Indian Journal of Agronomy **68** (3): 246–252 (September 2023)

Research Paper

Production potential of pulse-and oilseed-based climate-resilient alternative cropping systems for diversification of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) in North-western Indo-Gangetic Plains

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Received: December 2022; Revised accepted: September 2023

ABSTRACT

A field experiment was conducted during 2016–17, 2017–18 and 2018–19 at the Punjab Agrcultural University, Ludhiana, India, to evaluate the economic feasibility of pulse-and oilseed-based new alternative cropping systems in comparison to rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) cropping system. Among the 10 cropping systems evaluated in a randomized block design on a loamy sand soil, the highest rice-equivalent yield (23.2 t/ha) was obtained in groundnut (*Arachis hypogaea* L.)–garden peas (*Pisum sativum* L.)–sunflower (*Helianthus annuus* L.) with highest sustainable- yield index (0.81), followed by groundnut –garden peas– spring maize (*Zea mays* L.) (22.5 t/ha) as significantly better than rest of the cropping systems. In comparison to conventional rice–wheat system, higher net returns as well as relative economic efficiency were recorded in 4 cropping systems, viz. groundnut–garden peas–sunflower, groundnut–garden peas–spring maize, rice–wheat–summer mungbean [*Vigna radiata* (L.) R. Wilczek] and mungbean–*toria* [*Brassica rapa* subsp. *dichotoma* (Roxb.) Hanelt]–sunflower. Maximum apparent water productivity was observed in pigeonpea [*Cajanus cajan* (L.) Millsp.]–chickpea (*Cicer arietinum* L.)–summer mungbean, whereas the maximum nutrient-use productivity was observed in groundnut–garden peas–sunflower, followed by pigeonpea–chickpea–summer mungbean and the least values were recorded in rice–wheat system. Thus, resource-conserving biointensive cropping systems, viz. groundnut–garden peas–sunflower, groundnut–garden peas–spring maize, rice–wheat–summer mungbean and mungbean–*toria*–sunflower can be adopted for higher productivity, profitability and sustainability.

***Key words*:** Apparent water productivity, Diversification, Economics, Production efficiency, Pulse-based cropping systems, Rice-equivalent yield, Sustainable-yield index

Punjab, situated in the north western Indo Gangetic Plains (IGP), comprises an area of about 5 million ha and contributed 30.5% of wheat (*Triticum aestivum* L.) and 22.6% of rice (*Oryza sativa* L.) to the central foodgrain pool during the year 2020–21 (PAU, Ludhiana, 2021). Rice–wheat is the most predominant cropping system adopted by Punjab farmers even in non-traditional areas because of low risk, assured market, high productivity and profitability, but this system is now the source of many problems. Stagnant yield, development of resistance in weeds, insect and pests, declining factor productivity, deterioration of soil fertility and water resources both in terms of quality and quantity, environmental degradation are the important implications due to the adoption of this input-intensive system over a large area (Kaur and Palli, 2021). Diversification of crops is of immense importance for conserving the soil and water resources, crop productivity, income enhancement and to mitigate the weather extremes (Patel *et al*., 2022). Inclusion of pulses, oilseeds and vegetables can be a viable option to arrest the stagnant or declining trend in productivity of cereal-based cropping systems with additional economic returns and employment generation.

India is the largest producer, consumer, as well as importer of pulses in the world which is to the tune of 25, 27 and 14% of the global values respectively (FAO, 2021). Pulses occupied about 28.8 million ha area in India with production to the tune of 25.5 million tonnes, with average productivity of 885 kg/ha, during 2020–21 (www.indiastat.com.2022). Depending on the shortfall of pulse production at domestic level, India imported about 6.61 million tonnes worth ₹235.5 billion during 2016–17 which reduced to 2.53 million tonnes in 2018–19 (www.indiastatagri.com). Since pulses have the ability to grow in low-input manage-

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ment conditions and are of short duration, they can play important role in crop diversification and intensification (Ali and Gupta, 2012). Crop intensification by inclusion of legumes in the cropping systems enhances the crop/ system productivity, profitability, improves the soil health (Jacob *et al.,* 2016) and soil water conservation (Kaur *et al.,* 2018). Till now, pulse production remained unattractive to Indian farmers due to their low productivity and less policy support as compared to wheat and rice. Globally, India is the fourth largest edible oil economy and contributes 10% to the global production of oilseeds and 6–7% in case of vegetable oil. Still, India is among the largest importers of edible oils ($10.5 billion) in the world followed by China and the United States of America (Patel and Jat, 2022) and imported over 14.0 million tonnes of edible oils during 2021–22 (www.indiastat.com 2022).

Rising demands of pulses and oilseeds with ever-increasing population needs to be addressed through stepping up the domestic production of pulses and oilseeds supported with appropriate long-term strategies. The productivity gain is more imperative, as the scope of horizontal expansion is very limited. Therefore, the objective of present study was to explore other novel pulse and/ or oilseed-based cropping systems which are more productive, profitable, sustainable and also conserve natural resources; and can help to diversify some area from rice–wheat cropping system.

MATERIALS AND METHODS

A field experiment was conducted at the research farm of the Department of Agronomy, Punjab Agricultural University, Ludhiana (30°56' N, 75°52' E and 247 m above sea-level), during 2016–17, 2017–18 and 2018–19, on a permanent site. The climate of the experimental site is subtropical with hot and dry summer, wet monsoon season (July–September) and a cool dry winter with average annual rainfall of about 734 mm, 85% of which falls during the monsoon season. The soil of the experimental site was loamy sand with *p*H 7.6, electrical conductivity 0.16 dS/m, organic carbon 0.42%, available N 280.27 kg/ha, available P 21.65 kg/ha and available K 210.29 kg/ha.

The experiment was set up with 10 cropping systems, viz. mungbean [*Vigna radiata* (L.) R. Wilczek]–*toria* [*Brassica rapa* subsp. *dichotoma* (Roxb.) Hanelt]–sunflower (*Helianthus annuus* L.), mungbean–Indian mustard [*Brassica juncea* (L.) Czern.]–summer mungbean, mungbean–*gobhi sarson* (*Brassica napus* L.)–summer mungbean, soybean [*Glycine max* (L.) Merr]–*gobhi sarson*–summer mungbean, pigeonpea [*Cajanus cajan* L.) Millsp.]–*gobhi sarson*–summer mungbean, pigeonpea–chickpea (*Cicer arietinum* L.)–summer mungbean, groundnut (*Arachis hypogaea* L.)–garden peas (*Pisum sativum* L.) –sunflower, groundnut–garden peas–spring maize (*Zea mays* L.), rice–wheat–summer mungbean and rice–wheat, which were arranged in a randomized complete-block design with 3 replications. Different crops were raised by following recommended package of practices under irrigated conditions. The details of varieties, seed rate, row spacing, growing season, sowing time, harvesting time, duration, irrigation and nutrients applied to different crops are given in Table 1. In case of pigeonpea-based cropping system, crops were sown on very next day after field preparation in residual moisture content of previous crop to save time. Field was vacated after harvesting and threshing was done afterwards.

For comparison among different cropping systems, the yield of different non-rice crops were converted to rice-equivalent yield (REY) on the basis of prevailing market rates and calculated as follows:

$$\text{REY (t/ha)} = \frac{\text{Yield of non-rice crop (t/ha)} \times \text{price of non-rice crop (₹/t)}}{\text{Price of rice (₹/t)}}$$

The prices used were the prevailing price of respective crops in the respective years (Table 2).

Sustainable-yield index (SYI) was calculated as:

$$\text{SYI} = \frac{\text{Average yield} - \text{SD}}{\text{Maximum yield}}$$

For computing SYI, average yield, maximum yield and standard deviation (SD) over 3 cropping cycles were taken into account. Apparent nutrient-use productivity (ANUP) was calculated by dividing the system-equivalent yield by the total quantity of the nutrients applied to all the crops in the system. Relative production efficiency (RPE) was calculated by using the following formula where total yield is expressed in terms of total rice-equivalent yield:

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

Land-use efficiency (LUE) was calculated using the following method and expresses the extent to which land area was used in a year.

$$\text{LUE (\%)} = \text{TND} \times 100/365$$

where TND denotes total number of days field remained occupied under different crops.

Gross returns, net returns as well as benefit: cost ratio (B:C) were worked out by taking prevailing prices of the commodities as per treatment during the study. The cost of cultivation was calculated by taking into account all the costs involved for raising the different crops in a system (viz. seed, seedbed preparation, fertilizer, herbicide, insecticide, irrigation, labour involved. Benefit : cost ratio was worked out based on gross returns. Relative economic efficiency (REE) was calculated as:

$$\text{REE} = \frac{\text{Net returns of diversified cropping system} - \text{net returns of existing cropping system}}{\text{Net return of existing cropping system}} \times 100$$

Table1. Details of the varieties, seed rates, planting geometry, sowing and harvesting time, duration, irrigations and nutrients applied to different crops

Crop	Variety	Seed rate (kg/ha)	Planting geometry (cm × cm)	Sowing/ transplanting time	Harvesting time	Duration (days)	Average number of irrigations applied	Nutrients applied (kg/ha)		
								N	P_2O_5	K_2O
Rainy season crops										
Mungbean	'ML2056'	20	30 × 10	Second fortnight of July	End September	72	3	12.5	40	-
Soybean	'SL 744'	75	45 × 5	First fortnight of June	First fortnight of November	140	4	32	80	-
Pigeonpea	'PAU 881'	15	50 × 25	Second fortnight of May	First fortnight of November	148–156	3	15	40	-
Groundnut	'SG 99'	100	30 × 15	Second fortnight of May	End September	121–124	4	15	20	-
Rice	'PR126'	20	20 × 15	Second fortnight of June	End September/First fortnight of October	102	30	125	30	-
Winter season crops										
Toria	'TL 17'	3.75	30 × 10	End September	First fortnight of January	105	3	62.5	20	-
Gobhi sarson	'GSC 6'	3.75	45 × 10	October (First fortnight of November when followed by soybean and pigeonpea)	First fortnight of March	135–148	4	100	30	-
Wheat	'PBW 725'	100	20 cm (row-row)	End October	Mid-April	165	5	125	62.5	-
Chickpea	'GPF 2'	45	30 × 10	First fortnight of November	First fortnight of April	154	3	15	20	-
Indian mustard	'RLC 3'	3.75	30 × 10	Mid-October	Mid-March	148	3	100	30	-
Garden peas	'Pb 89'	75	30 × 10	October	End January	109	4	50	62.5	-
Summer/spring crops										
Spring maize	'PMH 10'	25	60 × 20	First fortnight of February	End May	112	11	125	60	-
Sunflower	'PSH 1962'	5	60 × 30	First fortnight of February	Mid-May	95	9	60	30	-
Summer mungbean	'SML 668'	30	22.5 × 7	End March	Second fortnight of May	66–68	4	12.5	40	-

Table 2. Price of different crops used in experiment

Crop	Price (₹/t)		
	2016–17	2017–18	2018–19
Rice	15,100	15,900	17,700
Wheat	16,250	17,350	18,400
Mungbean	52,250	55,750	69,750
Soybean	27,750	30,500	33,990
Pigeonpea	50,500	54,500	56,750
Garden peas	10,000	10,000	10,000
Groundnut	42,200	44,500	48,900
Toria	32,900	32,900	32,900
Gobhi sarson	32,900	32,900	32,900
Indian mustard	32,900	32,900	32,900
Chickpea	40,000	40,000	44,000
Sunflower	39,500	41,000	53,880
Spring maize	14,500	14,250	17,000
Summer mungbean	42,500	55,750	69,750

Profit margin was calculated by dividing the net returns with gross returns and expressed in percentage. Crop profitability in term of ₹/ha/day was calculated by dividing net monetary returns of the system with total duration of the crops in that system and the profitability of the system was calculated by dividing the net returns (₹/ha) in a system by 365 days (Kachroo *et al*., 2014).

The data were subjected to statistical analysis. The comparisons were made at 5% level of significance.

RESULTS AND DISCUSSION

System yield and productivity

Among the various cropping systems, the highest rice-equivalent yield was obtained in groundnut–garden peas–sunflower followed by groundnut–garden peas–spring maize and both were significantly better than the other cropping systems (Table 3). The per cent increase in rice-equivalent yield as compared to rice–wheat in these systems was 77.8 and 72.4 respectively. Inclusion of vegetables (Saini *et al*., 2020) and sunflower enhances productivity and the same was also reported by Prasad *et al.* (2016). Other systems which gave significantly higher rice-equivalent yield than rice–wheat system were rice–wheat–summer mungbean and mungbean–*toria*–sunflower with gain of 32.2 and 16.1% respectively. This might be owing to the inclusion of legumes/ pulses as well as summer or spring crops as third crop in the cropping systems. Singh *et al*. (2011) and Gan *et al*. (2015) also reported enhancement in the system productivity with the inclusion of pulses in rice–wheat system.

The maximum system productivity was obtained in groundnut–garden peas–sunflower, being significantly higher than the other cropping systems. The groundnut–garden peas–spring maize, mungbean–*toria*–sunflower and rice–wheat–summer mungbean gave higher system productivity than the conventional rice–wheat system. The least system productivity was obtained in soybean–*gobhi sarson*–summer mungbean system. The higher system productivity may be attributed to increase in cropping intensity from 200 to 300% in these systems. The maximum value of sustainable-yield index was obtained in groundnut–garden peas–sunflower (0.81), followed by groundnut–garden peas–spring maize (0.78) and the values among different cropping systems ranged from 0.31 to 0.81 (Table 4). Growing legumes in the systems maintain the agricultural sustainability (Stagnari *et al*., 2017). Thus, our results indicate that alternate cropping system options with higher productivity and sustainability are available in Indian Punjab for the diversification of rice–wheat system.

Relative production and land-use efficiency

Relative efficiency of different cropping systems was worked out with respect to the total productivity over the existing rice–wheat system. The maximum relative productivity was obtained in groundnut–garden peas–sunflower,

Table 3. Economic yields of different crops and system rice-equivalent yield under different cropping systems (pooled data of 3 years)

Treatment	Rainy season, crop yield (t/ha)	Winter season crop yield (t/ha)	Summer/Spring crop yield (t/ha)	Rice-equivalent yield (t/ha)
Mungbean–*toria*–sunflower	1.27	1.78	2.53	15.2
Mungbean–Indian mustard–summer mungbean	1.25	1.69	1.04	11.6
Mungbean–*gobhi sarson*–summer mungbean	1.21	1.93	1.09	12.1
Soybean–*gobhi sarson*– summer mungbean	1.99	2.09	1.17	12.0
Pigeonpea–*gobhi sarson*–summer mungbean	1.42	2.17	1.08	12.8
Pigeonpea–chickpea–summer mungbean	1.45	2.14	1.06	13.9
Groundnut–garden peas–sunflower	2.49	14.87	2.58	23.2
Groundnut–garden peas–spring maize	2.38	15.11	6.91	22.5
Rice–wheat–summer mungbean	7.51	5.40	1.16	17.3
Rice–wheat	7.32	5.35	-	13.1
SEm±	-	-	-	0.34
CD (P=0.05)	-	-	-	1.00

followed by groundnut–garden peas–spring maize, rice–wheat–summer mungbean and mungbean–*toria*–sunflower systems. Higher tonnage of economic yield of vegetable crops resulted in higher production efficiency and the same was also reported by Mal *et al.* (2018). The land-use efficiency was the highest in pigeonpea–chickpea–summer mungbean, followed by pigeonpea–*gobhi sarson*–summer mungbean and soybean–*gobhi sarson*–summer mungbean, which was owing to the longer duration of these crops in the field. The maximum crop duration was observed in case of chickpea followed by pigeonpea, soybean and *gobhi sarson* (Table 4).

Apparent water productivity and nutrient-use productivity

The highest apparent water productivity was observed in pigeonpea–chickpea–summer mungbean cropping system (2.62 kg/m^3) which was significantly higher than all the other cropping systems. Rice–wheat system recorded the lowest apparent water productivity as compared to all the other systems. The other cropping systems showed apparent water productivity in the range of 0.64 to 2.37 kg/m^3. Rice requires maximum number of irrigations and thereby the systems involving rice had lower water productivity as compared to the other systems. The second highest productivity was recorded in groundnut–garden peas–sunflower (2.37 kg/m^3) despite more irrigation requirement and this may be attributed to its higher system productivity (Table 4). Gan *et al*. (2015) also reported water saving by including pulses in diversified cropping systems. The maximum apparent nutrient-use productivity was realized in groundnut–garden peas–sunflower followed by pigeonpea–chickpea–summer mungbean and both these systems were significantly superior to rest of the systems. The least apparent nutrient productivity was recorded in rice–wheat system which might be due to the lesser system productivity coupled with higher nutrient requirement in comparison to the other systems.

Economic analysis

Of the 10 cropping systems evaluated, the maximum gross returns were recorded in groundnut–garden peas–sunflower, followed by groundnut–garden peas–spring maize, rice–wheat–summer mungbean and mungbean–*toria*–sunflower cropping systems (Table 5). Cost of cultivation increased with the increase in cropping intensity from 200 to 300% and inclusion of vegetables and spring maize further enhanced the cost of cultivation as compared to pulses and oilseeds. Although, the cost escalation was more in triple cropping systems, owing to the extra gain in system productivity, there was consequent gain in gross returns. The gross returns and net returns followed the same trend in groundnut–garden peas–sunflower, ground-

Table 4. Duration (days taken), system productivity, sustainable-yield index, apparent nutrient-use productivity and apparent water productivity under different cropping systems (pooled data of 3 years)

Treatment	Duration (days)	System productivity (kg/ha/day)	Sustainable-yield Index	Relative production efficiency	Land-use efficiency (%)	Apparent nutrient-use productivity (kg/ha/kg nutrient applied)	Apparent water productivity (kg/m^3)
Mungbean–*toria*–sunflower	273	55.58	0.47	16.2	74.7	67.4	1.74
Mungbean–Indian mustard–summer mungbean	288	40.17	0.31	−11.3	78.9	49.2	1.99
Mungbean–*gobhi sarson* –summer mungbean	288	42.00	0.34	−7.24	78.9	51.5	2.09
Soybean–*gobhi sarson* – summer mungbean	343	35.00	0.33	−7.94	94.0	40.8	1.88
Pigeonpea–*gobhi sarson* –summer mungbean	356	36.04	0.37	−1.61	97.5	54.0	2.21
Pigeonpea–chickpea–summer mungbean	363	38.31	0.41	6.65	99.5	97.6	2.62
Groundnut–garden peas–sunflower	328	70.51	0.81	77.9	89.9	97.7	2.37
Groundnut–garden peas–spring maize	342	65.79	0.78	72.5	92.3	67.7	2.05
Rice–wheat–summer mungbean	329	52.43	0.56	32.3	90.1	50.4	0.77
Rice–wheat	267	48.85	0.38	-	73.2	33.0	0.64
SEm±	-	1.01	-	-	-	1.42	0.04
CD (P=0.05)	-	3.04	-	-	-	4.27	0.12

nut–garden peas–spring maize, rice–wheat–summer mungbean and mungbean–*toria*–sunflower cropping sequences. Increase in net returns over rice– wheat system was 76.1 × 10^3 ₹/ha in groundnut–garden peas–sunflower, 52.3 × 10^3 ₹/ha in groundnut–garden peas–spring maize, 39.3 × 10^3 ₹/ha in rice–wheat–summer mungbean and 17.9 × 10^3 ₹/ha in mungbean–*toria*–sunflower cropping sequences. The highest benefit: cost ratio was obtained in rice–wheat system followed by rice–wheat–summer mungbean and mungbean–*toria*–sunflower sequences. Besides production efficiency, profitability is also a major factor for deciding the viability of a sustainable cropping system. The highest crop profitability was recorded in groundnut–garden peas–sunflower (644.7 ₹/ha/day) followed by mungbean–*toria*–sunflower (564.5 ₹/ha/day), groundnut–garden peas–spring maize (550.6 ₹/ha/day) and rice–wheat–summer mungbean (532.8 ₹/ha/day) systems and only these 4 systems were found more profitable than rice–wheat cropping system. System profitabilty was the maximum in groundnut–garden peas–sunflower, groundnut–garden peas–spring maize, rice–wheat–summer mungbean and mungbean–*toria*–sunflower cropping systems. Similar trend was observed in relative economic efficiency. Rest of the systems based on mungbean, pigeonpea and soybean resulted in lower economic efficiency relative to rice–wheat system. Highest profit margin was obtained in rice–wheat system, followed by rice–wheat summer mungbean and mungbean–*toria*–sunflower systems. The least profit margin was obtained in groundnut–garden peas–spring maize cropping system (51.6%). Owing to intensification of cropping systems, gross returns of multiple cropping systems increased as compared to totally mechanized rice–wheat system where cost of cultivation was less, thus ultimately reducing profit margin. Cost of cultivation was the maximum in groundnut–garden peas–spring maize and gross returns were also higher than rice–wheat, thereby lowering profit margin in this system.

Based on these results, it can be concluded that groundnut–garden peas–sunflower, groundnut–garden peas–spring maize, rice–wheat–summer mungbean and mungbean–*toria*– sunflower were the most productive and remunerative cropping systems under irrigated conditions of Indian Punjab as well as in North-western Indo-Gangetic Plain region and can be promoted as alternate to existing rice–wheat system among farmers and good success is expected because shift from rice–wheat cropping system is high on the agenda of the government with positive policy paradigm.

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Table 5. Different economic indices under different cropping systems (pooled data of 3 years)

Treatment	Gross returns (×10^3 ₹/ha)	Cost of cultivation (×10^3 ₹/ha)	Net returns (×10^3 ₹/ha)	B:C	Crop profitability (₹/ha/day)	System profitability (₹/ha/day)	Relative economic efficiency (%)	Profit margin (%)
Mungbean–*toria*–sunflower	246.3	92.4	153.9	2.67	564.5	421.7	13.2	62.5
Mungbean–Indian mustard–summer mungbean	188.0	86.2	101.8	2.18	353.4	278.9	–25.2	54.1
Mungbean–*gobhi sarson*–summer mungbean	197.4	88.4	109.1	2.23	378.7	298.8	–19.8	55.2
Soybean–*gobhi sarson*–summer mungbean	194.6	92.6	102.0	2.10	297.3	279.4	–25.0	52.4
Pigeonpea–*gobhi sarson*–summer mungbean	208.3	90.9	117.4	2.29	329.8	321.6	–13.7	56.4
Pigeonpea–chickpea–summer mungbean	225.8	95.9	129.9	2.36	358.0	356.0	–4.45	57.5
Groundnut–garden peas–sunflower	376.5	164.4	212.1	2.29	644.7	581.1	55.9	56.3
Groundnut–garden peas–spring maize	364.7	176.4	188.3	2.07	550.6	515.9	38.5	51.6
Rice–wheat–summer mungbean	279.9	103.6	175.3	2.68	532.8	480.2	28.9	62.6
Rice–wheat	211.2	74.2	136.0	2.81	509.4	372.6	-	64.4

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