

Effect of tillage practices and crop diversification on productivity, resource-use efficiency and economics of maize (*Zea mays*)/soybean (*Glycine max*)-based cropping systems

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ABSTRACT

The field experiment was conducted at Indian Agricultural Research Institute, New Delhi in a permanent layout, during the rainy, winter and spring/summer season of 2010–12 and rainy season of 2012; to study the effect of 2 tillage practices {Conventional tillage (CT) and minimum tillage (MT) with mulching of crop residue @ 5 tonnes/ha in each crop} and 10 cropping systems with 300% cropping intensity (Maize (*Zea mays* L.)/soybean [*Glycine max* (L.) Merrill] in rainy season—wheat [*Triticum aestivum* (L.) emend Fiori & Paol.]/coriander (*Coriandrum sativum* L.)/(fenugreek (*Trigonella foenum-graecum* L.)/vegetable pea [*Pisum sativum* (L.) var hortense }/potato (*Solanum tuberosum* L.) in winter season and green gram [*Vigna radiata* (L.) Wilezek] after wheat/coriander/fenugreek and sunflower (*Helianthus annuus* L.) after vegetable pea/potato during spring/summer seasons) on system productivity, resource-use efficiency and economics. MT with mulching resulted in 5.4% higher system productivity than CT during 2010–11, which increased to 7.4% in 2011–12. On an average, system productivity of soybean-based cropping systems was higher than the respective maize-based cropping systems. With intervention of vegetable pea and potato during winter and sunflower during spring, the productivity of maize/soybean–vegetable pea/potato–sunflower systems increased up to 128% over maize/soybean–wheat–green gram system. Similarly replacement of wheat with coriander in maize/soybean–wheat–green gram system also improved system productivity markedly. MT with crop residue cover recorded 12.7% increase in production efficiency (45.2 and 40.1 kg/ha/day, average of 2 years under minimum and conventional tillage) and 27.5 % in water productivity (3.06 and 2.40 kg/m³, average of 2 years under minimum and conventional tillage) over CT. In maize as well as soybean based cropping systems production efficiency {71.1 and 78.6 kg maize grain equivalent yield (MGEY)/ha/day average of 2 years under maize and soybean respectively} and water productivity (4.11 and 4.04 kg MGEY/m³) were the highest with vegetable pea during winter and sunflower during spring, followed by potato–sunflower. The employment generation was the maximum with potato–sunflower followed by vegetable pea–sunflower. MT resulted in higher net profit (₹ 119.2×10³) and economic efficiency (₹ 326/ha/day) than CT. Among cropping systems, maximum net returns (₹ 230×10³/ha), benefit : cost ratio (₹ 3.93) and economic efficiency (₹ 631 ha/day) were recorded in soybean–vegetable pea–sunflower system followed by maize–vegetable pea–sunflower system (₹ 204×10³; ₹ 3.62; ₹ 573/ ha/day, respectively). Based on the study, minimum tillage with crop residue cover and maize/soybean–vegetable pea–sunflower system followed by maize/soybean–potato–sunflower system were found more productive, resource-use efficient and remunerative under irrigated condition of north-west part of India.

Key words : Conventional tillage, Economics, Maize/soybean based cropping systems, Minimum tillage with mulching, Resource-use efficiency, System productivity.

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Conservation tillage and crop diversification are going to play major role for addressing the challenges of decline in soil health, water-table, size of land holding and factor productivity and rise in cost of cultivation and risk in agriculture and above all climate change, which are the stumbling blocks in achieving livelihood security, especially of smallholders. Minimum soil disturbance with organic soil cover and diversified crop rotations are gaining more attention to address these challenges (Gangwar

et al. 2006). Crop diversification and intensification with intervention of legumes, spices, vegetables, high-value crops, employment-generating crops and value-addition are becoming popular among the small holders to increase their profitability.

In the recent past, there is sizeable increase in the area of maize and soybean in India. Area under maize was only 6.6 million ha in 2000-01 which increased to 8.78 million ha in 2011-12 (Annual report 2013). The area under soybean was 6.1 million ha during 2000-01, which increased to 12.03 million ha in 2012-13. This area is occupied by these crops in different cropping systems, of which maize/soybean-wheat systems are predominant systems {(1.8 million ha. under maize-wheat and 4.5 million under soybean-wheat, (SOPA 2013)}. Along with area, there was also increase in production and productivity of these crops compared to other crops. So, both the crops are going to play important role in the food, nutritional and vegetable oil security as well as agro-based industry of the country in future. This increase in area, production and productivity under these crops is in response to market signals, government policies, industrial back-up, comparative economics in production, export potential and availability of high-yielding varieties and production technologies. As a result, both the crops are emerging as an alternative option for replacing rice in rice-based cropping systems in water-scarcity areas of north-west part of India and in area, where sowing of wheat is delayed after rice and also for enhancing resource-use efficiency (Gupta *et al.*, 2002). Soybean being legume, leaves 45 to 60 kg residual N/ha to the succeeding crop and sufficient litter and root biomass to improve the soil health. Experimental evidences have established that soybean could fit aptly in any of the traditional cropping system in all the 5 agro-climatic zones of India specified for soybean (Bhatnagar *et al.*, 1996).

Results revealed that maize-pea-wheat out yielded rice-wheat system and had higher water productivity. Similarly, in trans-Gangetic plains, the system productivity of maize-based cropping systems *viz.* maize-wheat-green gram, maize-potato-green gram and maize-potato-onion was remarkably higher over rice-wheat system (Gangwar *et al.*, 2006). Further, the irrigation water productivity in maize-based systems was more than double compared to 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. Studies carried out under various soil and climatic conditions under All India Coordinated Research Project on Cropping Systems revealed that compared to existing cropping systems like rice-wheat and rice-rice, maize-based cropping systems are better user of available resources and the water-

use efficiency of maize-based cropping systems was about 100 to 200% higher at different locations. Maize is being tried an alternative to rice in Punjab. Attempt has been made to diversify as well as to identify suitable break crops for soybean-wheat system under different inputs and agro-climatic conditions to make the system more sustainable, productive and remunerative by introducing durum wheat, mustard, chickpea, seed spices and medicinal plants (Ramesh *et al.*, 2009).

Traditionally, maize and soybean and succeeding crops are grown after thoroughly tilling the field till proper tilth is obtained for good crop emergence. The traditional practice of growing these crops has some limitations with respect to sustaining of crop and soil productivity. Zero/minimum tillage with residue covers is being advocated for soil, organic matter, water, hydrothermal regulation and energy management over traditional tillage practice (Gangwar *et al.*, 2006; Gill and Jat, 2007). Minimum tillage appears to be more practical to insure optimum plant stand, effective weed control, to reduce the requirement of special implements for sowing under residue cover and to meet specific land configuration requirement of crops.

Since information on the comparative performance of intensified and diversified maize and soybean-based cropping systems with 300% cropping intensity with minimum/conventional tillage with crop residue cover are very limited. Keeping these aspects in view, the study under reference was undertaken.

MATERIALS AND METHODS

The fixed layout field experiment was conducted during rainy, winter and summer seasons of 2010-11 and 2011-12 and rainy season of 2012 at research farm of the Division of Agronomy, Indian Agricultural Research Institute, New Delhi, which is situated at a latitude of 28°40' N and longitude of 77°12' E and an altitude of 228.6 meters above the mean sea level (Arabian Sea). The mean annual rainfall of Delhi is 650 mm and more than 80% generally occurs during the south-west monsoon season (July-September) with mean annual evaporation of 850 mm. The soil of experimental field was sandy loam and had 212 kg/ha alkaline permanganate oxidizable N (Subbiah and Asija, 1956), 17.5 kg/ha available P (Olsen *et al.*, 1954), 226 kg 1N ammonium acetate exchangeable K (Hanway and Heidel, 1952), and 0.35% organic carbon (Walkley and Black, 1934). The pH of soil was 7.5 (1:2.5 soil and water ratio) by (Jackson, 1973) and EC was 0.30 dS/m (Richards, 1928).

The effects of 2 tillage practices *viz.* (i) Conventional tillage (CT) (ii) Minimum tillage (MT) with mulching of crop residue @ 5 tonnes/ha in each crop and 10 cropping systems *viz.*, Maize/soybean-wheat-green gram, maize/

soybean–coriander–green gram, maize/soybean–fenugreek–green gram, maize/soybean–vegetable pea – sunflower and maize/soybean–potato–sunflower were evaluated on system productivity, economics, water requirement, water productivity and employment generation. The field experiment was laid out in a three times replicated split-plot design, assigning tillage practices to main plots and cropping systems to subplots. In the conventional tillage (CT) treatment, the tillage operations were carried out as per requirement of each crop. In (MT) minimum tillage treatment, one plowing with planking was done followed by sowing of crop on flatbed except maize and potato where ridges were made at 60 cm spacing and there after dibbling was done as per plant to plant spacing. After the sowing of crop, mulching was done in minimum tillage treatment, where crop residue of preceding crops was used on succeeding crops @ 5.0 tonnes/ha. Plant analysis of the crop residue was carried out and nutrient added through mulching are given in Table 2. In the third year rainy season, only the residual effect of preceding crops on maize and soybean over two seasons were assessed.

Input used such as varieties, fertilizers, irrigation, herbicides/pesticides and cultural practices followed in each crop are given in Table 1. In case of no rainfall, a pre-sowing irrigation was given to ensure timely sowing of the crop and thereafter irrigations were scheduled based on recommended IW/CPE ratio for each crop.

The weight of grain/seed yield of maize, soybean, wheat, coriander, fenugreek, green gram and sunflower from net plots in each treatment after threshing was weighed and weight was expressed in tonnes/ ha. In case of potato, tubers from the net plot area were dug out and after removing of soil adhering to tubers, weight of the tubers of each plot was recorded, separately. The values were finally expressed in tonnes/ha. The weight of green pods recorded from each plots over different picking was added and expressed as tonnes/ha. For comparison of cropping systems, system productivity was calculated by adding maize grain-equivalent yield (MGEY) of component crops, which was worked out considering the prevailing market prices of component crops (average): maize grain (₹10,000/tonne), soybean seed (₹20,000/tonne), wheat grain (₹12,000/tonne), coriander seed (₹50,000/tonne), fenugreek seed (₹40,000/tonne), vegetable pea (₹12,000/tonne), potato tubers (₹7,000/tonne), green gram grain (₹35,000/tonne) and sunflower seed (₹25,000/tonne). Production efficiency of the system (PES) was calculated by dividing the maize grain equivalent yield (MGEY) of each cropping system in a year by 365 (Devkant Prasad *et al.*, 2013).

Land use efficiency (LUE) of the cropping system was

calculated by taking the total field duration of the crops in individual cropping system divided by 365 days and expressed as per cent.

Total income (gross returns) obtained from seed and stover of each component crop was worked out using the MSP and prevailing prices at farm gate, where MSP is not available and expressed as ₹/ha. The net returns were computed by subtracting the cost of cultivation from gross returns and expressed as ₹/ha. The benefit : cost ratio for different treatments was calculated by dividing the net returns by the cost of cultivation of that treatment. Monetary efficiency of the system was worked out by dividing the net returns of the cropping system with total field durations of the crops in the system.

The total number of labour required for various agonomic practices under different cropping sequences were noted treatment-wise and area involved in each plot. Based on this total requirement of labour per hectare for each sequence was worked out (Newaj and Yadav, 1992).

Irrigation to each crop was given based on recommendation of IW/CPE ratio for each crop and quantity of water given to conventional and minimum tillage with mulching was measured with Parshal flume. Based on number of irrigation and water depth under each irrigation, irrigation water requirement of each crop sequence and tillage practice was worked out. Irrigation water-use efficiency was worked out by dividing maize grain-equivalent yield with irrigation water requirement.

The data were statistically analysed using the *F*-test as per the procedure given by Gomez and Gomez (1984). LSD values at *P* = 0.05 were used to determine the significance of difference between treatment means.

RESULTS AND DISCUSSION

System productivity

Effect of tillage practices: While comparing the total productivity of cropping systems in terms of maize grain-equivalent yield under different tillage practices, it was observed that tillage practices influenced the system productivity significantly during both the seasons (Table 3). Over the experimental period, system productivity was higher in the second season than the first season. Minimum tillage with mulching recorded 5.4% higher system productivity than conventional tillage during 2010–11, which increased to 7.4% in 2011–12. This behaviour of system productivity may be attributed to favourable effects of minimum tillage with mulching on the productivity of individual crop of cropping system by virtue of improvement in soil properties. Similar favourable effects of minimum tillage + mulching on system productivity due to improvement in moisture, heat and air regime, restriction on idle evaporation and weed suppression were also reported

by Bu *et al.* (2002), Ved Prakash *et al.* (2004) and Kumar *et al.* (2013).

Effect of cropping systems: Based on system productivity, soybean-based cropping systems were more productive than maize-based cropping systems during both the crop seasons. Maximum total productivity was recorded in maize/soybean-vegetable pea-sunflower cropping system closely followed by maize/soybean-potato-sunflower cropping system (Table 3). Maize-vegetable pea-sunflower system showed 96 and 114% higher system productivity during 2010-11 and 2011-12, respectively than conventional maize-wheat-green gram system. With respect to maize-potato-sunflower system the increase was 94 and 107% in respective season over maize-wheat-green gram system. Replacement of wheat with spices (coriander and fenugreek) in maize-wheat-green gram cropping system also improved the system productivity over conventional system. Advantage in productivity was more with coriander than fenugreek. Similar results were also observed in soybean based cropping systems. The lowest system productivity was recorded in soybean-wheat-green gram cropping system, which was 110 and 112% lower than the soybean-vegetable pea-sunflower system. Francis (1989), Chitale *et al.* (2011) and Sharma *et al.* (2014) also recorded improvement in the system productivity with the intervention of vegetables and spices in the conventional cropping systems. This improvement in productivity may be attributed to higher biological yield of vegetable crops and higher market values of the spices.

Resource-use efficiency

Effect of tillage practices: The results revealed that minimum tillage with crop residue cover improved resource-use efficiency in terms of production efficiency and water productivity over conventional tillage. On an average production efficiency (kg MGEY/ha/day) and water productivity (kg grain/m³) under the minimum tillage with crop residue cover was 12.1% and 27.5% higher than the conventional tillage, respectively. This increase in production efficiency under minimum tillage may be attributed to higher system productivity owing to favourable crop environment created by mulching in terms of soil moisture conditions, plant nutrient supply and microbial population. Under the minimum tillage with crop residue cover irrigation water requirement was less due to residue cover on the soil, which economize water by reducing evaporation losses and conservation of rain water. So higher water productivity under minimum tillage with crop residue cover was the combined effect of higher system productivity and less irrigation water requirement as compared to conventional tillage. Employment generation under minimum tillage was more owing to management of crop residue for

Table 1. Agronomic practices followed in different crops

Agronomic practices	Crops									
	Kharif season			Rabi season			Summer season			
	Maize	Soybean	Wheat	Potato	Pea	Fenugreek	Coriander	Sunflower	Green gram	
Varieties/hybrid	'PEHM 2'	'PUSA 9712'	'HD 2894'	'K. Badshah'	'Pusa Praphat'	'AM 1'	'ACR 1'	'KBSH 1'	'Pusa Vishal'	
Seed rate (kg/ha)	20	75	100	200	80	25	15	4	20	
Spacing (cm)	60×20	30×10	22.5×10	60×25	30×10	30×10	30×10	60×25	30×10	
Fertilizers (N:P:Kkg/ha)	120:60:40	30:60:40	120:60:40	120:60:80	30:60:40	20:40:30	60:40:30	80:40:40	20:50:40	
No of irrigation	2	2	4	5	4	3	3	4	4	
2010-11	3	4	6	5	4	4	4	5	4	
2011-12	3	4								
2012-13										
Dates of sowing	13/07/2010	13/07/2010	12/11/2010	12/11/2010	12/10/2010	13/11/2010	13/11/2010	25/03/2012	05/04/2011	
	20/07/2011	08/07/2011	13/11/2011	12/11/2011	15/11/2011	13/11/2011	22/03/2011	13/11/2011	07/04/2012	
	15/07/2012	08/07/2012								
Dates of harvesting	10/10/2010	05/11/2010	15/04/2011	05/03/2011	08/03/2011	23/03/2011	20/03/2011	20/06/2011	15/06/2011	
	13/10/2011	08/11/2011	17/04/2012	08/03/2012	10/03/2012	20/03/2012	25/03/2012	25/06/2012	18/06/2012	
	15/10/2012	06/11/2012								
Crop duration (Days)	87, 83, 90	112,120,118	153, 154	113, 116	116,115	133,127	127,132	88,90	70,71	

Table 2. Nutrient concentration and addition through crop residues years 2010–11 and 2011–12

Crop	Applied season	Nutrient concentration (%)			Nutrient added (kg/ha)						
		N	P	K	N		P		K		
		2010–11	2011–12	2010–11	2011–12	2010–11	2011–12	2010–11	2011–12	2010–11	2011–12
Green gram	Kharif	0.94	0.94	0.11	0.13	0.89	0.91	47.13	47.32	5.42	6.51
Soybean	Winter	0.88	0.96	0.16	0.17	2.02	2.11	44.04	48.02	8.31	8.50
Wheat	Summer	0.50	0.53	0.03	0.04	1.21	1.21	25.02	26.52	1.72	1.82

Crop residues were applied @ 5.0 t/ha dry-matter

Table 3. Effect of tillage practice and cropping systems on system productivity, production efficiency, per day returns, land-use efficiency, employment generation and economics

Treatment	System productivity (t/ha)		Production efficiency (kg/ha/day)		Per day returns (₹/ha/day)		Land-use efficiency (%)		Gross returns ($\times 10^3$ ₹/ha)		Net returns ($\times 10^3$ ₹/ha)		Benefit: cost ratio	
	2010–11	2011–12	2010–11	2011–12	2010–11	2011–12	2010–11	2011–12	2010–11	2011–12	2010–11	2011–12	2010–11	2011–12
<i>Tillage systems</i>														
CT	14.22	15.02	38.9	41.2	254	326	83.1	84.1	145.8	173.2	92.7	118.9	1.71	2.14
MT	15.89	17.08	43.5	46.8	283	370	83.1	84.1	162.9	196.2	103.2	135.2	1.69	2.17
SEm \pm	0.08	0.12	0.23	0.34	2.0	2.82	-	-	0.75	1.03	0.74	1.03	-	-
CD (P=0.05)	0.51	0.75	1.41	2.05	12.4	17.1	-	-	4.54	6.25	4.54	6.25	-	-
<i>Cropping systems</i>														
Maize–potato–sunflower	18.45	19.98	50.5	54.7	302	400	78.9	79.2	182.8	220.9	110.2	146.3	1.52	1.96
Maize–pea–sunflower	25.41	26.85	69.6	73.6	513	633	79.7	78.9	244.4	289.4	187.3	231.1	3.28	3.97
Maize–wheat–green gram	8.02	8.60	21.9	23.6	127	178	84.9	84.4	99.7	119.3	46.7	65.0	0.88	1.20
Maize–coriander–green gram	11.11	11.60	30.4	31.8	191	247	77.8	78.4	118.4	140.0	69.8	90.3	1.44	1.82
Maize–fengreek–green gram	7.82	7.59	21.4	20.8	114	142	79.5	77.0	89.9	101.2	41.8	51.8	0.87	1.05
Soybean–potato–sunflower	20.92	23.04	57.3	63.1	356	480	80.8	84.1	203.5	250.8	129.9	175.2	1.77	2.32
Soybean–pea–sunflower	27.97	29.41	76.6	80.6	569	694	86.6	89.0	265.9	312.7	207.8	253.5	3.57	4.28
Soybean–wheat–green gram	9.20	10.18	25.2	27.9	153	219	91.8	94.5	110.2	135.3	56.1	80.0	1.04	1.45
Soybean–coriander–green gram	12.57	13.57	34.4	37.2	218	293	84.7	88.5	129.5	157.7	79.9	107.1	1.61	2.11
Soybean–fengreek–green gram	9.08	9.70	24.9	26.6	137	191	86.3	87.1	99.3	120.3	50.2	69.9	1.02	1.39
SEm \pm	0.16	0.20	0.45	0.55	4.2	5.4	-	-	1.54	1.98	1.54	1.98	-	-
CD (P=0.05)	0.47	0.58	1.28	1.58	12.1	15.6	-	-	4.41	5.68	4.41	5.68	-	-

*CT, Conventional tillage without mulch; MT, minimum tillage with crop residue mulch

mulching the surface. Improvement in resource-use efficiency due to application of mulches and changing tillage intensity was also reported by Bu *et al.* (2002), Gill and Jat (2007) and Choudhary and Kumar (2014).

Effect of cropping system: Production efficiency of soybean-based cropping systems was higher than the production efficiency of corresponding maize-based cropping systems, which may be attributed to higher prices for soybean in the market and favourable effect of soybean on the productivity of succeeding crops of the systems as compared to maize (Table 3). Among the soybean based cropping systems, soybean-vegetable pea-sunflower cropping system resulted in the highest production efficiency (76.6 and 80.6 kg MGEY/ha/day during respective season), closely followed by soybean-potato-sunflower system. The lowest production efficiency was recorded in soybean-fenugreek-green gram system, which was however on par with soybean-wheat-green gram system but statistically inferior to other cropping systems. Maize-based cropping systems followed trend similar to soybean-based cropping systems. Intervention of vegetables such as vegetable pea and potato during the winter season and replacement of green gram with sunflower during spring/summer in the conventional maize-wheat-green gram system improved production efficiency markedly owing to more production of economic yield of vegetables as well as corresponding better prices especially for vegetable pea and higher productivity of sunflower (on an average 2.15 tonnes/ha) as compared to green gram (on an average 0.58 tonnes/ha) during the summer season. Improvement in production efficiency due to replacement of wheat with coriander may also be attributed to availability of very high prices/per unit of coriander in the market (₹50/kg for coriander and ₹12/kg for wheat). Between the fenugreek and coriander, coriander is a better replacement for wheat, as its yield per unit area and price per unit weight was higher than fenugreek. Singh and Bohra (2009) also reported similar variation in production efficiency due to intervention of vegetables in the cereal-based cropping systems.

The land-use efficiency of soybean-based cropping systems was higher than the corresponding maize-based cropping systems, which may be attributed to long duration of soybean as compared to maize. Among the soybean-based cropping systems, the highest land-use efficiency was recorded in soybean-wheat-green gram system closely followed by soybean-vegetable pea-sunflower system. Maize-based systems followed trend similar to soybean-based cropping systems (Table 3). During the winter season wheat occupied field for the longest duration, while duration of potato was the shortest. In the summer season crops, sunflower occupied field for longer period than

green gram.

On an average, irrigation water requirement of all the cropping systems was higher during the second season than the first season, which may be attributed to timely onset and withdrawal of monsoon and its uniform distribution during the first year as compared to the second year. In the first year, cropping system with potato consumed more irrigation water, while irrigation water requirement of cropping system with spices was the lowest. In the second season, the highest irrigation water requirement was that of soybean/maize-wheat-green gram system followed by soybean/maize-potato-sunflower cropping systems and it was the lowest in maize-fenugreek/coriander-green gram system (Table 4). This variation in irrigation water requirement may be attributed to the duration of crops (maize has less irrigation requirement than soybean during rainy season due to crop duration variation), coinciding part of growth period of crop with high temperature as in case of wheat and green gram and variations in irrigation interval period (shorter for potato and longer for spices). Water productivity of cropping systems depicted marked variation due to variation in system productivity and irrigation water requirement. On an average, water productivity of soybean based cropping systems was higher than the water productivity of corresponding maize-based cropping systems, due to variation in system productivity. Replacement of wheat with vegetable pea/potato during winter and green gram with sunflower during spring/summer caused marked increase in water productivity over maize/soybean-wheat-green gram cropping systems. There was a 100% increase in water productivity of maize/soybean-vegetable pea-sunflower system over maize/soybean-wheat-green gram system. Among the cropping systems, the lowest water productivity was recorded under maize/soybean-wheat-green gram systems. These variations in water productivity among the systems attributed to variation in MGEY among the systems. Maize-based cropping systems generated more employment than their corresponding soybean-based cropping systems. Among the systems, intervention of potato during winter generated more employment followed by vegetables pea, while in the summer crops, sunflower generated more employment than green gram. In base crops, maize generated more employment than soybean. In view of this variation in employment generation, maize-potato-sunflower generated more employment closely followed by soybean-potato-sunflower. Soybean-fenugreek-green gram generated the lowest employment among the systems. In rural areas, there are problems of underemployment and decline in holdings, so the intensive cropping systems with higher economic returns, better resource use efficiency and employment intensive are needed to sustain the livelihood

Tables 4. Comparative water productivity and employment generation of maize/soybean-based cropping systems

Treatment	Number of irrigations(no.)		Irrigation water use (mm)		Water productivity (kg gain/m ³)		Employment generation (Man-days/system)	
	2010–11	2011–12	2010–11	2011–12	2010–11	2011–12	2010–11	2011–12
<i>Tillage systems</i>								
CT	9.8	12.5	588	750	2.57	2.23	271	285
MT	9.8	12.5	490	625	3.25	2.87	278	292
SEm±	–	–	–	–	–	–	–	–
CD (P=0.05)	–	–	–	–	–	–	–	–
<i>Cropping systems</i>								
Maize–potato–sunflower	11	13	605	715	3.72	3.35	302	319
Maize–pea–sunflower	10	11	550	605	4.13	4.10	289	302
Maize–wheat–green gram	10	14	550	770	2.10	1.50	274	286
Maize–coriander–green gram	9	11	495	605	2.81	2.42	265	275
Maize–fenugreek–green gram	9	11	495	605	2.43	2.08	260	270
Soybean–potato–sunflower	11	14	605	770	4.05	3.42	295	314
Soybean–pea–sunflower	10	13	550	715	4.39	3.69	282	295
Soybean –wheat–green gram	10	14	550	770	2.09	1.61	265	276
Soybean–coriander–green gram	9	12	495	660	2.96	2.38	254	267
Soybean–fenugreek–green gram	9	12	495	660	2.57	2.12	252	263
SEm±	–	–	–	–	–	–	–	–
CD (P=0.05)	–	–	–	–	–	–	–	–

*CT, Conventional tillage without mulch; MT, minimum tillage with crop residue mulch

security of smallholders. Improvement in resource-use efficiency and employment were also reported due to inter-cropping of vegetables and spices in cereal-based cropping systems by Singh and Bora (2009) and Yadav *et al.* (2013).

Economic viability

Effect of tillage practices: The cost of cultivation under minimum tillage was higher than conventional tillage as the saving due to tillage operations under minimum tillage was less than the cost of crop residue used for mulching soil cover and its application cost. Economic analysis showed that despite higher cost of cultivation, the gross and net returns and monetary efficiency under minimum tillage with crop residue cover were significantly higher than the conventional tillage, which may be attributed to markedly higher yields of component crops under minimum tillage due to favourable effect of crop residue cover and improvement in soil fertility due crop residue recycling (Table 3). Gap in gross returns between the minimum and conventional tillage treatments was wider which narrowed down in net returns due to higher cost of cultivation under minimum tillage. Gap between the B:C ratio of minimum and conventional tillage was not conspicuous. Our findings confirm the results of Choudhary *et al.* (2014).

Effect of cropping system: Gross returns, net returns, monetary efficiency and benefit: cost ratio of soybean-based cropping system were higher than the corresponding

maize-based cropping systems, which assigned to the higher market price for soybean and higher yield of crops after soybean than after maize owing to favourable legume effect of soybean (Table 3). Among the soybean-based cropping systems, highest gross and net returns, monetary efficiency and benefit: cost ratio were recorded in soybean–vegetable pea–sunflower system, followed by soybean–potato–sunflower system. The lowest values of these economic parameters were recorded in soybean–fenugreek–green gram cropping system. Economics of maize-based cropping systems followed trend similar to soybean-based cropping systems. This may be attributed to variation in yield, cost of cultivation and prices of economic produce of component crops of cropping systems. Similar results were also reported by Walia *et al.* (2011), Choudhary *et al.* (2013) and Devkant Prasad *et al.* (2013).

Based on 2 years study, it was concluded that with replacement of wheat with vegetables viz. pea and potato and spices, viz. coriander during winter and replacement of green gram with sunflower during spring/summer, the productivity, resource-use efficiency and monetary efficiency of soybean/maize – wheat –green gram system can be increased substantially in the north-west part of India. Soybean-based system are more productive, economical and resource-use efficient than corresponding maize-based systems.

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