land-use efficiencies.

Different cropping systems consumed varying quantities of irrigation water. The field water supply was the highest in rice (S)–potato + radish–onion + maize relay cropping (960 mm), followed by rice (S)–cabbage + radish–okra + mungbean (900 mm) cropping system. This may be accounted for the high water requirement of onion + maize and okra + mungbean during the summer season. The rice (LD)–chickpea + coriander–maize (G) + cowpea (incorporation) cropping system consumed the lowest amount of water (480 mm). However, the water-use efficiency (WUE) was maximum (36.6 kg REY/ha-mm) with rice (H)–maize + potato–sorghum + cowpea (F) system, followed by rice (H)–garlic + coriander (L)–maize (G) + cowpea (incorporation) (34.3 kg REY/ha-mm) with a water requirement of 660 mm for both the systems, because of higher production with less water used. The cropping system rice (S)–potato + radish–onion + maize relay cropping *in-spite* of its highest system productivity (70.2 kg/ha/day) registered WUE of 27.9 kg REY/ha-mm due to the high water requirement of the system. The cropping system that included maize + potato as intercrop during the winter season and maize + cowpea during summer season registered higher WUE (30.0–36.6 kg REY/ha-mm) compared to the other cropping sequences. The inclusion of vegetable crops like potato and cowpea in these sequences were responsible for higher water-use efficiencies. The lowest WUE was obtained under rice–wheat (21.1 kg REY/ha-mm) and rice (LD)–maize (ZT)–clusterbean (F) (22.5 kg REY/ha-mm) systems whose water-use was 720 mm respectively.

Economics

The highest cost of cultivation (₹1,32,700) was incurred on rice (S)–potato + radish–onion + maize relay cropping followed by rice (H)–maize + potato–sorghum + cowpea as fodder, rice (S)–cabbage + radish – okra + mungbean, rice (DS)–maize + potato–maize + cowpea (F) and rice (H)– garlic + coriander (L)–maize (G) + cowpea (incorporation) systems involved ₹1,17,800, ₹1,15,100, ₹1,13,800 and ₹1,01,100 as their cost of cultivation (Table 3). Higher cost of production of these systems was mainly due to high requirement of fertilizer and labour by potato, onion, cabbage, garlic, coriander and okra crops as well as requirement of high quantity of potato tubers as seed. The least cost of cultivation was involved in rice–wheat production system. Systems involving higher cost of production also fetched higher net returns. Cropping sequences rice (S)–potato + radish–onion + maize relay cropping, rice (H)–maize + potato–sorghum + cowpea (F) and rice (H)–garlic + coriander (L)–maize (G) + cowpea (incorporation) gave higher net returns of ₹1,14,700, ₹1,12,200 and ₹1,11,600 respectively, which were statistically at par but significantly superior to other cropping systems. Inclusion of vegetable crops like potato, onion, cabbage, garlic, coriander, cowpea and okra in the cropping systems in addition to increasing system productivity, also fetched higher market prices, thereby increasing the net returns (Kumar *et al.,* 2008). Growing vegetable crops during the summer in areas with assured irrigation is economically remunerative because the supply of vegetables from rainfed areas is drastically reduced during the summer season.

The highest apparent nutrient-use productivity was found in rice (H)–garlic + coriander (L)–maize (G) + cowpea (incorporation) system (36.5 kg REY/ha-kg), while the lowest apparent nutrient use productivity was recorded in rice (H)–maize + *rajmash*–maize + cowpea (F) system (26.9kg REY/ha-kg). The highest benefit: cost ratio (1.39) was obtained with rice (LD) – wheat (ZT)–mungbean (ZT) system followed by rice (S)–wheat + fenugreek–mungbean (1.37) and rice (LD)–maize (ZT)–clusterbean (1.34). The higher benefit: cost ratio in the former system was mainly owing to lower cost of production of mungbean and wheat by zero tillage. The existing rice–wheat system had a benefit: cost ratio of 1.22 due to its

Table 3. Effect of different rice-based cropping systems on economics and land-use efficiency (Mean data of 3 years)

Crop sequence	Cost of cultivation (×10^3 ₹/ha)	Net income (×10^3 ₹/ha)	Benefit: cost ratio	System profitability (₹/ha/day)	Water applied (mm)	Land use efficiency (%)	Water use efficiency (kg REY/ ha-mm)	Apparent nutrient use productivity (kg REY/ ha-kg)
Rice–wheat	52.6	63.4	1.22	173.6	540	68.4	21.1	28.7
Rice (DS+ BM)–maize + potato–maize + cowpea (F)	113.8	100.2	0.89	274.6	720	93.1	32.6	27.7
Rice (S)–wheat + fenugreek–mungbean (G+R)	66.5	89.9	1.37	246.5	660	88.3	24.8	27.6
Rice (S)–potato + radish–onion + maize (RC)	132.7	114.7	0.87	314.3	960	89.8	27.9	27.6
Rice (S)–cabbage + radish–okra + mung bean	115.1	103.1	0.90	282.5	900	91.1	25.3	28.4
Rice (H)–maize + potato–sorghum + cowpea (F)	117.8	112.2	0.96	307.5	660	87.5	36.6	31.5
Rice (H)–maize + rajmash–maize + cowpea (F)	82.3	97.4	1.19	266.9	600	88.5	30.0	26.9
Rice (H)–garlic + coriander–maize (G) + cowpea*	101.1	111.6	1.12	305.8	660	93.5	34.3	36.5
Rice (LD)–wheat (ZT)–mungbean (ZT)	61.2	84.8	1.39	232.3	600	94.4	25.1	31.2
Rice (LD)–maize (ZT)–cluster bean (F)	65.9	87.1	1.34	236.5	720	94.4	22.5	32.2
Rice (LD)–oat (multicut)–pearl millet + rice bean (F)	61.8	78.8	1.28	215.8	540	89.6	29.6	33.2
Rice (LD)–chickpea + coriander – maize (G) + cowpea*	73.0	79.8	1.11	218.6	480	97.4	32.0	29.0
SEm±	-	3.0	0.04	-	-	-	-	-
CD (P=0.05)	-	9.1	0.13	-	-	-	-	-

Sale price of produce (₹/t): rice seed, 8,750; scented rice seed, 10,500; rice and wheat straw, 1750; wheat seed, 11,000; potato tuber, 4,000; maize seed, 8,000; okra fruit, 4,000; garlic bulb,18,000; cabbage head, 2,000; radish root, 2,000; rajmash seed, 35,000; coriander leaf, 5,000; chickpea seed, 30,000; fenugreek seed, 30,000; mung bean seed, 30,000; onion bulb, 7,000; maize stone, 200; maize stover, 50; maize cobs, 3,000 mungbean and chickpea straw, 2,000; maize+ cowpea, sorghum + cowpea and pearl millet + rice bean green fodder, 800; berseem and oat green fodder, 1,000.

lowest cost of cultivation. However, the rice (S)–potato + radish–onion + maize relay cropping system recorded the highest system profitability (314.3 ₹/ha/day) while rice–wheat production system *in-spite* of its high benefit: cost ratio recorded the lowest profitability of 173.6 ₹/ha/day.

Energetics

The energy input in different cropping systems ranged between 34.69 and 69.35 MJ × 10^3/ha (Table 4). Among the different cropping systems, the scented rice–potato + radish–onion + maize relay cropping required the highest energy inputs (69.35 MJ × 10^3/ha) followed by rice (DS)–maize + potato–maize + cowpea (F) (64.60 MJ × 10^3/ha) and hybrid rice–maize + potato–sorghum + cowpea grown for fodder purpose (63.73 MJ × 10^3/ha). The higher need of energy in these cropping systems was manifested in higher energy required over seed and fertilizers in growing potato and maize crops. The maximum energy input was also reported by Kachroo *et al.* (2012) with rice–potato–maize + greengram compared to rice–wheat system. This was also instrumental in lowering output: input ratio wherever potato was included in the system. However, energy-use efficiency was maximum (5.0) in rice (LD)–maize (ZT)–clusterbean (F), followed by rice (LD)–chickpea + coriander–maize (G) + cowpea (incorporation) system. Rice (H)–maize + potato–sorghum + cowpea (F) produced the highest output (287.01 MJ × 10^3/ha), followed by rice (DS)–maize + potato–maize + cowpea (F) system. The higher energy output in these cropping systems was because of higher potato and maize yield. Maize, a C_4 crop with negligible photo-respiration, has ability to utilize the solar energy more efficiently. Rice–wheat cropping system gave the lowest energy output.

Nutrient removal and balance sheet

The nutrient removal status showed that rice (H)–maize + potato–sorghum + cowpea (F) system removed significantly highest N (Table 5). The second major remover of N from soil was rice (DS)–maize + potato–maize + cowpea (F) system. These two cropping systems removed significantly higher N than rest of the cropping systems. Nutrient uptake by different cropping sequence is the function of crop yield and nutrient content. The maximum removal of N may be attributed to the greater production of biomass by the crops in the sequence. Our results confirm the findings of Yadav *et al.* (2013). The phosphorus and potassium uptake by different cropping systems varied from 54.4 to 130.0 kg P/ha and 202.4 to 457.2 kg K/ha. Highest uptake of P was noted from rice (H)–maize + potato–sorghum + cowpea (F) system followed by rice (S)–cabbage + radish–okra + mungbean system. So far as K uptake was concerned, the trend was similar to that of nitrogen uptake, except that K removal by rice (S)–potato + radish–onion + maize relay cropping system; rice (DS)–

Table 4. Total energy input and output (MJ × 10^3/ ha) of different rice-based cropping systems (mean data of 3 years)

Crop sequence	Input energy				Total energy input	Energy out put from major products	Energy use-efficiency (EUE) Output: input ratio
	Field operations	Seed	Chemicals and fertilizers	Irrigation			
Rice–wheat	8.17	2.44	17.31	6.76	34.69	140.83	4.06
Rice (DS+ BM)–maize + potato–maize + cow pea (F)	13.02	11.38	30.91	9.30	64.60	266.24	4.12
Rice (S)–wheat + fenugreek - mungbean (G+R)	11.27	3.19	20.47	8.45	43.39	155.04	3.57
Rice (S)–potato + radish–onion + maize (RC)	14.77	10.78	31.98	11.83	69.35	226.86	3.27
Rice (S)–cabbage + radish – okra + mungbean	13.80	1.79	29.52	10.99	56.10	142.38	2.54
Rice (H)–maize + potato–sorghum + cowpea (F)	13.40	11.45	29.58	9.30	63.73	287.01	4.50
Rice (H)–maize + rajmash–maize + cowpea (F)	12.09	3.56	28.29	8.45	52.38	240.83	4.60
Rice (H)–garlic + coriander–maize (G) + cow pea*	13.25	4.89	25.55	8.45	52.14	202.73	3.89
Rice (LD)–wheat (ZT)–mungbean (ZT)	10.79	3.48	19.08	9.30	42.65	163.61	3.84
Rice (LD)–maize (ZT)–clusterbean (F)	10.95	2.01	19.31	10.14	42.41	211.96	5.00
Rice (LD)–oat (Multi-cut)–pearl millet + rice bean (F)	9.81	3.28	19.01	8.45	40.54	144.90	3.57
Rice (LD)–chickpea + coriander – maize (G) + cowpea*	10.96	3.33	19.83	6.76	40.89	199.09	4.87

Energy equivalents for various inputs and outputs(MJ): Adult man (1.96/hr), bullock (10.10/hr), diesel (56.31/litre), N (60.60/kg), P_2O_5 (11.10/kg), K_2O (6.70/kg), chemicals requiring dilution (120/kg), zinc sulphate (20.9/kg) , grains of rice, wheat, maize, fenugreek, mungbean rajmash, chickpea, coriander (14.7/kg), potato tuber (3.6/ kg), okra fruit (1.9/ kg) , garlic bulb (5.6/ kg), cabbage head and coriander leaf (0.8/kg), radish root and onion bulb (1.6/kg), maize cobs (18.0/kg dry mass), maize + cowpea, sorghum + cowpea and pearlmillet + rice bean and oat green fodder (649.98/t) maize + potato–maize + cowpea (F) system and rice (S)–cabbage + radish–okra + mung bean system remained statistically at par. Higher N, P and K uptake in these systems might be due to greater biomass production of the crops and more content of nutrients. The lowest N, P and K uptake was observed in rice (LD)–chickpea + coriander–maize(G) + cowpea (incorporation) system followed by traditional rice–wheat system, mainly due to realization of lower rice equivalent yields (16.07 and 10.78 t/ha) of the systems.

Budgeting of nutrients added as fertilizer and removed by the crops showed a maximum deficit of nitrogen in the system having rice (LD)–maize (ZT)–cluster bean (F) system closely followed by rice (LD)–oat (multi-cut)–pearl millet + rice bean (F) system. This deficit was mainly due to the fact that the quantity of N applied to clusterbean (legume) forage crop as well as pearlmillet + rice bean (fodder) crop was small and N concentration in plants of rice bean and clusterbean as well as biomass production of forage crop was high. Out of 12 cropping systems tested, 8 showed negative balance, while 4 showed positive balance of N. Rice (H)–garlic + coriander (L)–maize (G) + cowpea (incorporation) cropping system showed the maximum positive N balance, which might be due to more addition of biomass and more fixation of atmospheric nitrogen by green-manure crop as well as less uptake of N by garlic + coriander.

The balance of P was positive under rice (LD)–wheat (ZT)–mung bean (ZT), rice (S)–potato + radish–onion + maize relay cropping, rice (S)–wheat + fenugreek–mungbean (G + R) and rice (LD)– chickpea + coriander–maize(G) + cowpea (incorporation) cropping system in ascending order, showing less removal of P than that of its application. Rest 8 cropping systems showed negative balance of P, removing more P by crops than the applied ones. The maximum deficit of P was found in rice (H)–maize + potato–sorghum + cowpea (F) system due to the higher removal of P by maize + potato and sorghum + cowpea crops as a result of their higher biomass production.

The largest gap between addition and removal was observed in potassium, which resulted in negative K balance in all the cropping systems. The maximum deficit of K was observed in rice (H)–maize + potato–sorghum + cowpea (F) system, which was similar to that of P uptake pattern. The K uptake in rice (LD)–oat (multicut)–pearl millet + rice bean (F) system, rice (LD)–maize (ZT)–clusterbean (F) system, rice (H)–maize + *rajmash*–maize + cowpea (F) system and rice (DS)–maize + potato–maize + cowpea (F) cropping system ranged from 252.1–263.7 kg/ha/year. The maximum deficit of K in these cropping systems was mainly due to the higher removal of K by forage crops like cowpea, rice bean and clusterbean. These results indicate alarming situation for mining of nutrients

Table 5. Nutrient removal and balance sheet of nutrients in rice-based cropping systems (mean data of 3 years)

Crop sequence	Total nutrient applied (kg/ha)			Total nutrient removed(kg/ha)			Nutrient balance in soil (kg/ha)		
	N	P	K	N	P	K	N	P	K
Rice–wheat	220	43.7	49.8	228.5	58.0	244.7	–8.5	–14.3	–194.9
Rice (DS+ BM)–maize + potato–maize + cow pea (F)	400	101.5	137.0	403.7	111.8	400.7	–3.7	–10.3	–263.7
Rice (S)–wheat + fenugreek–mungbean (G+R)	260	78.6	66.4	268.7	70.3	285.7	–8.7	8.3	–219.3
Rice (S)–potato + radish–onion + maize (R.C)	430	113.5	199.2	334.3	110.9	401.7	95.7	2.6	–202.5
Rice (S)–cabbage + radish–okra + mungbean	360	98.3	149.4	335.7	118.0	389.3	24.3	–19.7	–239.9
Rice (H)–maize + potato–sorghum + cowpea (F)	380	97.2	137.0	448.4	130.0	457.2	–68.4	–32.8	–320.2
Rice (H)–maize + *rajmash*–maize + cowpea (F)	360	89.5	87.2	382.4	98.3	347.0	–22.4	–8.8	–259.8
Rice (H)–garlic + coriander–maize (G) + cowpea*	340	54.6	128.7	221.2	70.3	234.0	118.8	–15.7	–105.3
Rice (LD)–wheat (ZT)–mungbean (ZT)	240	65.5	49.8	254.3	65.2	260.1	–14.3	0.3	–210.3
Rice (LD)–maize (ZT)–cluster bean (F)	240	72.1	58.1	351.3	94.2	313.1	–111.3	–22.1	–255.0
Rice (LD)–oat (multicut)–pearl millet + rice bean (F)	250	59.0	49.8	351.2	80.7	301.9	–101.2	–21.7	–252.1
Rice (LD)–chickpea + coriander –maize (G) + cowpea*	260	85.2	62.3	226.9	54.4	202.4	33.1	30.8	–140.1
SEm±	-	-	-	6.2	1.62	6.06	-	-	-
CD (P=0.05)	-	-	-	18.0	4.74	17.74	-	-	-

and thus need a fresh look to revise them as per needs of the crops in the cropping systems.

Thus it may be concluded that farmers with adequate resources have ample scope for crop diversification adopting scented rice–potato + radish–onion + maize relay cropping and hybrid rice–maize + potato–sorghum + cowpea (fodder) cropping system as alternatives, replacing wheat from the conventional rice–wheat system for higher productivity, profitability and energy harvest under irrigated conditions of Bihar.

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