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Diversification of rice (*Oryza sativa*) based cropping system for higher productivity and income enhancement in the middle Indo-Gangetic Plains of eastern India

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ABSTRACT

A field experiment was conducted for three consecutive years during 2019–20, 2020–21 and 2021–22 at ICAR-Research Complex for Eastern Region, Patna, Bihar to assess the best and profitable rice (*Oryza sativa* L.) based cropping system through crop diversification for sustainable agriculture. Diversification of wheat (*Triticum aestivum* L.) with *rabi* vegetables and inclusion of green gram (*Vigna radiata* L.) during summer season in rice-wheat cropping system was studied with rice cultivars of different duration. The rice-cauliflower (*Brassica oleracea* var. botrytis)-spinach (*Spinacia oleracea* L.)-green gram system recorded the highest system productivity with a rice equivalent yield of 34.26 t/ha, followed by the rice-broccoli (*Brassica oleracea* var. *italica*)-spring onion (*Allium fistulosum*)-green gram system (32.47 t/ha) which were more than double as compared to rice-wheat-green gram system (12.29 t/ha). Land use efficiency was recorded maximum in rice-tomato (*Solanum lycopersicum*)-green gram system (95.34%) and minimum in rice-garden pea (*Pisum sativum* L.)-green gram system (82.19%). Growing shorter duration rice cultivar (Swarna Shreya) in the cropping systems significantly enhanced the system productivity, system production efficiency and income as compared to longer duration rice variety in different cropping systems. Diversification of wheat with *rabi* vegetables enhanced the gross return, net return and benefit cost ratio irrespective of rice duration. The cropping intensity was also increased by diversifying wheat with cauliflower and broccoli grown after short duration rice (400%), as it provided an opportunity to grow a short span crop in the *rabi* season itself before sowing of green gram during summer season.

Keywords: Diversification, Income, Middle Indo-Gangetic plain, Rice-based cropping system, Rice equivalent yield, Vegetables

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system (RWCS) is one of the world's largest and important agricultural production systems, covering nearly 14 million hectares (Mha) in the Indo-Gangetic Plains of South Asia (Alam *et al*. 2016). This system is the prevalent cropping system of the middle Indo-Gangetic plain areas of India, which covers about 10.5 Mha area and contributes about 38% to the national food basket, and presently considered as the backbone of the food security (Singh *et al*. 2008). It is estimated that in future also rice-wheat cropping system is likely to play an important role in sustaining the self-sufficiency in food grains. However, continuous cultivation of rice-wheat cropping system has resulted in detrimental impacts such as resource depletion, soil degradation, nutrient deficiencies, increasing problem of weeds, insect-pest and diseases, stagnation in system productivity and profitability of the cropping system and a lowering of the groundwater table (Sidhu *et al.* 2009, Chauhan *et al*. 2012). Recognizing the inherent risks of relying on a limited number of major crops and stagnation in system productivity, especially in the face of global climate change, a need is being felt to diversify and intensify the existing rice-wheat cropping system and emphasize on crop diversification (Ebert 2014). Furthermore, inclusion of pulses/oilseeds/vegetables in the system has been found more beneficial than pure cropping of cereal after cereals (Prasad *et al*. 2013). The shift from cereals to vegetable crops is viewed as a practical strategy for both economic and ecological sustainability, contributing to heightened food security at the household level. Crop diversification improves food security by increasing the availability of pulses and vegetables alongside cereals, offering a more sustainable and diversified nutritional profile. According to Nguyen (2014), crop diversification is characterized as a strategic

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approach involving the transition from less profitable crops, alterations in crop varieties and cropping systems, and the augmentation of exports and competitiveness in both domestic and international markets. Development of improved production technology with suitable crop sequences for different agro-climatic zones play an important role in enhancing the productivity as well as monetary return without impairing the soil health.

Rice, being the main *kharif* crop of middle Indo-Gangetic plain (MIGP) areas cannot be replaced with other crops during the rainy season due to high rainfall, topographical conditions and farmers' preference. Farmers generally grow long duration rice varieties, which is harvested even up to second week of December. Consequently, sowing of wheat gets delayed as its optimum time of sowing is second to third week of November. Late sowing of wheat causes substantial decline in its economic yield. Mishra (2003) and Kumar *et al.* (2024) reported a decrease of 47 kg/ha/day and 58 kg/ha/day if sowing of wheat is done in the month of December and January, respectively. However, with development of short and medium duration rice varieties, it has now become possible to substitute wheat with *rabi* vegetables. On the other hand, cereal-cereal crop sequences are more exhaustive and put a heavy demand on soil compared to cereal-legume and cereal oilseed sequences. These days a significant slowdown in yield growth rate of this system has been reported and the sustainability of this important cropping system is at stake. Besides, cropping intensity of this region is also low i.e. 140%, which needs to be increased to meet the growing food and nutritional demands of the ever-increasing population (Upadhyaya *et al.* 2022). So, the only viable option to sustain the soil and crop productivity is crop diversification by growing short duration rice during *kharif* season and diversification of wheat with *rabi* vegetables may improve the sustainability of agricultural production of this region as vegetables are comparatively more remunerative. Keeping above points in view, an attempt was made to find out the feasibility of various alternative rice-based cropping sequences for irrigated ecosystem of middle Indo-Gangetic plains. The present investigation was carried out by diversifying *rabi* crop, especially wheat with vegetables, and incorporating green gram (*Vigna radiata* L.) during summer season along with rice cultivars of different duration.

MATERIALS AND METHODS

The experiment was conducted during 2019–20, 2020–21 and 2021–22 at main research farm of ICAR-Research Complex for Eastern Region, Patna, Bihar. The site location is at about 25°35' N latitude, 85°5' E longitude and 51 m above mean sea level. The climate is characterized as sub-tropical, hot, and humid. The soil at the research farm belongs to the Vertic Endoaqualfs order, with a silty loam texture comprising 22% sand, 54% silt, and 24% clay. The soil *p*H is 7.52, with 0.60% organic carbon content, 0.17 dS/m EC and nutrient levels of 290 kg/ha for available nitrogen, 31.5 kg/ha for available phosphorus, and 175 kg/ha for available potassium. The region experiences an average annual precipitation of 1167 mm, with 75–80% of it occurring between June and October. The average maximum temperature ranges from 35.1–40.6°C in June, while the minimum temperature varies from 7.4–10.4°C in January during the year of experimentation. The experiment was conducted in split plot design replicated thrice allocating different duration of rice (short and long duration) under transplanted condition, in main plot and cropping systems in sub-plot. The sub-plot treatments consisted of six cropping system, viz. Rice-wheat-greengram; Rice-potato-greengram; Rice-tomato-greengram; Rice-cauliflower-spinach-greengram; Rice-broccoli-spring onion-greengram and Rice-garden pea-greengram. With long duration rice variety, all cropping systems involved three crops/year. However, with short duration rice variety (Swarna Shreya), after harvesting of cauliflower and broccoli, short span crops like spinach and spring onion were grown before sowing of greengram. This allowed four crops/year, resulting in systems like Rice-cauliflower-spinach-greengram and Rice-broccoli-spring onion-greengram, utilizing the growing season efficiently. Varieties selected for cereals, pulses and vegetables in different cropping systems are given in Table 1. The net plot size of sub-plot was 6 m × 5 m for all treatments and all the crops under different cropping systems were sown and harvested as per their sequence. Recommended doses of fertilizer were applied to all crops through urea, DAP and Muriate of potash. Full dose of phosphorus and potassium along with 50% of nitrogen were applied as basal dose and remaining nitrogen was top dressed as per recommendations for cereal and vegetable crops. Irrigation was supplied optimally as and when required. The recommended package

Table 1 Variety and duration of different crops grown under different rice-based cropping systems

Crop	Variety	Duration (days)
Short duration rice	Swarna Shreya	120
Long duration rice	Swarna (MTU 7029)	145
Potato	Kufri Sinduri	125 (Timely sown) 120 (Late sown)
Tomato	Swarna Sampada	150 (Timely sown) 146 (Late sown)
Cauliflower	Moti	100 (Timely sown) 105 (Late sown)
Broccoli	Shishir	86 (Timely sown) 96 (Late sown)
Pea	SwarnaMukti	105 (Timely sown) 95 (Late sown)
Wheat	HD 2967	132 (Timely sown) 121 (Late sown)
Onion	Nasik red	60
Spinach	All green	45
Green gram	IPM 2-3	70 (Timely sown) 65 (Late sown)

of practices (cultural and plant protection operations) was followed for successful cultivation of the various crops. For comparison between different cropping systems, the yield of *kharif, rabi* and summer crops were converted into rice equivalent yields (REY) using the formula cited by Kumar *et al*. (2019):

REY (t/ha) = {Yield of first crop (t/ha) × Price of first crop (₹/t)/Price of paddy (₹/t)} + {Yield of second crop (t/ha) × Price of second crop (₹/t)/Price of paddy (₹/t)} + {Yield of third crop (t/ha) × Price of third crop (₹/t)/Price of paddy (₹/t)}

The system production efficiency (kg/ha/day) was expressed as the ratio of system productivity (kg REY/ ha) to total duration of the system in days in the cropping system.

The land use efficiency was computed by dividing the total number of days occupied by the respective crop by 365 days and multiplying by 100. For economic evaluation of various rice-based cropping systems, averaged data of three crop cycles were used. The cost of cultivation of different crops was calculated based on the various operations performed and materials used for raising the crops. Gross returns included income from sale of main product of all crops and straw/haulm in rice, wheat and green gram. Net returns were the difference between the gross return of a system and the total cost of cultivation of the component crops in a cropping system. Economics was computed based on the prevailing market prices of the inputs during their respective crop seasons. Gross returns were computed based on the grain and straw yields and their minimum support prices and prevailing market prices during their respective crop seasons. Net returns (₹/ha) were computed by subtracting gross returns (₹/ha) from the total cost of cultivation (₹/ha). The benefit: cost ratio was obtained using the formula:

Benefit Cost ratio=Net profit (₹/ha) / Cost of cultivation (₹/ha)

System profitability (₹/ha/day) = Net return (₹/ha)/365 days

Statistical analysis: All recorded parameters were analysed statistically using two-way ANOVA in IBM® SPSS® Statistics (Version 16) to assess treatment effects and interactions. Additionally, Microsoft Excel was utilized for basic computations, including system profitability, system productivity, and system production efficiency, ensuring a comprehensive evaluation of the cropping system's performance.

RESULTS AND DISCUSSION

Effect of duration of rice on yield, system productivity and land use efficiency: System productivity and yield of *rabi* and summer crops i.e. green gram were significantly influenced by duration of rice crop grown during *kharif* season irrespective of cropping systems (Table 2). The results of pooled data of three years revealed that Swarna Shreya, a short duration rice variety, released from ICAR Research Complex for Eastern Region, Patna took 120 days to attain maturity whereas, Swarna or MTU7029, a long duration variety took 25 more days to attain maturity (Table 1). Swarna produce 28% higher yield than Swarna Shreya (5.26 t/ha) which was significantly superior than short duration rice variety. Long duration rice recorded the highest paddy yield (6.74 t/ha), attributable to its extended growth period. Short duration rice yielded slightly lower (5.26 t/ha), balancing quicker maturation with reduced productivity. However, the trend was reverse in case of *rabi* and green gram yield. Yield of *rabi* crop was nearly double when sown timely after Swarna Shreya rice variety. Due to longer duration of rice, the sowing time of wheat as well as all *rabi* vegetables followed by summer crop were delayed resulting into significantly lower production than timely sown crop. Wheat and vegetables sown/ transplanted after harvesting of Swarna rice got exposed to both the extreme temperature i.e. low temperature during early growth period, which restrict the vegetative phase, and high temperature during post anthesis period, which finally leads to forced maturity and reduce the duration of grain development and consequently the grain yield. Temperature is an important weather parameter that influence the growth and phenophases of most of the vegetables cereals and pulses. Plants have definite temperature requirement before attaining a certain phenological stages. Being a temperature sensitive crop, it has been observed during all the three years that due to delayed sowing the maturity of crop is accelerated and crops are forced to mature early in north Indian condition (Gupta *et al*. 2017). According to Dubey *et al*. (2014) and Kumar *et al*. (2024), the number of days taken to attain different phenophases decreases with delay in sowing that resulted into reduced life span of late sown crop and ultimately reduced the yield (Table 1). Green gram grown after potato and garden pea performed better than those sown after rice and other vegetables due to timely sowing of green gram that provided favourable weather condition for initial growth and development (Banjara *et al*. 2021).

System productivity was significantly influenced by duration of rice crop (Table 2). Yield of wheat, all vegetables and green gram was converted into rice equivalent yield (REY) and summation of REY of all crop with rice yield became the system productivity of that particular cropping system. It was interesting to note that long duration rice produced more rice grain yield but system productivity was 58% higher under cropping systems with short duration rice, which might be only due to availability of optimum weather condition during crop growth season (Shivani *et al*. 2017). Cauliflower and broccoli grown after short duration rice harvested well before than those grown after long duration rice, which provided an opportunity to take short span crop before sowing of green gram. Hence, spinach and spring onion were sown after cauliflower and broccoli respectively, which further enhanced the cropping intensity and system productivity of respective cropping systems. Although yield of cauliflower and spinach was significantly higher (28%) than yield of broccoli and spring onion but when it was converted into REY, both treatments were at par with each

Table 2 Yield and rice equivalent yield of different rice-based cropping systems

Treatment	Paddy grain yield (t/ha)	*Rabi* yield (t/ha)	Greengram yield (t/ha)	Rice equivalent yield (t/ha)		System productivity (t/ha)	Land use efficiency (%)
				Rabi	Greengram		
Duration							
Short duration	5.26	24.72	1.0	21.29	3.80	30.35	88.72
Long duration	6.74	11.58	0.68	9.94	2.50	19.18	89.91
CD (*p*=0.05%)	0.48	2.62	0.12	1.27	0.29	1.80	0.52
Cropping systems							
Rice-Wheat-Greengram	5.99	3.82	0.6	4.03	2.26	12.29	89.45
Rice-Potato-Greengram	5.88	21.27	1.08	17.08	4.08	27.03	91.92
Rice-Tomato-Greengram	5.84	23.14	0.62	18.58	2.34	26.76	95.34
Rice-Cauliflower-Spinach-Greengram	6.1	31.26	0.81	25.10	3.06	34.26	89.04
Rice-Broccoli-Sp. onion-Greengram	6.15	24.38	0.75	23.49	2.83	32.47	87.95
Rice-Garden Pea-Greengram	6.23	5.04	1.17	5.40	4.42	16.05	82.19
CD (*p*=0.05%)	NS	4.02	0.22	2.48	0.66	3.58	0.96

other due to a bit higher cost of broccoli and spring onion. Land use efficiency as shown in Table 2 was significantly higher under long duration crop (89.91%) as compared to short duration crop (88.72%) due to the longer duration of crop (Kumar *et al*. 2019).

Effect of diversified cropping system on yield, system productivity and land use efficiency: Crop diversification in the rice-wheat cropping system significantly influenced the yield of *rabi* and summer crop and the system productivity (Rice equivalent yield). Pooled analysis of three years data of rice in various cropping systems revealed that rice yield of all cropping systems were at par with each other without showing any significant effect (Table 2). However, maximum yield of rice was obtained in rice-garden pea-green gram system. It is well established fact that inclusion of leguminous crop in rice-wheat cropping system enhance the system productivity. Inclusion of legume crops in the system not only fixes atmospheric-N but also enriches soil fertility, increase nutrient availability, improve soil structure, reduce disease incidence and promote mycorrhizal colonization (Banjara *et al*. 2021), and ultimately help to sustain the long-term productivity of cereal-based cropping systems. Further, in this experiment it was found that all cropping systems having vegetable crop during *rabi* season produced significantly higher *rabi* yield than wheat. In rice-cauliflower-spinach-green gram system and rice-broccoli-spring onion-green gram system, two crops were grown during *rabi* season resulted into higher *rabi* yield. Yield of green gram was significantly higher in rice-garden pea-green gram system followed by rice-potato-green gram system. The inclusion of pulses and vegetables in cropping systems are more beneficial than monocropping for achieving sustainable food and nutritional security (Banjara *et al*. 2022, Kumar *et al*. 2024). In rice-wheat-green gram system, the yield of green gram was minimum (0.6 t/ha) due to delayed sowing.

The system productivity was highest in rice-cauliflower-spinach-greengram system (34.26 t/ha) followed by rice-broccoli-spring onion-green gram (32.47 t/ha) and significantly superior among all other cropping systems (Table 2). System productivity of rice-potato-green gram and rice-tomato-green gram system was at par to each other and performed better than rice-garden pea-green gram and rice-wheat-green gram system. Shivani *et al*. (2014) through their earlier studies reported 8.7 t/ha rice equivalent yield for rice-wheat cropping system in MIGP. Further inclusion of leguminous crop i.e. green gram in the system enhanced the system productivity of rice-wheat-green gram system (12.29 t/ha). However, diversification of wheat with *rabi* vegetables enhanced the system productivity further and thus, system productivity of rice-wheat-green gram system became comparatively lowered. Higher system productivity of diversified cropping systems might be due to higher tonnage and per unit value of vegetable crops (Singh *et al*. 2012). Intensification and inclusion of vegetable crop during *rabi* season may be attributed to higher system productivity as vegetables are remunerative crop (Samant 2015).

Land use efficiency was significantly affected by diversification of cropping systems (Table 2). The land use efficiency was maximum for rice-tomato-green gram system (95.34%) due to more number of days taken by this crop sequence while it was minimum for rice-garden pea-green gram system. As the land use efficiency mainly depends on the total duration of the crops, inclusion of summer crops in these sequences occupied field for longer duration and increases land use efficiency (Saha *et al.* 2022). Higher land use efficiency confirmed that crop diversification utilizes land resources efficiently, which would not only increased productivity but also profitability (Upadhyaya *et al.* 2022).

Interaction effect: The interaction effect of rice duration and cropping system was found significant on yield of *rabi* crop (Table 3), system productivity (Fig. 1) and system production efficiency (Fig. 2). Pooled data of three years showed that all *rabi* crops performed well when sown after

Table 3　Effect of rice duration on yield of diversified *rabi* vegetables

Treatments	Wheat (t/ha)	Potato (t/ha)	Tomato (t/ha)	Cauliflower + Spinach (t/ha)	Broccoli + Spring onion (t/ha)	Garden pea (t/ha)	Mean
Short duration rice (Swarna Shreya)	4.63	27.53	28.42	45.63	35.50	6.58	24.72
Long duration rice (Swarna)	3.00	15.0	17.86	16.89	13.25	3.5	11.58
Mean	3.82	21.27	23.14	31.26	24.38	5.04	

CD for duration: 1.5; cropping system: 2.9

CD at same level of duration: 4.3; CD at same level of cropping system: 3.99

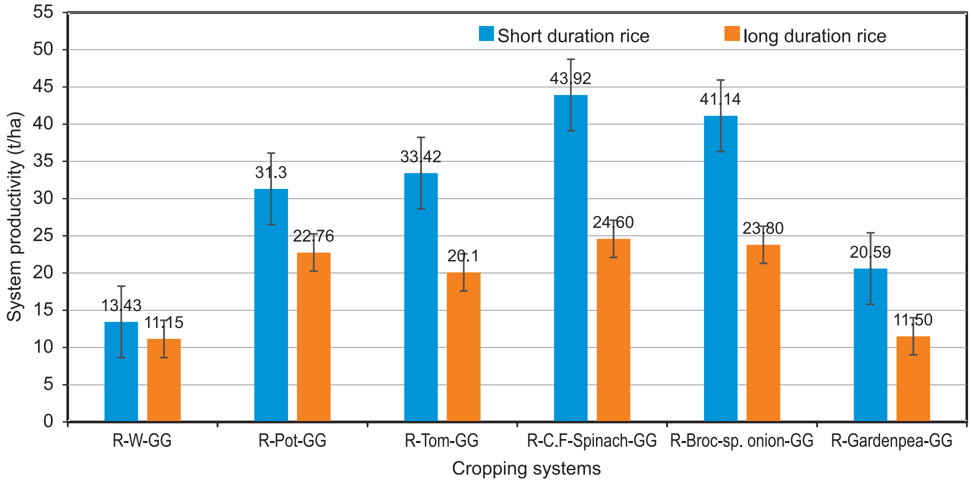

Fig. 1　Effect of rice duration on system productivity (t/ha) of different cropping systems.

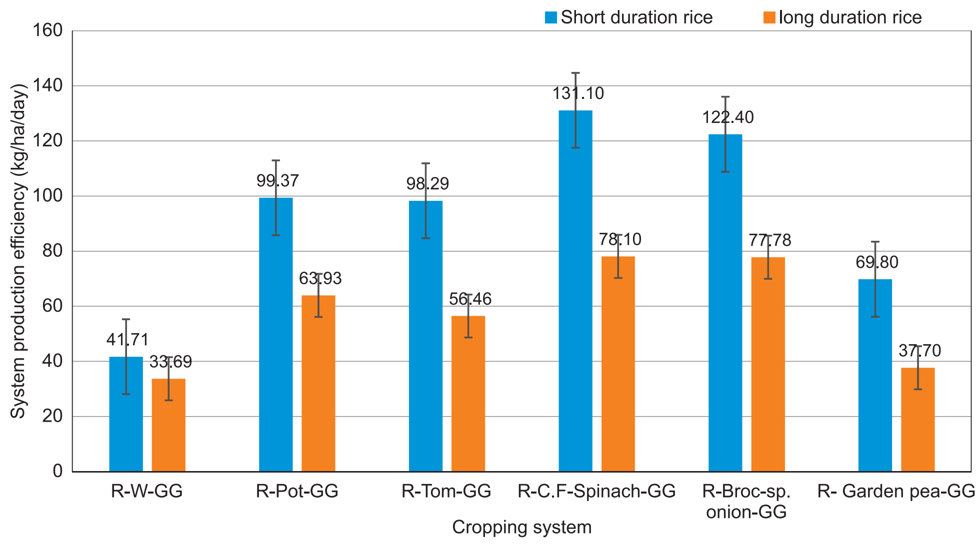

Fig. 2　System production efficiency (kg/ha/day) of diversified cropping system.

short duration rice. *Rabi* yield ranged from 4.63–45.63 t/ha when sown after short duration rice. While this range reduced from 3.0–17.86 t/ha when sown after long duration rice. *Rabi* crop sown after long duration rice could not perform as good as that of short duration rice resulting into low yield reason being the extended duration of rice crop which limited the growth period of *rabi* crop and unavailability of favourable weather condition during that period. With short duration rice, cauliflower-spinach produced maximum yield (45.63 t/ha) but in case of long duration rice, maximum yield was produced by tomato crop (17.86 t/ha). However, in both cases wheat produced minimum yield (Table 3). Moreover, growing winter crops such as carrot, potato, tomato, French bean, pea, and lentil after rice harvest not only enhance the yield, system productivity but also incomes of rural communities (Kumar *et al*. 2018).

System productivity and system production efficiency were also markedly affected by interaction of rice duration and cropping systems. System productivity was found higher for all cropping systems with short duration of rice crop in the system (Fig. 1). System productivity of different cropping systems with short duration rice ranged from 13.43–43.92 kg/ha while, it was lower with long duration rice variety (11.15–24.6 kg/ha). System production efficiency varied significantly due to diversified cropping system (Upadhyaya *et al*. 2022). Further adoption of short duration rice variety in the diversified cropping system enhanced the system productivity. This suggests that the relatively shorter duration of rice crop in the system allows for more efficient use of *rabi* growing period which is beneficial for all crops (Banjara *et al*. 2021). The system production efficiency was found highest in rice-cauliflower-spinach- greengram system with both short as well as long duration of rice (131.1 and 78.1 kg/ha/day) followed by rice-broccoli-spring onion-green gram (122.4 and 77.78 kg/ha/day).

Economics: Economics and system profitability of all the cropping systems for both longer and shorter duration rice

Table 4 Economics and system profitability of rice based cropping systems with rice cultivars of different rice duration

Cropping systems	Gross income (₹/ha)	Net return (₹/ha)	B: C ratio	System profitability (₹/ha/day)
SDR-Wheat-Greengram	249798	122462	0.96	380
SDR-Potato-Greengram	582180	404644	2.28	1108
SDR-Tomato- Greengram	621661	453447	2.70	1242
SDR-Cauliflower-Spinach-Greengram	816865	612265	2.99	1677
SDR-Broccoli-Sp. onion-Greengram	765139	559614	2.72	1533
SDR-Garden Pea-Greengram	382999	258932	2.09	709
LDR-Wheat-Greengram	207390	73490	0.55	201
LDR-Potato-Greengram	423336	258752	1.57	709
LDR-Tomato-Greengram	373860	185948	0.99	509
LDR-Cauliflower-Greengram	457560	276002	1.52	756
LDR-Broccoli-Greengram	442680	260333	1.43	713
LDR-Garden Pea-Greengram	213900	90396	0.73	248

SDR, Short duration rice cultivar; LDR, Long duration rice cultivar; Price of Potato, tomato, cauliflower, spinach: ₹15/kg; Broccoli and spring onion: ₹18/kg; Garden pea: ₹20/kg and MSP for rice, wheat and green gram was used for calculating REY.

is depicted in Table 4. Among all the cropping systems, rice and green gram were the common *kharif* and summer crop, respectively. Rice was transplanted on same date. Therefore, it was observed that economic parameters were mostly governed by *rabi* crop and to some extent by green gram. Gross return and net return were directly proportion to the economic yield of crop and the variable cost of cultivation. The duration of rice yield influenced the economics of all cropping systems. Comparatively cropping systems having shorter duration of rice produced higher yield and thereby increased the gross return, net return and benefit cost ratio of those systems. Short duration rice-cauliflower-spinach-green gram system fetched the highest gross return (₹8.16 lakh/ha), net return (₹6.12 lakh/ha) and benefit:cost ratio (2.99) while long duration rice-cauliflower-green gram system fetched lower income (Table 4). Lower income may be due to reduction in *rabi* and green gram yield (Samant 2015). Other systems also performed better with short duration rice. With long duration rice, cropping system rice-potato-green gram recorded highest B:C ratio (1.57) followed by rice-cauliflower-green gram (1.52). The system profitability obtained by all cropping systems with shorter duration of rice was much higher as compared to those with longer duration rice. Prasad *et al*. (2013) reported better economic parameters under the diversified cropping systems by adding vegetables and pulses. Higher productivity of vegetables and higher sale price of green gram resulted into higher system profitability (Singh *et al*. 2012).

On the basis of above study, it can be emphasized that there is significant scope of diversification for rice-based cropping system. Crop diversification in the existing rice-wheat cropping system, with introduction of vegetables and pulses along with shorter duration rice variety Swarna Shreya improved the system productivity, system production efficiency, land use efficiency, net return and system profitability. Diversified cropping systems like rice-cauliflower-spinach-green gram and rice-broccoli-spring onion-green gram system were found promising to other cropping systems, as four crops can be grown per year with higher cropping intensity (400%). Growing short duration rice variety enhanced the productivity and profitability of the system. Diversification of rice-wheat cropping system with vegetables were biologically efficient and highly profitable with a potential to serve as a viable option for middle Indo-Gangetic plains.

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