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Review/Overview

Productivity, profitability and land-use efficiency of soybean (*Glycine max*)-based cropping systems under different nutrient-management practices

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ABSTRACT

A field experiment was conducted during the rainy (*kharif*), winter (*rabi*) and summer seasons of 2011–12 and 2012–13 at New Delhi, to evaluate the productivity, profitability and land-use efficiency of 4 soybean [*Glycine max* (L.) Merr.]-based cropping systems involving wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.], chickpea (*Cicer arietinum* L.), potato (*Solanum tuberosum* L.), mungbean [*Vigna radiata* (L.) Wilczek] and fodder sorghum [*Sorghum bicolor* (L.) Monech], under 5 nutrient-management practices. System productivity of soybean-based cropping system in terms of soybean-equivalent yield (SEY) was significantly higher under soybean–chickpea–fodder sorghum (7.44 t/ha) during 2011–12 and under soybean–potato–mungbean system (8.99 t/ha) during 2012–13. Land-use efficiency (LUE) was higher in soybean–chickpea–sorghum (F) and soybean–wheat–mungbean systems than soybean–wheat–fallow and soybean–potato–mungbean systems during both the years. Soybean–chickpea–sorghum (F) and soybean–potato–mungbean systems recorded the highest production efficiency (PE) based on SEY (22.8 and 31.4 kg SEY/ha/day) and monetary terms (₹255 and ₹363/ha/day) during 2011–12 and 2012–13 respectively. Application of 25% recommended dose of fertilizer (RDF) + 50% RDN through FYM + biofertlizers in soybean gave significantly highest seed yield during both the years. Application of 100% RDF resulted in the highest wheat yield and potato tuber yield during both the years. Highest yield of chickpea, mungbean and sorghum fodder were obtained with 50% RDF + 50% RDN through FYM during both the years. The highest SEY (6.73 t/ha and 6.84 t/ha) was achieved with of 50% RDF + 50% RDN, through FYM during both the years.

Key words **:** Crop production, Cropping systems, Land-use efficiency, Net returns, Nutrient management, Productivity, Profitability, Soybean

Soybean has become the premier oilseed crop in India, producing 12.28 m t from 10.18 m ha area with productivity of 1,207 kg/ha (DAC, GoI, 2012). It contributes 40% of oilseed area and 25% of edible oil production, besides 8 m t of soy-meal production in the country. Soybean is mainly grown in central part of the country, Madhya Pradesh, Maharashtra and Rajasthan covering about 95% of the production. In recent years, agricultural production systems in India are struggling for sustained growth to achieve food and nutritional security. Since there is very little scope for horizontal growth, only alternative left is vertical growth through increased productivity of the crops. There is need for development and adoption of eco-farming techniques, which are ecological sound, environmentally safe and economically efficient. Besides adoption of proper input-management technologies, diversification or intensification through crops of diverse nature may be a good proposition to break the monotony of the system (Tripathi and Singh, 2008). Therefore, crop diversification is going to play major role for sustaining the productivity, while conserving the natural resources and utilizing them more efficiently in the long-run.

Indian agriculture is continuously facing the problem of increase in fertilizer prices and imbalanced use of fertilizers. Current nutrient-management strategies aims at delivering soluble inorganic nutrients directly to crops and have uncoupled carbon, nitrogen and phosphorus cycles in space and time. The existing system of fertilizer application is based on the nutrient requirement of individual crop ignoring the carryover effect of fertilizer or organic manure applied to the succeeding crop to a great extent and the system productivity becomes sustainable through integrated use of organic or inorganic sources of nutrients (Singh *et al*., 2008). Integration of inorganic fertilizers

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with organic manures and biofertilizers will not only sustain the crop production but also will be effective in improving soil health and enhancing the nutrient-use efficiency (Verma *et al*., 2005). Therefore, an attempt was made to diversify soybean–wheat system under different sources of nutrient to find out the most economical and sustainable system.

MATERIALS AND METHODS

A field experiment was conducted during the rainy (*kharif*), winter (*rabi*) and summer seasons of 2011–12 and 2012–13 at the research farm of Indian Agricultural Research Institute, New Delhi. The soil was sandy clay loam (sand 63.8%, silt 12.2% and clay 24.0%) with pH 7.9, cation-exchange capacity 10.5 c mol/kg and electrical conductivity 0.34 dS/m in the top 15 cm of soil. The soil was low in available nitrogen (157 kg/ha) and medium in phosphorus (14.2 kg/ha), potassium (240 kg/ha) and organic carbon (0.42%). -The treatments comprised 4 cropping systems, viz. soybean–wheat–fallow (CS_1), soybean–wheat–mungbean (CS_2), soybean–chickpea–sorghum (fodder) (CS_3) and soybean–potato–mungbean (CS_4), and 5 nutrient-management practices, viz. control (NS_0), 100% recommended dose of fertilizer (RDF) (NS_1), 50% RDF + 50% RDN through FYM (NS_2), 50% RDF + 25% RDN through FYM + biofertilizers (NS_3) and 25% RDF + 50% RDN through FYM + biofertilizers (NS_4). The experiment was laid out in strip-plot design and replicated thrice. Soybean 'Pusa 9712', wheat 'HD 2967', potato 'Kufri Badshah', chickpea 'Pusa 1103' mungbean 'Pusa Vishal' and sorghum (fodder) 'HC 308' were taken for experiment. The recommended dose of fertilizers (RDF) for different crops were decided based on soil test crop response (STCR) approach as per initial soil-test values of available N, P and K at the beginning of experiment and targeted yield of crops as 2.0, 5.0, 2.0 and 1.0 t/ha for soybean, wheat, chickpea and mungbean respectively. The RDF for potato and fodder sorghum were decided based on recommended rates as STCR equations were not available. The RDF of soybean, wheat, potato, chickpea, mungbean and fodder sorghum were 50:75:26, 158:76:47, 150:60:80, 44:27:3, 25:30:0 and 120:60:40 kg $N:P_2O_5:K_2O$/ha respectively. Farmyard manure (FYM) was applied before sowing/planting of crops based on the nitrogen-equivalent basis and nutrient requirement of each crop in respective treatment. The FYM consisted 0.57, 0.28 and 0.52% of N, P and K respectively. The fertilizers and FYM were applied as per recommended methods and time of application for each crop. Seeds/tubers of crops were treated with *Rhizobium*/*Azotobator* and phosphate solubilising bacteria (PSB) according to treatments. Higher and relatively well-distributed rainfall was received during 2012–13 as compared to 2011–12. The total rainfall received during July–October, November–March and April–June was 434, 34, 21 and 482, 164, 162 mm during 2011–12 and 2012–13 respectively. The average monthly air temperature, relative humidity and sunshine hours were almost similar during both the years. However, during 2012-13 minimum temperature decreased up to freezing point in the last week of December.

Soybean was sown in the first forth-night of July and harvested in the first week of November (2011) and last week of October (2012). The winter crops (wheat, potato and chickpea) were sown/planted in the second week of November and harvested in the second week of April (Wheat and chickpea). Potato was digged out in the third week of February (2011–12) and first week of March (2012–13). Sowing of summer mungbean after potato was done in the second week of March and harvested in the fourth week of May during both the years. Whereas mungbean followed by wheat and fodder sorghum were sown in the third week of April and harvested in the third/forth week of June. The number of irrigations applied in soybean, wheat, potato, chickpea, mungbean and fodder sorghum were 4, 5, 4, 2, 3, 6 and 3, 4, 3, 1, 3, 5 during 2011–12 and 2012–13 respectively. Economic yields of the component crops were converted to soybean-equivalent yield (SEY), taking into account the prevailing minimum support price (MSP)/market prices of the crops. System productivity was calculated by adding the SEY 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. Production efficiency (PE) was expressed as the ratio of system productivity in kg SEY/ha to total duration of the system in days. Production efficiency in economic terms was calculated by taking system net returns instead of SEY. Statistical analysis of the data was carried out using standard analysis of variance (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Productivity of soybean

There was no significant difference in soybean yield among different cropping systems during 2011, as the experiment commenced from soybean crop. During 2012 significantly highest soybean seed yield was recorded in soybean–wheat–mungbean system than soybean–wheat–fallow system (Table 1). Soybean–potato–mungbean and soybean–chickpea–sorghum (F) systems remained statistically similar to soybean–wheat–mungbean in soybean yield. Soil is a dynamic medium for plant growth and keeping the land fallow in summer season increases compaction, temperature of soil profile and reduces pore space and aeration which reduces crop yield in the succeeding season after fallow (Bastia *et al.,* 2008).

All the nutrient sources produced significantly higher soybean yield than control (Table 1). Soybean responded better to organic source (FYM) and biofertilizers, whereby application of 25% RDF + 50% RDN through FYM along with inoculation of *Rhizobium* and phosphate solubilising bacteria (PSB) gave significantly highest soybean yield over the control during both the years and found statistically equal to remaining nutrient levels. This might be ascribed to lower levels of nitrogen fertilization, inoculation with *Rhizobium* increases the nodulation, resulted in higher BNF (Salvagiotti *et al*., 2008) and solubilization of more amount of P by PSB. At the same time, organic manure (FYM) acts as a substrate for microorganisms and also improves soil condition favourable for availability of nutrients to crop (Sharma *et al*., 2008). Therefore, synergistic effect of biofertilizers and FYM resulted in higher soybean yield.

Productivity of rabi crops

Wheat yield under soybean–wheat–fallow and soybean–wheat–mungbean systems did not differ significantly during both the years; however, higher wheat yield was recorded in soybean–wheat–mungbean than soybean–wheat–fallow system during 2012–13 (Table 1). Wheat grain and potato tuber yields were significantly higher under application of 100% RDF through fertilizers during both the years (Table 1). However, no significant variations were observed among all sources of nutrient except control in 2011–12 and 100% RDF and substitution of 50% RDN through FYM in 2012–13 for both the crops. The productivity of potato was very low during 2011–12, as the crop was affected by chilling temperature in December–January. In wheat and potato, substitution of RDF with organic manure or biofertilizers was found insufficient to achieve potential yield in both the years. However during 2012–13, only marginal difference was observed between 100% RDF and substitution of 50% RDN through FYM in next year, which might be due to residual effect of FYM applied to previous crops. Behera *et al*. (2007) reported similar findings in wheat and Kumar *et al*. (2009) in potato, whereas significantly maximum chickpea yield was obtained in the treatment 50% RDF + 50% RDN through FYM, followed by 100% RDF during 2011–12 and 25% RDF + 50% RDN through FYM + biofertilizers during 2012–13 (Table 2). As FYM and biofertilizers releases nutrients slowly, which

Table 1. Yields of crops and system productivity as influenced by cropping systems and nutrient management practices

Treatment	Soybean seed yield (t/ha)		Wheat grain yield (t/ha)		Chickpea grain yield (t/ha)		Potato tuber yield (t/ha)		Mungbean grain yield (t/ha)		Sorghum green fodder yield (t/ha)		System productivity (SEY, t/ha)	
	2011	2012	2011–12	2012–13	2011–12	2012–13	2011–12	2012–13	2011–12	2012–13	2011–12	2012–13	2011–12	2012–13
Cropping system														
Soybean–wheat–fallow	1.76	1.59	4.50	4.97	-	-	-	-	-	-	-	-	5.18	4.59
Soybean–wheat–mungbean	1.75	1.64	4.49	5.08	-	-	-	-	0.51	0.59			6.22	4.70
Soybean–chickpea–fodder sorghum	1.77	1.60	-	-	1.78	2.12	13.73	31.29			45.91	44.65	7.44	6.40
Soybean–potato–mungbean	1.77	1.62	-	-	-	-	-	-	0.45	0.55	-	-	6.36	8.99
SEm±	0.014	0.010	0.060	0.08	-	-	-	-	0.007	0.008	-	-	0.049	0.026
CD (P=0.05)	NS	0.034	NS	NS	-	-	-	-	0.040	NS	-	-	0.168	0.088
Nutrient management														
Control	1.57	1.40	3.43	3.53	1.52	1.82	8.73	16.52	0.40	0.49	32.70	33.20	4.98	4.51
100% RDF	1.75	1.64	4.91	5.67	1.87	2.10	15.17	38.84	0.49	0.59	48.71	47.53	6.63	6.81
50% RDF + 50% RDN through FYM	1.78	1.65	4.76	5.55	1.95	2.35	15.07	37.09	0.55	0.62	51.63	51.20	6.73	6.84
50% RDF + 25% RDN through FYM + biofertilizers	1.83	1.66	4.72	5.40	1.75	2.05	15.04	30.72	0.45	0.55	48.00	44.22	6.52	6.27
25% RDF + 50% RDN through FYM + biofertilizers	1.88	1.72	4.68	5.00	1.82	2.26	14.66	33.29	0.52	0.60	48.50	47.10	6.64	6.42
SEm±	0.060	0.024	0.116	0.077	0.061	0.081	0.435	1.140	0.012	0.015	1.153	1.609	0.144	0.027
CD (P=0.05)	0.195	0.078	0.377	0.250	0.198	0.264	1.418	3.716	0.041	0.048	3.759	5.247	0.469	0.087

RDN, Recommended dose of nitrogen

meets the requirement of slow growing chickpea during winter season and increase the yield (Ramesh *et al*., 2009). Relatively higher rainfall was received during all months, which resulted in higher yields of *rabi* crops during 2012–13.

Productivity of summer crops

Significantly higher mungbean yield was obtained under soybean–wheat–mungbean system than soybean–potato–mungbean during 2012; however, no significant variation was observed under both the cropping systems during 2013 (Table 1). Among the nutrient sources, application of 50% RDF + 50% RDN through FYM recorded significantly highest mungbean yield and sorghum green fodder (Table 1). However, mungbean yield with the application of 50% RDF + 50% RDN through FYM was statistically similar to application of 25% RDF + 50% RDN through FYM + biofertilizers during 2012 and with 25% RDF + 50% RDN through FYM + biofertilizers and 100 % RDF during 2013. Similarly, the all nutrient sources gave statistically similar sorghum green fodder yield during 2012, whereas application of 50% RDF + 50% RDN through FYM, 25% RDF + 50% RDN through FYM + biofertilizers and 100% RDF produced statistically similar yield during 2013. Integration of FYM and biofertilizers resulted in increased availability of nutrients along with retention of higher moisture in soil profile and moderation of soil temperature during summer, favoured better growth and yield of mungbean and fodder sorghum.

System productivity

System productivity in terms of soybean-equivalent yield (SEY) indicated that soybean–chickpea–fodder sorghum registered significantly higher SEY followed by soybean–potato–mungbean during 2011–12, whereas soybean–potato–mungbean, followed by soybean–chickpea–fodder sorghum gave significantly highest system productivity during 2012–13 (Table 1). Application of 50% RDF + 50% RDN through FYM registered significantly highest SEY (6.73 t/ha and 6.84 t/ha) during both the years. The interaction effect was also significant in SEY and showed significantly maximum SEY (8.07 t/ha) under CS_3 (soybean–chickpea–fodder sorghum) and NS_2 (50% RDF + 50% RDN through FYM) in 2011–12, whereas during the second year CS_4 and NS_1 remaining on par with NS_2 nutrient sources gave maximum SEY (Table 3).

System economics

Soybean–chickpea–sorghum (F) and soybean–potato–mungbean system gave significantly maximum gross and net returns during 2011–12 and 2012–13 respectively (Table 2). Increased potato yield under soybean–potato–mungbean system increased the net returns over soybean–chickpea–sorghum (F) during the second year. Application of 50% RDF + 50% RDN through FYM remaining on a par with 100% RDF gave significantly maximum gross

Table 2. Economics and land use efficiencies of soybean-based cropping systems and nutrient management practices

Treatment	Total cost (×10³ ₹/ha)		Net returns (×10³ ₹/ha)		LUE (%)		PE (kg SEY/ha/day)		PE (₹/ha/day)	
	2011–12	2012–13	2011–12	2012–13	2011–12	2012–13	2011–12	2012–13	2011–12	2012–13
Cropping system										
Soybean–wheat–fallow	40.2	41.4	71.0	86.5	70.7	70.4	20.1	17.8	275	336
Soybean–wheat–mungbean	53.1	54.3	77.7	104.5	89.0	87.7	19.2	14.7	239	326
Soybean–chickpea–fodder sorghum	55.5	55.4	83.1	101.2	89.3	87.7	22.8	20.1	255	316
Soybean–potato–mungbean	89.2	103.9	25.0	103.9	73.4	78.4	23.7	31.4	93	363
SEm±	-	-	0.29	0.43	-	-	-	-	-	-
CD (P=0.05)	-	-	1.01	1.49	-	-	-	-	-	-
Nutrient management										
Control	48.9	51.5	49.5	69.3	81.0	81.0	16.9	15.2	168	234
100% RDF	58.0	65.4	72.6	112.9	81.0	81.0	22.5	23.0	247	382
50% RDF + 50% RDN through FYM	66.1	69.9	65.7	109.4	81.0	81.0	22.9	23.1	223	370
50% RDF + 25% RDN through FYM + biofertilizers	60.4	64.9	67.6	100.5	81.0	81.0	22.2	21.2	230	340
25% RDF + 50% RDN through FYM + biofertilizers	64.2	66.9	65.8	102.9	81.0	81.0	22.6	21.8	224	348
SEm±	-	-	2.30	3.15	-	-	-	-	-	-
CD (P=0.05)	-	-	7.50	10.27	-	-	-	-	-	-

The MSP/market prices of soybean, wheat, potato, chickpea, mungbean and fodder sorghum during 2011–12 and 2012–13 were 16.9, 12.9, 4.5, 28, 35, 1 and 22.4, 13.5, 4.5, 30.0, 44.0, 1 /kg respectively

Table 3. Interaction effect of soybean-based cropping systems and nutrient sources on SEY (t/ha)

Treatment	NS_0	NS_1	NS_2 2011–12	NS_3	NS_4	Mean	NS_0	NS_1	NS_2 2012–13	NS_3	NS_4	Mean
CS_1	4.14	5.49	5.41	5.43	5.45	5.18	3.47	5.00	4.95	4.89	4.62	4.59
CS_2	5.08	6.51	6.59	6.38	6.56	6.22	3.61	5.13	5.08	4.92	4.77	4.70
CS_3	6.04	7.78	8.07	7.54	7.76	7.44	5.26	6.57	7.09	6.38	6.87	6.43
CS_4	4.66	6.74	6.84	6.74	6.79	6.36	5.70	10.54	10.24	8.87	9.58	8.99
Mean	4.98	6.63	6.73	6.52	6.64		4.51	6.81	6.84	6.27	6.46	

	CS	NS	CS×NS	CS	NS	CS×NS
SEm±	0.049	0.144	0.095	0.099	0.093	0.129
CD	0.168	0.469	0.276	0.342	0.303	0.375

returns, whereas highest net returns were obtained under 100% RDF which remained statistically similar to substitution of 50% RDN through FYM during both the years. Integration of FYM also increased the cost of treatment, therefore reduced the system net returns as compared to chemical fertilizers.

Land-use efficiency and production efficiency

Soybean–chickpea–sorghum (F) and soybean–wheat–mungbean systems expressed maximum land-use efficiency (LUE) during both the years (Table 2). These two systems occupied land for almost similar duration, thereby achieved similar LUE. Soybean–wheat–fallow gave the lowest LUE, as no summer crop was grown in this system. The LUE did not differ significantly among different nutrient sources during both the years. Soybean–potato–mungbean system registered the highest production efficiency (PE) based on both SEY and monetary returns during both the years (Table 2). Further, application of 50% RDF + 50% RDN through FYM and 100% RDF through fertilizers recorded highest PE in terms of SEY and monetary returns respectively, during both the years.

System nutrient uptake

Among the cropping systems soybean–chickpea–sorghum (F) recorded the highest total system uptake of N (456.2 kg/ha/annum), P (65.0 kg/ha/annum) and K (324.3 kg/ha/annum), followed by soybean–wheat–mungbean system (Fig. 1). Among the different nutrient management practices application of 50% RDF + 50% RDN through FYM recorded significantly maximum total system uptake of N (354.6 kg/ha/annum), P (52.2 kg/ha/annum) and K (227.5 kg/ha/annum) followed by application of 100% RDF. Higher yield of most of the crops of the system and better availability of nutrients under integrated use of inorganic and FYM resulted in higher uptake of nutrients under this treatment.

Soybean–potato–mungbean cropping system was found to be most productive and remunerative. As responses of system productivity (SEY) varied with nutrient

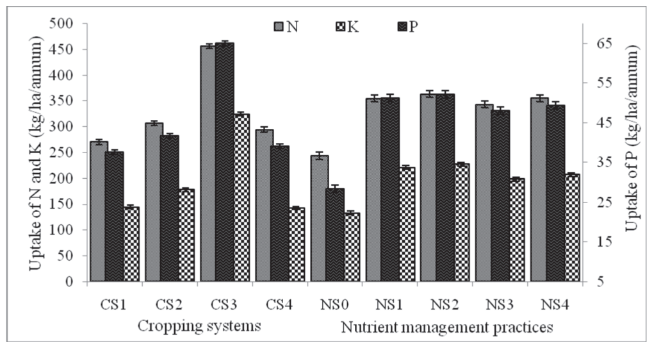

Fig. 1. Effect of cropping systems and nutrient-management practices on mean total system uptake of nutrients/annum

sources among cropping systems, shows scope of optimization of nutrient sources according to needs of crops in the particular system. Crops like wheat and potato can be fertilized with 100 % RDF to get potential yield, whereas in soybean, chickpea, mungbean and sorghum, part of RDF can be substituted with organic manure and biofertilizers, which gives optimum yields, while maintains good soil condition.

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