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System Productivity and Energetics of High-Value Crops Embedded Diversified Cropping Systems

B. Bhargavi[1,3*] and U.K. Behera[2,3]

[1]*Division of Crop production, ICAR Central Institute for Cotton Research, Nagpur, Maharashtra-441108, India*
[2]*Central Agricultural University, Umiam, Meghalaya -793103, India*
[3]*ICAR-Indian Agricultural Research Institute, New Delhi 110012, India*

**Corresponding author*

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A B S T R A C T

A field experiment was conducted during 2 rainy (*kharif),* winter (*rabi*) and summer seasons (2015-17) on a sandy clay loam soil at New Delhi to evaluate 5 cropping systems *viz.*, maize–pea–okra, maize–mustard–green gram, cotton–wheat, bottle gourd–onion and okra–wheat, for productivity, profitability and energetics. The experiment was laid-out in a randomized block design replicated 4 times. Bottle gourd–onion cropping system recorded the highest wheat-grain-equivalent yield (WGEY) of 19.9 t/ha, followed by maize–pea–okra (14.06 t/ha). The lowest WGEY was recorded with maize–mustard–green gram (9.12 t/ha). The gross returns (□ 313.56x 10^3/ha), net returns (□ 123.5x10^3/ha), benefit: cost ratio (3.23), were also higher with bottle gourd–onion cropping system, while maize–mustard–green gram registered the lowest gross returns, net returns and B: C ratio. The lesser input energy (25.68 x 10^3 MJ/ha) and higher energy productivity (775.2 g/MJ) was recorded with bottle gourd – onion cropping system. All the five cropping systems can suitably substitute the existing rice – wheat cropping system under marginal farmer's situations, not only by providing higher productivity and returns, but also provide a regular income throughout the year.

Introduction

In the Green Revolution areas of the Indo-Gangetic Plains (IGP), continued adoption of the rice–wheat system for over 4-decades has posed a serious threat to agricultural sustainability in that region (Bhatt *et al.*, 2016). These problems include deterioration of land, build-up of obnoxious weeds, declining factor of productivity, plateauing of yield, receding water tables, loss of biodiversity and development of multiple nutrient deficiencies (Jain 2008, Bhullar and Chauhan 2015). Concerns about stagnating productivity, increasing production costs, declining resource quality, declining water tables and increasing environmental problems are the major forcing factors to look for alternative technologies in the IGP region of India. The traditional monoculture and disciplinary approach is unable to meet the growing and changing food demand and improve the livelihood of these smallholders on a sustainable basis (Mahapatra and Behera 2011). There is now a growing demand for agricultural diversification and reorientation of strategies with emphasis on resource conservation technologies for improving productivity on a sustainable basis. Crop diversification is very often advocated for alleviating the problems encountered in the post Green Revolution era (Behera *et al.*, 2007).

Among rice and wheat cropping systems, irrigated rice, is a heavy water consumer as it took around 5000 litres of water to produce 1 kg of rice. Rice–wheat cropping system consumes about 11,650 m^3/ ha water out of which 7650 m^3 is by rice (Bhatt *et al.,* 2016). Thus, the water table in IGP is declining down at alarming rates (Soni 2012). As a result submersible pumps replacing the centrifugal pumps which lift up water from the deeper depths but they required more energy for this purpose (Hira 2009). In the era of shrinking resource base of land, water and energy, resource use efficiency is an important aspect for considering the suitability of a cropping system. Hence, selection of component crops needs to be suitably planned to harvest the synergism among them towards efficient utilization of resource base and to increase overall productivity (Singh *et al.*, 2017). With increasing purchasing power of people in the country, the demand for vegetable crops has increased enormously leading to sharp increase in their prices and it has been the dominant factor for high inflationary pressure in Indian economy during recent years. Inclusion of crops like oilseeds, pulses, vegetables and fodder crops will improve the economic condition of small and marginal farmers owing to higher price and/or higher volume of their main and by-products (Dass*et al.,* 2009, Sharma *et al.*, 2007). Hence, efforts are needed to promote diversification of rice-based cropping sequence in the country with high-value crops for sustaining the productivity and meet out demand for vegetables, pulses and oilseeds. Therefore, the present investigation was carried out to find out most productive, resource-use efficient and remunerative cropping system for Indo-Gangetic Plains region.

Materials and Methods

A field experiment was conducted from the rainy season (*kharif*) 2015 to summer 2017 at ICAR-Indian Agricultural Research Institute, New Delhi (28^{o}38’N and 77 ^{o}38’E, 228.6 m above mean sea-level). The meteorological data of maximum temperature, minimum temperature, evaporation and rainfall for the period of experimentation (*i.e*. June 2015 to May 2017) were recorded at the meteorological observatory of ICAR-IARI, New Delhi. The climate of above unit is semi-arid with dry, hot summers and cold winters with an average annual rainfall of 1088 mm, 83% of which is received through south-west monsoon during July–September. Soil of the experimental field was sandy clay loam in texture, slightly alkaline in reaction (pH 6.9), low in organic carbon (0.38%), available nitrogen (251.8 kg/ha), available phosphorus (11.2 kg/ha) and medium in potassium (254 kg/ha).

The experiment was carried out in randomized block design replicated four times. The treatments include 5-cropping systems, viz. maize (*Zea mays*) – pea (*Pisum sativum*) – okra (*Abelmoschus esculentus*), maize (*Zea mays*) – mustard (*Brassica juncea*) – green gram (*Vigna radiata*), cotton (*Gossypium hirsutum*) – wheat (*Triticum aestivum*), bottle gourd (*Lagenaria siceraria*) – onion (*Allium cepa*) and okra (*Abelmoschus esculentus*) – wheat (*Triticum aestivum*). The net plot size of each treatment was 150 m^2.

The details of varieties used, seed rate, fertilizer doses and spacing are given in Table 1. Nitrogen, phosphorus and potassium were applied through urea, di-ammonium phosphate and muriate of potash, respectively. In maize, half dose of nitrogen and full doses of phosphorus and potassium were applied at the time of sowing, while remaining N was applied 1 month after sowing. In cotton, half of N and full dose of P and K were given at the time of sowing and remaining was given before flowering. Full doses of N, P and K were applied at sowing time in bottle gourd. One-third of N, P and K at sowing and remaining two splits at 4 weeks and 8 weeks after sowing in okra. At physiological stage of maturity, all the crops were harvested manually. After drying in the sun, the total biomass was weighed. Economic yield was recorded for all the crops. After harvesting of *kharif*crops, *rabi*crops were sown in the same plots without disturbing the layout as per recommended package of practices mentioned in Table 1. In wheat half dose of nitrogen and full doses of P and K were applied at the time of sowing, while remaining nitrogen was top-dressed at the first irrigation. Half of N and full dose of P and K at the time of sowing of mustard and remaining half dose of nitrogen was applied after one month of sowing. In onion one-third dose of N and full dose of P and K were applied with last field operation. Remaining two-third N was given in two equal splits after 30 and 60 days after transplanting. After harvesting of *rabi* crops, summer crops, viz. green gram and okra, were raised as per treatments without disturbing the original layout following standard package of practices (Table 1). Green gram was harvested at physiological stage of maturity while 5-6 pickings of okra were taken to harvest it in green and immature stage.

Economic yields of the component crops were converted to wheat-grain-equivalent yield (WGEY), taking into account the prevailing minimum support price/market prices of the crops (Uddin *et al.*, 2009). System productivity was calculated by adding the WGEY of the component crops. For estimation of energy inputs and outputs for each item of inputs and agronomic practices, equivalents were utilized as suggested by Mittal and Dhawan (1988), Baishaya and Sharma (1990), Panesar and Bhatnagar (1994) and Singh *et al.*, (1997). Energy efficiency, energy productivity and specific energy were calculated using the following formula as suggested by Singh *et al.*, (1997) and Burnett (1982).

Results and Discussion

Performance of crops and cropping systems

Economic yield and stover yield of individual crop have been given in tables 2 and 3.

CS-1: Maize – pea – okra

The grain yield of maize was 4.14 and 4.78 t/ha during 2015 and 2016, respectively. Similarly, stover yield was 7.04 and 7.36 t/ha during 2015 and 2016, respectively. The green pod yield of pea during 2015-16 and 2016-17 was found to be 1.37 and 1.56 t/ha, respectively. The stover yield and biomass obtained from pea was 2.94, 4.31 t/ha and 3.21, 4.77 t/ha, respectively during the study period. The fruit yield of okra recorded during 2016 and 2017 was 3.39 and 3.01 t/ha, whereas the stover yield was 3.73 and 3.22 t/ha, respectively.

CS-2: Maize – mustard – green gram

The grain yield of maize was 4.27 and 4.47 t/ha during 2015 and 2016, respectively. Similarly stover yield was 7.16 and 7.22 t/ha during 2015 and 2016, respectively. The seed yield of mustard during 2015-16 and 2016-17 was found to be 1.61 and 1.42 t/ha, respectively. The pod yield of green gram recorded during 2016 and 2017, was 0.48 and 0.61 t/ha, whereas the stover yield was 0.68 and 0.73 t/ha, respectively.

CS-3: Cotton – wheat

The yield of seed cotton was 1.95 and 2.14 t/ha during 2015 and 2016, respectively. Similarly stover yield was 4.85 and 5.43 t/ha during 2015 and 2016, respectively. The grain yield of wheat during 2015-16 and 2016-17 was found to be 5.12 and 5.25 t/ha, respectively. The straw yield obtained from wheat was 6.86, 6.97 t/ha, respectively during the study period.

CS-4: Bottle gourd – onion

Bottle gourd fruit yield during 2015 and 2016 was 8.12 and 8.26 t/ha, respectively. Similarly stover yield was 3.28 and 3.54 t/ha during 2015 and 2016, respectively, whereas the bulb yield of onion during 2016 and 2017 was found to be 9.01 and 10.65 t/ha, respectively. The stover yield obtained from onion was 1.42, 1.27 t/ha, respectively during the study period.

CS-5: Okra – wheat

The fruit yield of okra recorded during 2015 and 2016 was 5.67 and 6.42 t/ha, whereas the stover yield was 3.41 and 3.28 t/ha, respectively. The grain yield of wheat during 2015-16 and 2016-17 was found to be 5.18 and 5.31 t/ha respectively. The straw yield obtained from wheat was 6.91, 7.08 t/ha, respectively during the study period.

System productivity

The total productivity of various cropping systems was worked out after converting the economic yield of all the crops grown in sequence into wheat-grain-equivalent yield (WGEY) (Table 3). Among the various cropping systems tried, system productivity was significantly higher in bottle gourd – onion cropping system being 118.1, 89, 50.4 and 41.55% greater than maize – mustard – green gram, cotton – wheat, okra-wheat and maize – pea – okra cropping systems, respectively. Higher tonnage and better price of both bottle gourd and onion played a vital role in improving the wheat-grain-equivalent yield. The next cropping system in the order was maize – pea – okra with WGEY of about 14.28 and 13.84 t/ha during 2015-16 and 2016-17, respectively. It can be attributed mainly to okra which fetched higher prices in the market besides having higher productivity. However, WGEY of maize – pea – okra was statistically at par with okra – wheat cropping system.

The system productivity was higher in cropping systems through the inclusion of high value crops i.e. vegetables. Mishra *et al.*, (2007) also observed higher productivity with the inclusion of vegetables in rice – based cropping systems. These results are in line with the findings of Singh *et al.*, (2007) who reported rice – pea – okra followed by rice – pea – onion as the most productive cropping sequence for eastern Uttar Pradesh, India. The lowest WGEY was noticed in maize – mustard – green gram during both the years of experimentation, due to poor yields of mustard and green gram. These results corroborate with Prasad *et al.*, (2013), who reported that wheat substituted by mustard or wheat + mustard (5:1) resulted in very poor performance of the system. It was apparent that poor yield of the mustard was responsible for lower REGY than rice– wheat sequence. It clearly shows the importance of summer crops to raise the system productivity and sustainability under irrigated conditions. The total productivity of the cropping systems was higher during second year of the study (2016-17) in comparison to the first year of the study

(2015-16). This is attributed to higher temperatures during summer months in first year and residual effect of application of biogas slurry and farm yard manure produced within the farming system during first year, provided nutrients gradually to the crop, which is very much essential for nutrient exhaustive vegetable crops and cereals. The similar findings were reported by Khan *et al.*, (2016) that 50% biogas slurry along with 50% chemical fertilizer gave highest crop growth and corn yield in baby corn.

Economics

Cost structure of different cropping systems was given in table 4. The cost of cultivation per hectare was higher in maize – pea – okra cropping system (Table 4). To realize higher returns from the vegetable crops, farmers have to spend more on seed, fertilizer, labour, irrigation and adopt newer technologies. Besides, okra and onion crops required more man days for weeding and harvesting. So with inclusion of vegetables cultivation cost increased as compared to other cropping systems. Shah *et al.*, (2015) and Prasad *et al.*, (2013) also concluded that the inclusion of vegetables in the cropping system increased the total variable cost due to higher fertilization and human labour requirements. Jain *et al.*, (2015) also reported that inclusion of vegetable (okra) increased the cost of cultivation. On the other hand, the lowest cost was expended in maize – mustard – green gram cropping system owing to less number of man-days and irrigations. Reddy (2014) also reported that the total cost per hectare was higher in high value crops (vegetables, fruits and flowers) followed by cotton, oilseeds, rice-wheat, pulse-cereal based, pulse based and the least in coarse cereal based cropping systems. Significantly higher net returns were realized from bottle gourd – onion cropping system (□ 216.34 x 10^3/ha). Bottle gourd – onion cropping system fetched an additional income of 92.84 x 10^3, 142.95 x 10^3, 136.89 x 10^3 and 94.54 x 10^3 □/ha over maize – pea – okra, maize – mustard – green gram, cotton – wheat and okra – wheat cropping systems respectively. This was due to inclusion of vegetable crops (bottle gourd and onion) in the system, besides improving the system productivity due to their higher tonnage, fetched good market price thereby, increasing net returns. Besides, rising of vegetable crop (onion) during summer season is economically remunerative as supply of vegetables from rainfed area is drastically reduced and vegetable prices are much higher. Therefore surplus onion produced can be transported in areas of high demand even after 2–3 months after harvesting, as they have good shelf life. The next cropping system in the order was maize – pea – okra cropping system with □ 123.50 x 10^3/ha. Kumar *et al.,* (2008) reported that inclusion of vegetable crops in rice – based crop sequences improved the net returns. These results corroborate the findings of Jat *et al.*, (2012). The lowest net returns of □ 73.39 x 10^3 /ha was noticed with maize – mustard – green gram system. This was due to lower yields from mustard and green gram. However, significantly higher benefit: cost ratio was recorded under bottle gourd – onion cropping system probably owing to higher returns in comparison to cost of cultivation.

Energetics

Input energy

Maize – pea – okra cropping system required higher input energy (33.07x 10^3 MJ/ha), this could be ascribed to higher requirement of primary inputs *viz*., seeds, fertilizer, labour etc. In vegetable crops (okra) there was an involvement of more number of labours in picking of fruits/pods followed by cotton – wheat system (31.96 x 10^3 MJ/ha). The lower input energy was used in bottle gourd – onion cropping system (25.68 x 10^3 MJ/ha). This was because of less inputs like seed, irrigations and labour comparatively (Table 5).

Table.1 Production technology adopted for raising crops during 2015-16 and 2016-17

Cropping system	Variety			Seed rate (kg/ha)			Spacing (cm ×cm)			Fertilizer (kg/ha) ($N:P_2O_5:K_2O$)		
	Kharif	***Rabi***	**Summer**	***Kharif***	***Rabi***	**Summer**	***Kharif***	***Rabi***	**Summer**	***Kharif***	***Rabi***	**Summer**
Maize-pea-okra	PMH-1	FVS-1000	Arka Anamika	20	60	15	60x 15	40×10	60×50	120:60:40	25:50:50	70:40:40
Maize-mustard-green gram	PMH-1	Pusa-25	SML-668	20	6	20	60 x15	50×10	30×10	120:60:40	60:60:40	20:40:30
Cotton – wheat	Shriram-6588 (BG-II)	HD-2967	-	3	100	-	75x50	20 ×10	-	120:60:60	120:60:40	-
Bottle gourd-onion	PSPL	Pusa Riddhi	-	3	8	-	250x100	25×10	-	60:40:50	120:60:80	-
Okra-wheat	Arka Anamika	HD-2967	-	15	100	-	60x50	20×10	-	60:30:30	120:60:40	-

Table.2 Economic yield of different crops in cropping systems

Treatment	Economic yield (t/ha)						Mean of two years (economic yield t/ha)		
	2015-16			**2016-17**					
	Kharif	***Rabi***	**Summer**	***Kharif***	***Rabi***	**Summer**	***Kharif***	***Rabi***	**Summer**
Cropping systems									
CS_1: Maize - pea - okra	4.14	1.37	3.39	4.78	1.56	3.01	4.46	1.47	3.20
CS_2: Maize - mustard – green gram	4.27	1.61	0.48	4.47	1.42	0.61	4.37	1.52	0.55
CS_3: Cotton - wheat	1.95	5.12	-	2.14	5.25	-	2.05	5.19	-
CS_4: Bottle gourd - onion	8.12	9.01	-	8.26	10.65	-	8.19	9.83	
CS_5: Okra – wheat	5.67	5.18	-	6.42	5.31	-	6.05	5.25	

Table.3 Straw yield and wheat-grain-equivalent yield of various cropping systems

Treatment	Straw/stover yield (t/ha)						Mean of 2 years (straw yield t/ha)			WGEY (t/ha)		
	2015-16			2016-17						2015-16	2016-17	Mean
Cropping systems	***Kharif***	***Rabi***	**Summer**	***Kharif***	***Rabi***	**Summer**	***Kharif***	***Rabi***	**Summer**			
CS_1: Maize – pea – okra	7.04	2.94	3.73	7.36	3.21	3.22	7.20	3.08	3.48	14.28	13.84	14.06
CS_2: Maize – mustard – greengram	7.16	4.26	0.68	7.22	4.15	0.73	7.19	4.21	0.71	8.93	9.32	9.12
CS_3: Cotton – wheat	4.85	6.86	-	5.43	6.97	-	5.14	6.92	-	10.34	10.71	10.53
CS_4: Bottle gourd – onion	3.28	1.42	-	3.54	1.27	-	3.41	1.35	-	19.66	20.14	19.90
CS_5: Okra – wheat	3.41	6.91	-	3.28	7.08	-	3.35	7.00	-	12.93	13.53	13.23
SEm±										0.42	0.39	0.41
LSD (*P*=0.05)										1.29	1.19	1.24

Table.4 Economics (gross returns, cost of cultivation, net returns and returns per rupee invested) of different cropping systems

Treatment	Gross Returns (x10^3 □ /ha)			Cost of cultivation (x10^3 □ /ha)			Net Returns (x10^3 □ /ha)			B:C Ratio		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
Cropping systems												
CS_1: Maize – pea – okra	217.79	224.84	221.32	95.13	100.50	97.82	122.66	124.34	123.50	2.29	2.24	2.26
CS_2: Maize – mustard – greengram	136.15	151.48	143.81	68.20	72.65	70.43	67.95	78.83	73.39	2.00	2.09	2.04
CS_3: Cotton – wheat	157.67	174.12	165.90	84.62	88.27	86.45	73.05	85.85	79.45	1.86	1.97	1.92
CS_4: Bottle gourd – onion	299.76	327.36	313.56	98.85	95.58	97.22	200.91	231.78	216.34	3.03	3.42	3.23
CS_5: Okra – wheat	197.24	219.87	208.55	85.20	88.30	86.75	112.04	131.57	121.80	2.31	2.49	2.40
SEm±	-	-		-	-		2.19	2.57	2.37	0.02	0.04	0.03
LSD (*P*=0.05)	-	-		-	-		6.74	7.91	7.31	0.06	0.13	0.09

Table.5 Energetics (energy input, energy output and energy net returns) of different cropping systems during 2015-16 and 2016-17

Treatment	Energy input ($x10^3$ MJ/ha) Mean of two years ($x10^3$ MJ/ha)				Energy output ($x10^3$ MJ/ha) Mean of two years ($x10^3$ MJ/ha)				Energy net returns Mean of two years ($x10^3$ MJ/ha)			
	Kharif	***Rabi***	**Summer**	**Total**	***Kharif***	***Rabi***	**Summer**	**Total**	***Kharif***	***Rabi***	**Summer**	**Total**
Cropping systems												
CS_1 : Maize – pea – okra	13.31	6.91	12.85	33.07	195.16	59.43	49.52	304.11	181.85	52.52	36.67	271.04
CS_2 : Maize – mustard – green gram	13.32	11.04	6.90	31.26	193.66	90.44	16.82	300.92	180.34	79.40	9.92	269.66
CS_3 : Cotton – wheat	15.29	16.67	0.00	31.96	88.38	162.66	-	251.04	73.09	145.99	0.00	219.08
CS_4 : Bottle gourd – onion	8.83	16.86	0.00	25.68	49.18	24.87	-	74.05	40.35	8.02	0.00	48.37
CS_5 : Okra – wheat	10.89	16.35	0.00	27.24	53.30	164.54	-	217.84	42.41	148.19	0.00	190.60
SEm±				0.26				7.60				3.73
LSD (*P*=0.05)				0.81				23.41				11.49

Table.6 Energy use efficiency, energy productivity and specific energy of various cropping systems

Treatment	Energy use efficiency			Energy productivity (g/MJ)			Specific energy (MJ/kg)		
	2015-16	**2016-17**	**Mean**	**2015-16**	**2016-17**	**Mean**	**2015-16**	**2016-17**	**Mean**
Cropping systems									
CS_1 : Maize – pea – okra	9.03	9.36	9.20	432.1	414.8	423.4	2.31	2.41	2.36
CS_2 : Maize – mustard – green gram	9.66	9.59	9.63	286.9	296.9	291.9	3.49	3.37	3.43
CS_3 : Cotton – wheat	7.66	8.05	7.86	323.8	335.0	329.4	3.09	2.98	3.04
CS_4 : Bottle gourd – onion	3.18	2.60	2.89	784.0	766.3	775.2	1.28	1.31	1.29
CS_5 : Okra – wheat	8.05	7.95	8.00	482.1	489.5	485.8	2.07	2.04	2.06

Output energy

Maize – pea– okra cropping system produced maximum output energy (304.11 x 10^3 MJ/ha), because of higher energy equivalents of the produce. It indicates that more energy should be incurred to produce the yield (both grain and straw). The minimum output energy was generated from bottle gourd – onion cropping system (74.05 x 10^3 MJ/ha) owing to lower energy values of both bottle gourd and onion.

Net Energy

Higher net returns of energy was recorded with maize – pea – okra system (271.04 x 10^3 MJ/ha), and the lower net energy was generated from bottle gourd – onion cropping system (48.37 x 10^3 MJ/ha).

Energy use efficiency and specific energy

Maize – mustard – green gram system showed maximum values of mean energyuse efficiency (9.63) and specific energy (3.43 MJ/kg) while minimum was recorded in bottle gourd – onion cropping system (2.89, 334.2 MJ/ha/day,1.29 MJ/kg and 0.76 MJ/□ , respectively) owing to lower energy equivalent values of both bottle gourd and onion (Table 6).

Energy productivity

Bottle gourd – onion cropping system registered highest energy productivity of 775.2 g/MJ owing to more WGEY in comparison to input energy used. Bottle gourd – onion cropping system was followed by okra – wheat system (485.8 g/MJ) in terms of energy productivity. These results are in conformity with the findings of Jain *et al.,* (2011). The lowest energy productivity was recorded with maize – mustard – green gram system (291.9 g/MJ). This was obviously owing to lower wheat-grain-equivalent yield in comparison to input energy used.

It can be concluded that bottle gourd – onion cropping system was found to be more productive, profitable followed by maize – pea – okra system. The lower input energy, higher energy productivity was registered with bottle gourd – onion cropping system. It clearly indicated that rice–wheat cropping system could be suitably diversified with bottle gourd – onion, maize – pea – okra, cotton – wheat and okra – wheat cropping systems under marginal farmer's situations. These systems not only provide higher productivity and returns, but also provide the farmers a regular income throughout the year.

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