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Bio-intensive complimentary cropping systems for north-west India

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ABSTRACT

A field experiment was conducted during 2014–15 and 2015–16 at Punjab Agricultural University, Ludhiana to evaluate bio-intensive complementary cropping systems as a possible replacement of the prevailing rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system. The treatments comprised 12 cropping systems and were set in a three-time replicated randomized block design. The results revealed that maize (*Zea mays* L.) (cobs) + vegetable cowpea [*Vigna unguiculata* (L.) Walp.] + *Sesbania*-gram (*Cicer arietinum* L.) + *gobhi sarson* (*Brassica napus* L.) cropping system showed maximum rice equivalent yield (229.9 q/ha), production efficiency (79.4 kg/day/ha) and net returns (₹30,6066/ha). These systems also ensured saving of 127.5 cm irrigation water over the existing rice-wheat system (247.5 cm) and proved to be a viable option to avail higher profitability for farmers in Punjab. The removal of N, P and K was significantly higher in all the maize based cropping systems over rice-wheat cropping system. In addition, maize (furrow) + turmeric (*Curcuma longa* L.) (bed)-wheat (bed) + linseed (*Linum usitatissimum* L.) (furrow) cropping system gave highest viable counts of actinomycetes and fungi, whereas maize (furrow) + turmeric (bed)-barley (*Hordeum vulgare* L.) (bed) + linseed (furrow) gave highest count for bacteria. The fodder based cropping system, viz. sorghum [*Sorghum bicolor* (L.) Moench] + cowpea (fodder)-wheat + *gobhi sarson* with high energy output showed the highest energy-use efficiency (48.28) and energy output efficiency (6.35×10^3 MJ/ha/day). Maize (cobs)+vegetable cowpea + *Sesbania*-gram + *gobhi sarson* cropping system showed the highest average maximum energy productivity (8.24 kg REY/MJ) and it was mainly due to its higher REY.

Keywords: Energy productivity, Energy use efficiency, Production efficiency, Rice equivalent yield, Net returns

In the era of shrinking resource base of land, water and energy, resource use efficiency is an important aspect for considering the sustainability of a cropping system (Yadav 2002). Agricultural diversification has become a significant component for realizing higher output growth, higher farm income, employment generation, sustainability of natural resources and poverty alleviation. Several researchers have argued that agricultural diversification can be used as an instrument to raise farm income, generate employment opportunities, alleviate poverty and for conservation of natural resources (Dass and Sudhishri 2010 and Walia *et al*. 2017).

Hence, identification of bio-intensive complimentary cropping systems by inclusion of cereals, vegetables, oilseeds and pulse crops which are ecologically sustainable and more viable is pertinent. Hence, selection of component crops needs to be suitably planned to make use of the synergy among them for efficient utilization of resource base and to increase overall productivity (Anderson 2005). By using bio-intensive agriculture in its modern, scientifically proven form, at intermediate-level yields, with a reasonable build-up of soil quality and farmer skill, on approximately 4000 square feet (317.6 m^2) per person it is possible to raise a complete vegan diet plus all the carbonaceous and nitrogenous compost materials necessary to maintain fertile soil and a modest income. A healthy bio-intensive farm has the capacity to use 67–88% less water, 50–100% less fertilizer, and 99% less energy than conventional agriculture practices. Furthermore, bio-intensive farming has been known to replenish soil nutrients 60 times faster than nature does on its own (Jeavons 2006). Thus, the current study aimed at evolving alternative cropping systems with higher productivity and profitability over the widely adopted rice-wheat cropping system.

MATERIALS AND METHODS

Present study was carried out at Punjab Agricultural University, Ludhiana Centre under All India Coordinated Research Project on Integrated Farming System (IFS) during 2014–15 to 2015–16. Soil of the experimental field was sandy loam in texture. Twelve cropping systems were evaluated for their production potential and economics, viz.

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T_1: Rice-wheat, T_2: Basmati rice-hayola (transplanted)-summer moongbean [*Vigna radiata* (L.) R. Wilczek] (G+R), T_3: Basmati rice-radish (*Raphanus sativus* L.)-spring maize, T_4: Maize-potato-spring maize, T_5: Maize (furrow) + turmeric (Bed)-barley (Bed) + linseed (furrow), T_6: Maize (furrow) + turmeric (bed)-wheat (bed) + linseed (furrow), T_7: Maize (furrow) + radish (bed)-wheat (bed) + linseed (furrow)–summer moongbean, T_8: Groundnut (*Arachis hypogaea* L.) + *arhar* [*Cajanus cajan* (L.) Millsp.] (5:1)–wheat + *sarson* (9:1), T_9: Maize + *mash* (*Vigna radiata* L.)-peas (*Pisum sativum* L.) (bed) + celery (*Apium graveolens* L.) (furrows), T_{10}: Maize + *mash*-peas (bed) + celery (furrows), T_{11}: Maize (cobs) + vegetable cowpea + *Sesbania* (BBF: 105 cm wide bed and 30 cm wide furrow, *Sesbania* in furrow and incorporation at 42 days after sowing. Two rows of maize on beds (70 × 25 cm) and row of cowpea for vegetable (fodder purpose) mustard sown in furrow and gram on beds-3 rows in *rabi* green gram (G+R in summer) and T_{12}: Sorghum + cowpea (fodder)-wheat + *gobhi sarson* (9:1).

A four-time replicated randomized complete block design was used. For comparison among crop sequences, the yields of all the crops were converted into Rice Equivalent Yield (REY) on price basis. System yield was obtained by adding REY of component crops and prices were used as an average of all the years. Total field duration of a cropping system expressed in percentage of 365 days was taken as the land-use efficiency (LUE) of the system. Irrigation water use efficiency (IWUW) was worked out by dividing the rice equivalent yield of the system with the total quantity of water applied through irrigation in that cropping system. System productivity of different rice-based cropping systems was obtained by dividing the system yield by 365 and was expressed in kg REY/ha/day. Production efficiency (PE) was calculated by dividing the system yield by total duration of the system and was expressed in kg REY/ha/day. The mean of prevailing market rates during 2014–15 and 2015–16 were used for computing economic viability.

The equivalent energy values of various inputs and outputs as suggested by Devasenapathy *et al*. (2009) were used for computing total energy input and energy output of a cropping system. The energy input and output were computed as Mega Joule (MJ). The energy input for a particular cropping system was calculated as the summation of energy requirement for a human, animal, machineries, diesel, seed, herbicide, FYM, chemical fertilizers and pesticides used in that system. Similarly, the energy output for a particular cropping system was calculated as the summation of energy output from the main product and by-products in that system. The energy use efficiency, energy output efficiency (MJ/ha/day) and energy productivity (kg REY/MJ) were calculated as explained by Walia *et al*. 2014.

Nutrient removal by different cropping sequences was also worked out by estimating the nutrient concentrations (N, P and K) in grain and straw of crops. To understand the impact of various cropping systems on soil fertility, post-harvest soil was analyzed for organic carbon, available N, P and K status and microbial count of soil by following the standard procedures.

RESULTS AND DISCUSSION

Productivity and system yield of different cropping systems: The maize (cobs) + vegetable cowpea + *Sesbania*-gram + *gobhi sarson* and maize-potato-spring maize gave rice equivalent yield of 289.7 and 229.9 q/ha/annum as against 130 q/ha/annum in rice-wheat cropping system (Table 1). Maize (cobs) + vegetable cowpea + *Sesbania*-gram + *gobhi sarson* also revealed two times higher system yield than existing rice-wheat cropping system. These systems also play a vital role in saving irrigation water. In trans-Gangetic plains, the maize based cropping systems, viz. maize-wheat-green gram, maize-potato-green gram and maize-potato-onion produced higher system productivity and irrigation water productivity over rice-wheat system. (Gill and Sharma 2005). Singh (2006) reported that in peri-urban interface, high value cropping systems involving maize are more remunerative than the rice-wheat cropping system. Further, maize-potato-onion, summer groundnut-potato-pearl millet and maize-potato-summer moongbean cropping systems produced significantly higher REY over rice-wheat system (Walia *et al*. 2010). Choudhary *et al.* (2001) also reported greater productivity by replacing wheat in rice-wheat system with vegetables crops like potato and radish. In two years experiment, with diversification of cotton-legume-corn rotation, the yield increase to tune of 11% was recorded as compared to continuous cotton grown without legumes (Sankaranarayanan *et al.* 2010).

Land use efficiency: The LUE is mostly governed by duration of rainy (*kharif*) season and winter (*rabi*) season crops and the existing rice-wheat cropping system showed 72.60% LUE. The maize based cropping system showed the highest land use efficiency, viz. maize (furrow) + radish (bed)-wheat (bed) + linseed (furrow)-summer moongbean measured at 95.62% which is closely followed by maize-potato-spring maize (90.68%) (Table 1). Groundnut + *arhar* (5:1)-wheat + *sarson* (9:1) also proved to be a good cropping system with maximum land use efficiency (89.32%).

Production efficiency and water saving: The groundnut + *arhar* (5:1)-wheat + *sarson* (9:1) cropping system showed a great performance as it used 165 cm less water than rice-wheat cropping system. The maize based cropping system, viz. maize + *arhar*-gram (bed) + *gobhi sarson* (furrows) proved second best alternative by saving 150 cm of irrigation water (Table 1). The maize based cropping system with 300% cropping intensity, viz. maize-potato-spring maize saved 127.5 cm of irrigation water and showed 63 kg/day/ha production efficiency. Maize (cobs) + vegetable cowpea + *Sesbania*-gram + *gobhi sarson* proved to be another promising cropping system that gave 114.35 kg/day/ha production efficiency using 120 cm of irrigation water leading to 127.5 cm saving of water. Sharma *et al.* (2004) also revealed that maize-potato-onion, summer groundnut-potato-bajra (fodder), maize-potato-summer

Table 1 Economic yield of grain and straw and economic analysis of different cropping systems

Cropping system	Economic Yield (q/ha)					Straw/Stover Economic Yield (q/ha)					Economic analysis									
	Kharif		*Rabi*		Summer	*Kharif*		*Rabi*		Summer	Pro-duction efficiency (kg/day/ha)	LUE (%)	Rice equiva-lent yield (q/ha)	System produc-tivity (kg/day/ha)	Irrigation water (cm)	IWUE (kg grain/m³ irrigation water)	Gross returns (₹/ha)	Input cost (₹/ha)	Net returns (₹/ha)	B:C ratio
	Main	Inter-crop	Main	Inter-crop	Main	Main	Inter-crop	Main	Inter-crop	Main										
T_1	62.3	0.0	51.5	0.0	0.0	104.9	0.0	92.4	0.0	0.0	42.93	72.60	130.0	35.6	247.5	0.525	185264	76074	109191	1.44
T_2	38.9	0.0	17.4	0.0	11.3	102.0	0.0	81.4	0.0	33.4	34.77	53.15	163.2	44.7	180.0	0.907	231983	102835	129148	1.26
T_3	38.4	0.0	241.0	0.0	63.6	99.8	0.0	0.0	0.0	92.5	110.25	85.21	207.4	56.8	265.0	0.783	295288	152604	142684	0.93
T_4	48.1	0.0	223.0	0.0	56.4	97.5	0.0	64.4	0.0	97.6	98.96	90.68	229.9	63.0	120.0	1.916	327441	195340	132101	0.68
T_5	36.7	160.1	33.9	3.6	0.0	84.0	107.6	63.7	16.9	0.0	92.23	69.59	204.8	56.1	123.8	1.659	291477	88666	202811	2.29
T_6	37.1	162.5	37.2	3.6	0.0	83.6	109.2	64.3	17.9	0.0	89.02	73.97	206.6	56.6	123.8	1.671	294347	88237	206111	2.34
T_7	36.7	84.1	36.2	3.6	10.4	83.2	0.0	72.2	20.0	27.9	48.99	95.62	160.1	43.9	157.5	1.017	228084	97438	130647	1.34
T_8	15.3	4.7	47.7	2.3	0.0	72.8	17.5	83.1	10.3	0.0	21.46	89.32	134.5	36.9	82.5	1.631	191597	85684	105914	1.24
T_9	33.4	3.5	96.9	11.3	0.0	60.3	16.3	216.8	21.0	0.0	75.20	52.88	183.5,	50.3	105.0	1.748	261014	137016	123998	0.90
T_{10}	32.1	8.9	14.1	14.0	0.0	51.8	36.3	45.8	38.1	0.0	25.57	73.97	134.9	37.0	97.5	1.383	192074	85257	106817	1.25
T_{11}	218.1	27.1	3.2	15.5	10.6	111.0	86.7	18.7	54.0	41.3	114.35	65.75	289.7	79.4	120.0	2.415	413188	107122	306066	2.86
T_{12}	571.6	0.0	48.7	2.3	20.3	0.0	0.0	79.9	10.1	157.0	318.30	55.34	136.1	37.3	105.0	1.297	193710	69897	123814	1.77
CD	4.17	29.4	3.85	0.36	5.42	3.19	21.4	10.9	1.01	58.4	-	-	-	-	-	-	-	-	-	-
SEM(±)	1.39	9.8	1.28	0.12	1.80	1.06	7.13	3.63	0.33	19.46	-	-	-	-	-	-	-	-	-	-

Treatment details given under Materials and Methods. Pooled Data of two years (2014–15 and 2015–16).

Table 2 Energy input-output relationship, Nutrient uptake (kg/ha) (N, P, K), soil fertility status and microbial count after winter (*rabi*) season 2017–18 at 0–15 cm depth of different bio-intensive cropping system

Cropping systems	Energy input-output relationship					*Kharif* nutrient uptake			*Rabi* nutrient uptake			Summer nutrient uptake			Soil fertility status				Viable count (cfu/g)		
	Energy input ($\times 10^3$ MJ/ha)	Energy output ($\times 10^3$ MJ/ha)	Energy use effi-ciency	Energy output efficiency ($\times 10^3$ MJ/ha/day)	Energy produc-tivity (kg REY/MJ)	N	P	K	N	P	K	N	P	K	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)	Bacteria ($\times 10^6$)	Actino-mycetes ($\times 10^4$)	Fungi ($\times 10^3$)
T_1	28.66	413.96	14.44	1.56	4.54	138.3	37.2	112.4	117.2	36.8	101.4	-	-	-	0.38	187.4	39.9	98.2	25.3	28.9	16.1
T_2	23.05	459.62	19.94	2.37	7.08	95.1	27.7	90.2	73.8	30.2	110.3	50.8	16.9	39.8	0.47	196.0	47.8	101.5	27.3	31.0	16.5
T_3	39.08	479.72	12.28	1.54	5.31	96.3	28.2	106.5	119.1	30.5	327.5	137.2	44.1	138.3	0.42	198.3	45.5	92.6	29.0	32.7	19.4
T_4	48.80	694.21	14.23	2.10	4.71	138.5	38.0	140.6	262.9	27.6	327.7	125.1	45.0	155.4	0.49	181.1	46.2	97.0	31.0	32.1	17.7
T_5	44.55	459.17	10.31	1.81	4.60	119.8	34.8	133.3	74.9	27.9	78.2	-	-	-	0.44	193.4	42.9	89.4	38.1	34.8	23.8
T_6	50.30	506.57	10.07	1.88	4.11	112.3	34.3	132.4	82.8	27.6	83.3	-	-	-	0.42	199.8	47.0	91.0	40.0	33.2	18.9
T_7	46.33	444.89	9.60	1.27	3.46	113.7	37.7	135.1	85.1	29.0	84.2	41.8	15.4	38.3	0.43	207.2	44.8	96.2	31.1	29.0	22.0
T_8	27.06	360.24	13.31	1.11	4.97	65.2	27.2	60.5	105.4	33.7	105.4	-	-	-	0.45	209.2	46.2	103.1	29.9	30.6	19.0
T_9	42.36	589.06	13.91	3.05	4.33	96.5	29.0	53.8	362.8	142.5	316.2	-	-	-	0.39	174.8	49.1	94.9	26.7	28.8	16.5
T_{10}	32.24	404.56	12.55	1.50	4.18	91.3	25.7	52.2	40.0	18.3	50.1	33.0	12.8	37.5	0.39	189.7	41.2	92.0	25.8	31.9	15.8
T_{11}	35.14	878.41	25.00	3.66	8.24	316.8	51.4	134.0	16.6	7.5	22.0				0.41	193.9	45.3	103.2	28.5	31.8	17.0
T_{12}	26.58	1283.37	48.28	6.35	5.12	0.0	0.0	0.0	98.5	42.9	82.0	-	-	-	0.42	193.5	48.5	101.0	30.2	32.9	22.3
CD	-	-	-	-	-	55.1	12.9	46.1	7.97	6.12	16.1	12.1	5.87	22.3	0.47	NS	NS	9.04	-	-	-
SEM (±)	-	-	-	-	-	18.3	4.3	15.4	2.65	2.04	5.36	4.03	1.95	7.43	0.15	-	-	3.01	-	-	-

Treatment details given under Materials and Methods. LUE, Land use efficiency; IWUE, Irrigation water use efficiency.

moong and maize-wheat-summer moong gave 278.6 q/ha/annum, 233.0 q/ha/annum, 191.0 q/ha/annum and 161.8 q/ha/annum productivity, respectively, with net saving of 82 cm, 103 cm, 109 cm and 120 cm irrigation water. It has been viewed that there is an urgent need to adopt water saving crops in many areas as excessive exploitation has pushed the groundwater table below the critical depth of 10 m (Dhawan and Singh 2015).

Irrigation water use efficiency: The maize based cropping system, viz. maize (cobs) + vegetable cowpea + *Sesbania*-gram + *gobhi sarson* and maize-potato-spring maize showed highest IWUE (2.415 kg grain/m^3 and 1.916 kg grain/m^3) against the lowest IWUE value of 0.525 kg grain/m^3 in rice-wheat cropping system (Table 1). Low IWUE is apparently attributed to excessive use of water and non-adoption of appropriate cropping system. The continuous rotation of rice-wheat cropping system has been marked with indiscriminate exploitation of groundwater.

Economics of different cropping systems: The net returns were observed to be higher in maize based cropping systems in comparison to existing rice-wheat cropping system. Maize (cobs) + vegetable cowpea + *Sesbania*-gram + *gobhi sarson* showed highest net returns measured at ₹306066/ha with 2.86 B:C ratio followed by maize (furrow) + turmeric (bed)-barley (bed) + linseed (furrow) (Table 1). Maize-potato-spring maize and basmati rice-hayola (transplanted)-summer moongbean system gave 1.20 and 1.18 times more net returns, respectively, over existing rice-wheat cropping system. Similar results were observed by Walia *et al.* (2017).

Nutrient uptake: Nutrient uptake by different cropping systems during *kharif*, *rabi* and summer season varied significantly (Table 2). Maize (cobs)+vegetable cowpea + *Sesbania*-gram + *gobhi sarson* cropping system removed higher quantities of N, P and K during *kharif* season and was closely followed by maize-potato-spring maize system. During *rabi* season, maize+*mash*-peas (bed) + celery (furrows) removed highest quantities of N (362.8 kg/ha), P (142.5 kg/ha) and K (316.2 kg/ha) followed by maize-potato-spring maize cropping system. On the other hand, during summer season, the maximum N was removed by basmati rice-radish-spring maize cropping system (137.2 kg/ha) followed by maize-potato-spring maize (125.1 kg/ha) and these systems also removed maximum amount of P and K from the soil.

Soil fertility status: The soil OC and available nutrient status (N, P and K) values after *rabi* 2017–18 at 0–15 cm depth for different cropping system did not differ considerably (Table 2). Organic C content in soil varied between 0.38–0.47%. However, availability of N, P and was found to be highest in groundnut + *arhar* (5:1)-wheat + *sarson* (9:1), maize + *mash*-peas (bed) + celery (furrows) and maize (cobs) + vegetable cowpea + *Sesbania*-gram + *gobhi sarson*, respectively. It can be inferred that alternate systems gave better results in terms of available NPK in comparison to prevailing rice-wheat cropping system.

Microbial count of the soil: Maize (furrow) + turmeric (bed)-wheat (bed) + linseed (furrow) system gave highest viable counts of actinomycetes (33.2 $\times 10^4$) and bacteria (40.0 $\times 10^6$), whereas maize (furrow) + turmeric (bed)-barley (bed) + linseed (furrow) gave highest count for fungi (23.8 $\times 10^3$) over pre-dominant rice-wheat cropping system (Table 2). These alternate cropping systems thus, clearly indicate the superiority of these systems over rice-wheat as they also help in improving the microbial status of the soil thereby, promoting better soil health.

Energy use efficiency: The total energy input of different cropping systems varied in the range of 23.05×10^3 to 50.30×10^3 MJ/ha (Table 2). The total energy requirement by rice-wheat cropping system was 28.66×10^3 MJ/ha. Maize (furrow) + turmeric (bed)-wheat (bed) + linseed (furrow) (50.30×10^3 MJ/ha) showed the highest energy input and the higher energy inputs required for maize based cropping systems might be due to the use of energy-richer inputs like seed and fertilizer, respectively, in higher quantity. Similarly, the total energy output as computed from main product and by-product of different cropping systems varied from 360.24×10^3 to 1283.37×10^3 MJ/ha (Table 2). The fodder based cropping system, viz. sorghum + cowpeas (fodder)-wheat + *gobhi sarson* showed the highest total energy output (1283.37×10^3 MJ/ha), energy-use efficiency (48.28) and energy output efficiency (6.35×10^3 MJ/ha/day) over the prevailing rice-wheat cropping system. Maize (cobs) + vegetable cowpea + *Sesbania*-gram + *gobhi sarson* cropping system revealed the highest average maximum energy productivity and it was mainly due to its higher REY. The above results are supported by the study of Prajapat *et al.* (2018) and concluded that the soybean-chickpea-fodder sorghum system recorded highest net energy (333.9 ×10 MJ ha), energy efficiency (9.56), energy productivity (179 gMJ), highest energy output (286.1 MJ ha), net energy (240.3 MJ ha) and energy output efficiency (968 MJ ha day).

The study concluded that alternate systems gave better results in terms of productivity, water use efficiency, soil fertility status and energy use efficiency in comparison to prevailing rice-wheat system in Punjab. The results elucidated that the maize based cropping system proved to be a better alternative in terms of returns and profitability to the farmers as they showed highest net returns. In addition, maize based cropping system produced an additional rice equivalent yield of 289.7 to 160.1 q/ha, as a result they revealed the highest average maximum energy productivity and also ensured saving of 123.7 to 150 cm of irrigation water over the traditional rice-wheat system. The fodder based cropping system viz. sorghum + cowpea (fodder)-wheat + *gobhi sarson* with high energy output showed the highest energy-use efficiency and energy output efficiency. Simultaneously, the maize based cropping systems gave highest viable counts of actinomycetes, bacteria and fungi over rice-wheat cropping system. These alternate cropping systems thus, clearly indicate the superiority of these systems over traditional rice-wheat cropping system. Therefore, introducing bio-intensive agriculture in Punjab state was a step in the right direction and at the right time. Further spread of bio-intensive agriculture across the country may benefit the smallholder farmers.

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