Indian Journal of Agricultural Sciences **89** (5): 821–7, May 2019/Article
https://doi.org/10.56093/ijas.v89i5.89664

Productivity, resource-use efficiency and profitability of high-value crops embedded diversified cropping systems

B BHARGAVI[1], U K BEHERA[2], K S RANA[3] and RAJ SINGH[4]

ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India

Received: 12 October 2018; Accepted: 17 December 2018

ABSTRACT

A field experiment was conducted during rainy (*kharif),* winter (*rabi*) and summer seasons of 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 resource-use efficiency. 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 (₹ 313.56 × 10^3/ha), net returns (₹ 123.5 × 10^3/ha), B:C ratio (3.23), production efficiency (54.52 kg/ha/day) and monetary efficiency (593 ₹/ha/day) 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. All the five cropping systems can substitute the existing rice – wheat cropping system under marginal farmers situations, not only by providing higher productivity and returns, but also a regular income throughout the year.

Key words: Cropping systems, High-value crops, Profitability, Resource-use efficiency and Sustainability.

Input intensive agricultural technology widens the income inequality among the different sections of farming population and provides proportionately large benefits to the big farmers as compared to the small farmer, because the small farmers are slow to accept the new technology (Wilson 2002). Also, small farmers could not afford farm investment from their own savings to transform traditional agriculture into scientific farming (Singh and Toor 2005).

The success of one such agricultural technology package has been the green revolution. In the green revolution areas of the Indo-Gangetic Plains (IGP), continued adoption of the rice–wheat system for over four decades has posed a serious threat to agricultural sustainability (Bhatt *et al*. 2016). The 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). The traditional monoculture and disciplinary approach is unable to meet the growing and changing food demand and improve the livelihood of 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 and integrated farming systems (IFS) are 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 takes 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 at alarming rates (Soni 2012). As a result submersible pumps replaced the centrifugal pumps which lift up water from the deeper depths but they require 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). 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 main crop and by-products (Dass *et al*. 2002, 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

[1]Ph D Scholar (bhargavibussa@gmail.com), [2,3,4]Principal Scientist, Division of Agronomy..

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°38'N and 77 °38'E, 228.6 m amsl).The meteorological data of maximum temperature, minimum temperature, evaporation and rainfall for the experimentation period recorded at the meteorological observatory of ICAR-IARI, New Delhi are depicted graphically in Fig 1 and 2. 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 – wheat. 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 were applied 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. Total field duration of a cropping system expressed in percentage of 365 days was taken as the land-use efficiency (LUE) of the system (Tomar and Tiwari 1990). System productivity and system profitability values in terms of kg/ha/day and ₹/ha/day were calculated by WEY and net returns of the system divided by 365 days, respectively

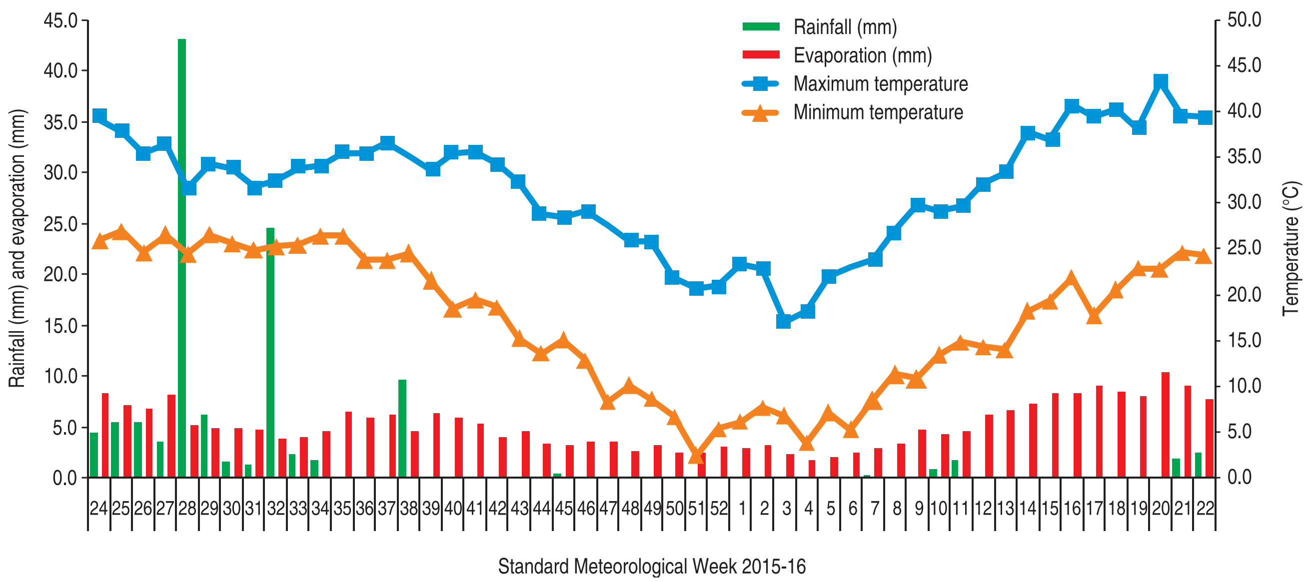

Fig 1 Weekly meteorological data for the crop growing seasons (June, 2015 to May, 2016)

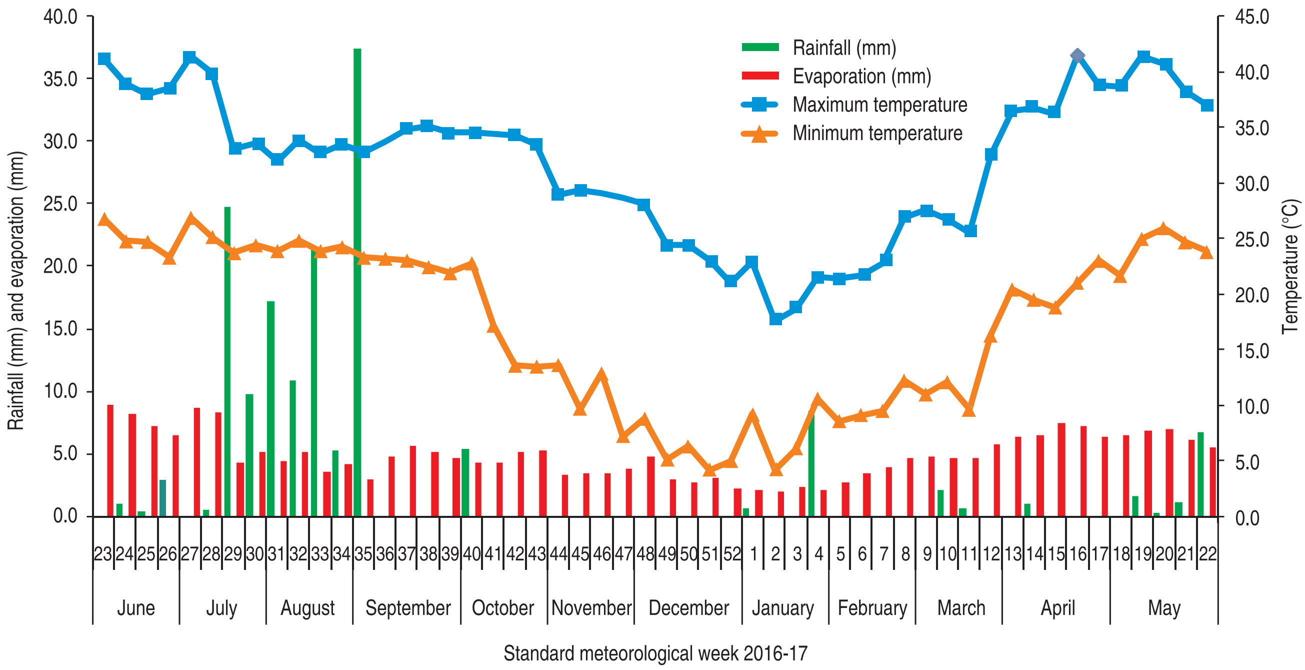

Fig 2 Weekly meteorological data for the crop growing seasons (June, 2016 to May, 2017)

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	60×15	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	60×15	50×10	30×10	120:60:40	60:60:40	20:40:30
Cotton – wheat	Shriram-6588 (BG-II)	HD-2967		3	100		75×50	20 ×10		120:60:60	120:60:40	
Bottle gourd-onion	PSPL	Pusa Riddhi		3	8		250×100	25×10		60:40:50	120:60:80	
Okra-wheat	Arka Anamika	HD-2967		15	100		60×50	20×10		60:30:30	120:60:40	

(Sharma *et al*. 2014).

RESULTS AND DISCUSSION

Perfomance of crops and cropping system

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 during 2015 and 7.36 t/ha in 2016. The green pod yield of pea during 2015-16 and 2016-17 was 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 2016 for 2016 was 3.39 t/ha and 3.01 t/ha in 2017, whereas the stover yield was 3.73 and 3.22 t/ha, respectively.

CS-2: Maize – mustard – greengram: The grain yield of maize was 4.27 and 4.47 t/ha during 2015 and 2016, respectively. Similarly stover yield during 2015 and 2016 was 7.16 and 7.22 t/ha respectively. The seed yield of mustard during 2015-16 and 2016-17 was 1.61 t/ha and 1.42 t/ha, respectively. The pod yield of green gram recorded during 2016 was 0.48 and 0.61 t/ha 2017, whereas the stover yield was 0.68 and 0.73 t/ha. Hence the biomass yield obtained was 1.16 t/ha during 2016 and 1.34 t/ha is 2017. Harvest index was 41.4% and 45.5% for 2015-16 and 2016-17, 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 during 2015 and 5.43 t/ha in 2016. The grain yield of wheat during 2015-16 and 2016-17 was 5.12 and 5.25 t/ha, respectively. The straw yield obtained from wheat was 6.86 and 6.97 t/ha.

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									
CS1 : Maize - pea - okra	4.14	1.37	3.39	4.78	1.56	3.01	4.46	1.47	3.20
CS2 : Maize - mustard – greengram	4.27	1.61	0.48	4.47	1.42	0.61	4.37	1.52	0.55
CS3 : Cotton - wheat	1.95	5.12		2.14	5.25		2.05	5.19	
CS4 : Bottle gourd - onion	8.12	9.01		8.26	10.65		8.19	9.83	
CS5 : 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								
	Kharf	*Rabi*	Summer	*Kharf*	*Rabi*	Summer	*Kharf*	*Rabi*	Summer	2015-16	2016-17	Mean
Cropping systems												
CS1 : 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
CS2 : 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
CS3 : Cotton – wheat	4.85	6.86		5.43	6.97		5.14	6.92		10.34	10.71	10.53
CS4 : Bottle gourd – onion	3.28	1.42		3.54	1.27		3.41	1.35		19.66	20.14	19.90
CS5 : 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

CS-4: Bottle gourd – onion: Bottle gourd fruit yield during 2015 and 2016 was 8.12 and 8.26 t/ha, respectively. Stover yield was 3.28 t/ha during 2015 and 3.54 t/ha in 2016, whereas the bulb yield of onion during 2016 and 2017 was 9.01 and 10.65 t/ha, respectively. The stover yield obtained from onion was 1.42 and 1.27 t/ha 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 was 5.18 t/ha 5.31 t/ha in 2016-17. The straw yield obtained from wheat was 6.91 and 7.08 t/ha during the study period.

The data (Table 3) for both the years of study revealed that system productivity was significantly higher in bottle gourd–onion cropping system, i.e. 118.1, 89, 50.4 and 41.55% more 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 good productivity.

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 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 farmyard 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. 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 is given in Table 4.The cost of cultivation per hectare was higher in maize–pea–okra cropping system. 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 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 × 10^3/ha). Bottle gourd – onion cropping system fetched an additional income of 92.84 × 10^3 , 142.95 × 10^3, 136.89 × 10^3 and 94.54 × 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 of harvesting, as they have good shelf life. The next cropping system in the order was maize–pea–okra cropping system with ₹ 123.50 × 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 × 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.

Resource-use efficiency

The data regarding resource-use efficiency was projected in Table 5.

Maize–pea–okra system registered the highest land-use

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

Treatment	Gross Returns (×10^3 ₹/ha)			Cost of cultivation (×10^3 ₹/ha)			Net Returns (×10^3 ₹/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												
CS1 : 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
CS2 : 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
CS3 : 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
CS4 : 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
CS5 : 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 Resource-use efficiencies of different cropping systems

Treatment	Land use efficiency (%)			Duration of the system (days)			Production efficiency (kg/ha/day)			Monetary efficiency (₹/ha/day)		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
Cropping systems												
CS1 : Maize – pea – okra	93.7	94.8	94.2	342	345	344	39.13	37.91	38.52	336.05	340.7	338.4
CS2 : Maize – mustard – green gram	93.2	92.0	92.6	340	335	338	24.46	25.54	25.00	186.17	216.0	201.1
CS3 : Cotton – wheat	81.9	83.0	82.4	299	302	301	28.33	29.36	28.84	200.15	235.2	217.7
CS4 : Bottle gourd – onion	61.1	60.4	60.8	223	220	222	53.85	55.19	54.52	550.43	635.0	592.7
CS5 : Okra – wheat	74.0	76.9	75.4	270	280	275	35.43	37.07	36.25	306.95	360.5	333.7
SEm±	2.38	2.38	2.38				1.31	1.31	1.31	16.90	19.34	18.08
LSD (P=0.05)	7.74	7.76	7.75				4.29	4.29	4.29	55.12	63.08	58.97

efficiency of 94.2%, as it used land for maximum period in a year (344 days). The next best system with respect to land-use efficiency was maize–mustard–green gram system. These results are in conformity with the findings of Prasad *et al*. (2013), who reported that intensification of rice-based cropping sequence by growing green gram recorded markedly higher land-use efficiency than crop sequences without summer crops. On the other hand, land-use efficiency was lowest in bottle gourd – onion cropping system (60.75%) because the system utilized the field for less duration in a year (222 days) due to raising of two crops in a year.

Bottle gourd–onion cropping system recorded the maximum production efficiency (54.52 kg/ha/day) and monetary efficiency (593 ₹/ha/day). This was due to higher WGEY of the system. Sharma *et al*. (2004) have also reported that intensification through inclusion of vegetables increases the production efficiency. The next system in the order was maize–pea–okra system. Minimum production efficiency and monetary efficiency was registered with maize–mustard–greengram system with 25 kg/ha/day and 201 ₹/ha/day, respectively. This was obviously owing to lower WGEY of maize–mustard–green gram system.

Bottle gourd–onion rotation gained 101.8 % higher production than the existing rice-wheat cropping system. The next best system with respect to relative production efficiency was maize–pea–okra system (42.58%). Minimum relative production efficiency was registered with maize–mustard–green gram system (-7.46 %) followed by cotton–wheat system (6.77 %). However, all these diversified cropping systems showed production efficiency higher than the existing rice-wheat cropping system except maize–mustard–green gram system.

It can be concluded that bottle gourd–onion cropping system was more productive, profitable followed by maize–pea–okra 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 farmers situations. These systems not only provide higher productivity and returns, but also provide the farmers a regular income throughout the year.

ACKNOWLEDGEMENT

The award of National fellowship by the University Grants Commission, New Delhi, to B Bhargavi and Institutional support from Indian Agricultural Research Institute (IARI), New Delhi, India, is gratefully acknowledged. Authors are especially thankful to Division of Agronomy, IARI, New Delhi, India for carrying out the present research work.

REFERENCES

Behera U K, Sharma A R and Mahapatra I C. 2007. Crop diversification for efficient resource management in India: Problems, prospects and policy. *Journal of Sustainable Agriculture* **30**(3): 97–127.

Bhatt R, Kukal S S, Busari M A, Arora S and Yadav M. 2016. Sustainability issues on rice–wheat cropping system. *International Soil and Water Conservation Research* **4**(1): 64–74.

Bhullar M S and Chauhan B S. 2015. Seed bank dynamics and emergence pattern of weeds as affected by tillage systems in dry direct-seeded rice. *Crop Protection* **67**: 168–77.

Dass A, Patnaik U S, Sudhishri S and Choudhury P R. 2002. Vegetable Cultivation: A major intervention for tribal watershed development. *Indian Journal of Soil Conservation* **30**(3): 240–7.

Dass Anchal, Sudhishri S, Patnaik U S and Lenka N K. 2009. Effect of agronomic management on watershed productivity, impact indices, crop diversification and soil fertility in Eastern Ghats of Orissa. *Journal of Soil and Water Conservation* **8**(3): 34–42

Hira G S. 2009. Water management in northern states and the food security of India. *Journal of Crop Improvement* **23**(2): 136–57.

Jain T C. 2008. New paradigms in agronomic research and development. *Indian Journal of Agronomy* **53**(4): 241–4.

Jain N K, Singh H, Dashora L N and Mundra S N. 2015. Diversification and intensification of maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system for sustainable productivity and profitability. *Indian Journal of Agronomy* **60**(1): 38–44.

Jat R A, Dungrani R A, Arvadia M K and Sahrawat K L. 2012. Diversification of rice (*Oryza sativa* L.)–based cropping systems for higher productivity, resource–use efficiency and economic returns in south Gujarat, India. *Archives of Agronomy and Soil Science* **58**(6): 561–72.

Kumar A, Tripathi H P, Yadav R A and Yadav D S. 2008. Diversification of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system for sustainable production in eastern Uttar Pradesh. *Indian Journal of Agronomy* **53**(1): 18–21.

Mahapatra I C and Behera U K. 2011. Rice–based farming systems for livelihood improvement of Indian farmers. *Indian Journal of Agronomy* **56**(1): 1–19.

Mishra M M, Nanda S S, Mohanty M, Pradhan K C and Mishra S S. 2007.Crop diversification under rice–based cropping system in western Orissa. Extended summaries of 3rd National Symposium on Integrated farming systems and its role towards livelihood improvement. Organized by Farming Systems Research and Development Association, 26–28 October, Agricultural Research Station, Durgapura, Jaipur. pp 154–6.

Prasad D, Yadava M S and Singh C S. 2013. Diversification of rice (*Oryza sativa*) –based cropping systems for higher productivity, profitability and resource–use efficiency under irrigated ecosystem of Jharkhand. *Indian Journal of Agronomy* **58**(2): 77–83.

Reddy AA. 2014. Profitability and labour use in cropping systems. *Indian Journal of Dry land Agricultural Research and Development* **29**(1): 97–106.

Shah M S, Verma N and Vishwkarma S K. 2015. Paper Diversification of rice (*Oryza sativa*)–based cropping systems for higher production efficiency, water productivity and economic viability in Madhya Pradesh. *Indian Journal of Agronomy* **60**(1): 25–30.

Sharma A R and Behera U K. 2004. Fertiliser use and option for diversification in rice – wheat cropping systems in India. *Fertiliser News* **49**: 115–31.

Sharma H R. 2007. Crop diversification in Himachal Pradesh: extent, impact, determinants and challenges. *Indian Journal of Labour Economics* **50**(4): 689–702.

Sharma R P, Dutta S K and Ghosh M. 2014.Diversification of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system for sustainable production in south Bihar alluvial plains. *Indian Journal of Agronomy* **59**(2): 191–9.

Singh S and Toor M S. 2005. Agrarian crisis with special reference to indebtedness among Punjab farmers. *Indian Journal of Agricultural Economics* **60**(3): 335–46.

Singh P, Singh J P, Gill M S and Singh Y. 2007. Alternate cropping systems to sugarcane–ratoon–wheat in peri urban areas of Meerut. Extended summaries 3rd National Symposium on Integrated Farming Systems. October 26–28, 2007, organized by Farming System and Development Association (Project Directorate for Cropping System Research, Modipuram, Meerut) at Agricultural Research Station, Durgapura, Jaipur.

Singh M K, Singh S P and Ujjwal V. 2017. Alternative Arable Cropping Strategies: A Key to Enhanced Productivity, Resource-Use-Efficiency, and Soil-Health under Subtropical Climatic Condition. *International Journal of Current Microbiology and Applied Sciences* **6**(11): 1187–205.

Soni V. 2012. Groundwater loss in India and an integrated climate solution. *Current Science* **102**(8): 1098–101.

Tomar S S and Tiwari A S. 1990. Production potential and economics of different crop sequences. *Indian Journal of Agronomy* **35**(1,2): 30–5.

Uddin M J, Quayyum M A and Salahuddin K M. 2009.Intercropping of hybrid maize with short duration vegetables at hill valleys of Bandarban. *Bangladesh Journal of Agricultural Research* **34**(1): 51–7.

Wilson K. 2002. Small cultivators in Bihar and New technology choice or compulsion? *Economic and Political Weekly* **37**(11): 1229–38.