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Production potential, nutrient uptake, soil fertility and economics of soybean (*Glycine max*) - based cropping systems under organic, chemical and integrated nutrient management practices

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ABSTRACT

A field experiment was conducted during 2004-05 to 2007-08 at Bhopal, Madhya Pradesh, to study the effect of organic, chemical and integrated (50:50) nutrient management (INM) practices on the productivity, nutrient uptake, soil fertility and economics of 4 soybean (*Glycine max* (L.) Merr.) based cropping systems involving *durum* wheat (*Triticum durum* Desf), mustard (*Brassica juncea* L. Czern & Coss.), chickpea (*Cicer arietinum* L) and *isabgol* (*Plantago ovata* Forsk). The productivity of crops in these systems was higher in the integrated nutrient management compared to either chemical fertilizers or organic manures, in all the years. In the first year (2004-05), the organic manure treatment recorded 7.8, 5.6, 9.4, 3.0 and 2.5 % reduction in the productivity of soybean, *durum* wheat, mustard, chickpea and *isabgol* crops, respectively, whereas in the fourth year (2007-08), the productivity of these crops was improved by 11.1, 1.1, 3.0, 4.2 and 11.2 % than chemical fertilizers. Among the treatments, soybean-*durum* wheat cropping system recorded the highest soybean equivalent yield (4.54 t/ha) under integrated nutrient management. Maximum uptake of N, P and K was recorded in integrated nutrient management and soybean-*durum* wheat cropping system. At the end of the 4 cropping cycles, application of organic manures resulted in significantly higher soil organic carbon, available N, P and K than chemical fertilizers but was on par with the integrated nutrient management. Economic returns were the highest in the INM and soybean-*durum* wheat cropping system and they were similar between the treatments receiving organic manures and chemical fertilizers.

Key words: Cropping systems, Intercropping, Nutrient management, Nutrient uptake, Organic farming, Organic manure, Soil fertility, Soybean

Soybean in rainy season (July-October) and wheat during winter season (November-March) is the predominant cropping system in deep vertisols of central India. The productivity of this cropping system depends largely on the judicious and balanced application of nutrients besides the amount of irrigation water available for the wheat crop. Recently macaroni or *durum* wheat, which can be grown successfully with limited number of irrigations, is being recommended in these soils and the prevailing climatic conditions (Behera and Thakur, 1999). Under these conditions, it is also feasible to grow mustard, chickpea and medicinal crops like *isabgol* depending on the availability of water for irrigation and marketing facilities available for the produce.

Of late, there is a growing awareness among the farmers to cultivate crops under organic farming system because of the escalating cost of chemical fertilizers, decreased soil fertility in respect of organic matter, secondary and micronutrients, environmental and health concerns due to pesticides usage and expected premium prices for the organically produced crops (Ramesh *et al*., 2005). One of the important aspects in organic farming that needs attention is the soil fertility management to optimize the productivity of crops/cropping systems. The use of manures from livestock is an important way of recycling or out-turning nutrients to the soil. Organic manures influence soil productivity through their effect on soil physical, chemical and biological properties. The management of manure within a crop rotation can have large effects on yields and crop quality (Stein-Bachinger and Werner, 1997). Generation of information regarding the influence of organic management practices *vis-à-vis* chemical or integrated management practices on the crop/cropping system productivity, soil fertility and economics is important to the farmers and community at large. The present experiment was conducted with an objective to study the effect of organic, chemical and integrated nutrient man-

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agement practices on the productivity, soil fertility and economics in 4 soybean based cropping systems on vertisols of central India.

MATERIALS AND METHODS

A field experiment was conducted during 2004-05 to 2007-08 at the research farm of this Institute on deep vertisols. The soil of the experimental site is clayey in texture (clay 56.8 %, silt 18.0 % and sand 25.2 %) and classified as *Typic Haplustert* having pH 7.9, cation exchange capacity 44.5 c mol (p+)/kg and EC 0.52 dS/m in the top 15 cm of soil. The available soil nitrogen, phosphorus and potassium were 154.2, 12.77 and 530.2 kg /ha, respectively. The organic carbon concentration of the soil was 0.53 %. The field capacity, bulk density and porosity of the surface (0-15 cm) soil were 62 % on volume basis, 1.47 Mg/m^3 and 45 %, respectively.

The treatments tested include 3 nutrient management practices *viz.*, organic manures, chemical fertilizers and integrated (50:50) and 4 cropping systems (soybean-*durum* wheat, soybean-mustard, soybean-chickpea and soybean-*isabgol*) in strip plot design, replicated 4 times. The crop varieties *viz.*, soybean 'JS 335', *durum* wheat 'HI 8498', mustard 'Pusa Bold', chickpea 'JG 74' and *isabgol* 'GI 2' were taken at 45 cm x 5 cm, 22.5 cm x 5 cm, 45 cm x 10 cm, 30 cm x 10 cm and 30 cm x 5 cm spacing, respectively. In organic manure treatment, nutrients were applied through cattle dung manure for soybean crop during rainy season (July-October) and combination of cattle dung manure + vermicompost + poultry manure, $^1/_3$ each for wheat, mustard, chickpea and *isabgol* crops during winter season (November-March). These manures were applied based on the nitrogen equivalent basis and nutrient requirement of each crop. Soybean crop received 3.75 t/ha of cattle dung manure in each season. The quantity of cattle dung manure, vermicompost and poultry manure applied for each season were: 3.33, 2.22 and 1.48 t/ha to *durum* wheat, 2.50, 1.66 and 1.11 t/ha to mustard, 1.25, 0.83 and 0.55 t/ha to chickpea and 0.83, 0.56 and 0.37 t/ha to *isabgol*, respectively. Phosphorus requirement of soybean crop was supplemented through rock phosphate (containing 13.9 % P) addition after adjusting the amount of P supplied through manures. The nutrient composition of cattle dung manure, vermicompost and poultry manure were 0.8-0.4-0.8, 1.2-0.8-0.9 and 1.8-1.6-1.4 % N, P and K, respectively. To control weeds, two-hand weedings were carried out at 30 and 60 days after sowing (DAS) of soybean. Neem oil (*Azadiractin* 0.03 %) was sprayed thrice at 30, 45 and 60 DAS of soybean for the control of leaf eating caterpillars. *Dhaincha* (*Sesbania aculeata*), a green manure crop which was grown as a border crop around the soybean field, controlled the soybean girdle beetle acting as a trap crop. In chemical fertilizer treatment, nutrients were supplied through the chemical fertilizers *viz.*, urea, single superphosphate and muriate of potash and plant protection was through the recommended pesticides as and when required. The recommended dose of fertilizers of soybean, wheat, mustard, chickpea and *isabgol* were 30-26.2-16.6, 80-17.5-33.3, 60-17.5-0, 30-17.5-0 and 20-17.5-0 kg N-P-K/ha, respectively. In integrated nutrient management (INM) treatment, 50 % of nutrients were supplied through organic manures and the other 50 % through chemical fertilizers and plant protection by adopting the integrated pest management (IPM) practices. Soybean and chickpea were inoculated with *Rhizobium* culture and phosphorus solubilizing bacteria (PSB) was used for all crops.

Soybean was sown in the first week of July and harvested in the second week of October. The winter crops (*durum* wheat, mustard, chickpea and *isabgol*) were sown in the second week of November and harvested in the second/third week of March. The calculated doses of organic manures were applied 2 weeks prior to sowing of each crop. The total rainfall received during the rainy season (July-October) was 798, 888, 1,514 and 783 mm during 2004, 2005, 2006 and 2007, respectively. Four irrigations, each of 5 cm depth were given to wheat and *isabgol* crops at pre-sowing, 30, 60 and 90 DAS. Chickpea and mustard crops received two irrigations each at pre-sowing and 30 DAS. The total productivity of the systems were expressed in terms of soybean equivalent yield. The market price of soybean, wheat, mustard, chickpea and isabgol are Rs 15, 8, 16, 16 and 20/kg, respectively. Soil samples (0-15 cm depth) were collected at the end of cropping cycle and analyzed for organic carbon, available N, P and K. Statstical analysis of the data was carried out using standard analysis of variance.

RESULTS AND DISCUSSION

Productivity of crops

In general, the productivity of soybean was less in 2004 and 2006. This was due to deficit rainfall during pod filling stage in 2004 and water-logging due to excess rainfall (1,514 mm) during 2006 causing poor pod setting and smaller seed yields (Table 1). Even though the total rainfall was low (783 mm) in 2007, but its distribution favoured the soybean productivity. On an average, application of organic manures recorded significantly higher number of pods/plant compared to chemical fertilizers but was on par with integrated nutrient management (INM). However, seeds/pod and test weight of soybean was not affected due to nutrient management and cropping systems. During the first year (2004), application of organic manures recorded significantly lower seed yield of soybean which was 7.8 % less than the chemical fertilizers. In the second year (2005), even though nutrient management practices not differed significantly, but organic manure treatment recorded 5.3 % less yield than chemical fertilizers. However, in the subsequent years (2006 and 2007), organic manure treatment recorded significantly higher seed yields which were 10.6 and 11.1 % higher than the chemical fertilizers. The seed yield of soybean between the chemical fertilizers and integrated nutrient management was on par in all the years of study. On an average, organic manure treatment recorded better soybean seed yield which was similar to chemical fertilizers and integrated nutrient management. The seed yield of soybean was not affected significantly among the 4 cropping systems. However, the productivity of soybean was slightly higher where *durum* wheat was the preceding crop. This was due to higher amounts of nutrients applied for the *durum* wheat and the resultant favorable residual effect on the soybean.

During *rabi* season, number of spikes/m row in wheat, siliqua/plant in mustard and pods/plant in chickpea were significantly higher in INM than either organic or chemical fertilizers (Table 2). However, such differences were not observed for other yield attributing characters. Similarly, the productivity of *durum* wheat and mustard were higher in the integrated nutrient management as compared to either organic or chemical fertilizers. Whereas, such differences in the productivity due to nutrient management were not observed in chickpea and *Isabgol*, especially in the initial years (Table 3). Organic manures resulted in the reduction of *durum* wheat yield by 5.6 % in 2004-05 and 2.9 % in 2005-06 but in the third (2006-07) and fourth years (2007-08), it resulted in the similar yield when compared with the chemical fertilizers. Similarly, the mustard yields in organic manure treatment were reduced by 9.4, 9.6 and 0.9 % in 2004-05, 2005-06 and 2006-07, respectively. Whereas, in the fourth year (2007-08), mustard yield was higher by 3.0 % in organic manure treatment than the chemical fertilizers. However, the reduction in the seed yields of chickpea and *isabgol* crops under organic manure treatment were less than 3 % than the chemical fertilizers in the initial years. However, in the fourth year (2007-08), the organic manure treatment resulted in 4.2 and 11.2 % higher seed yield of chickpea and *isabgol*, respectively when compared to the chemical fertilizers.

Since the nutrient release from organic sources is slow (Bharadwaj and Omanwar, 1994), the crops which require higher rates of nitrogen application like wheat and mus-

Table 1. Yield attributes and seed yield of soybean as influenced by nutrient management and cropping system

Treatment	Yield attributes*			Seed yield (kg/ha)				
	Pods/ plant	Seeds/pod	Test weight (g)	2004	2005	2006	2007	Pooled
Nutrient management								
Organic manures	28.3	2.7	100.1	714	1,399	918	1,144	1,044
Fertilizers	26.8	2.6	98.3	775	1,478	830	1,030	1,028
Integrated (50:50)	27.4	2.7	98.6	751	1,437	876	1,090	1,038
SEm±	0.4	0.2	1.4	17	28	24	26	26
CD (P=0.05)	1.2	NS	NS	52	NS	72	78	NS
Cropping system								
Soybean-*durum* wheat	28.2	2.7	97.3	798	1,461	924	1,110	1,114
Soybean-mustard	27.2	2.6	97.7	773	1,496	841	1,042	1,038
Soybean-chickpea	27.1	2.6	99.3	720	1,396	868	1,105	1,022
Soybean-*isabgol*	27.3	2.7	101.6	696	1,398	867	1,094	1,013
SEm±	0.5	0.2	1.6	36	34	28	24	35
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

*Pooled data of 4 years

Table 2. Yield attributes of crops during *rabi* as influenced by nutrient management (pooled data of 4 years)

Nutrient management	*durum* wheat			Mustard			Chickpea			*Isabgol*		
	Spikes /m	Grains/ spike	Test weight (g)	Siliqua/ plant	Seeds/ siliqua	Test weight (g)	Pods/ Plant	Seeds/ pod	Test weight (g)	Spikes/ m	Seeds/ spike	Test weight (g)
Organic manures	69.2	36.7	63.1	173.7	14.4	6.70	88.0	1.32	179.2	405	49.5	1.94
Fertilizers	71.0	37.7	63.4	173.2	14.5	6.71	85.7	1.28	174.3	388	48.2	1.91
Integrated (50:50)	73.9	39.5	64.5	184.6	14.3	6.81	92.5	1.26	186.0	409	49.2	1.92
SEm±	0.8	0.6	0.5	2.8	0.2	0.10	1.4	0.10	4.8	7.6	0.6	0.02
CD (P=0.05)	2.4	NS	NS	8.4	NS	NS	4.2	NS	NS	NS	NS	NS

tard respond better to chemical fertilizers than organic manures especially in the initial years. The nitrogen requirement of chickpea and *isabgol* is low and hence, the differences between the organic and chemical source of nutrients were not conspicuous. Organic nitrogen applied as manure is slowly available over a long period compared to chemical fertilizers. This often limits plant growth due to mismatch between crop nutrient demand and nutrient supply from organic sources, especially during initial phase of conversion from conventional to organic management systems (Pang and Letey, 2000 and Nasholm and Pearson, 2001).

Total productivity

In general, INM recorded the highest system productivity than the organic or chemical fertilizer treatments in all the years of study (Table 4). The reduction in the total productivity under organic manure treatment was 5.8 % in the first year, 4.8 % in the second year whereas in the third and fourth years, it resulted in 3.6 and 6.2 % higher productivity when compared to the chemical fertilizers. Among the four cropping systems, soybean-*durum* wheat recorded the highest total productivity followed by soybean-chickpea, soybean-mustard and soybean-*isabgol* cropping systems. The pooled data of 4 years indicated that the soybean-*durum* wheat cropping system under INM recorded the highest total productivity (soybean equivalent yield) of 4.54 t/ha (Table 5). The differential productivity of these cropping systems was due to the differences in the individual crop performance and the price, they command in the market. The feasibility to adopt these cropping systems depends mainly upon the extent of irrigation water available during the winter season for successful cultivation and marketing facilities for the pro-

Table 3. Productivity of crops (t/ha) during *rabi* as influenced by nutrient management

Nutrient management	2004-05	2005-06	2006-07	2007-08	Mean	2004-05	2005-06	2006-07	2007-08	Mean
			durum wheat					*Mustard*		
Organic manures	4.16 (-5.6)*	4.09 (-2.9)	4.11 (+0.9)	4.91 (+1.1)	4.31	1.47 (-9.4)	1.42 (-9.6)	1.89 (-0.9)	1.94 (+3.0)	1.68
Fertilizers	4.41	4.22	4.07	4.86	4.39	1.62	1.57	1.91	1.89	1.75
Integrated (50:50)	4.93	4.63	4.26	5.16	4.74	1.80	1.64	2.09	2.15	1.92
SEm±	0.12	0.09	0.08	0.10		0.04	0.04	0.05	0.08	
CD (P=0.05)	0.36	0.29	NS	NS		0.13	0.12	0.16	NS	
			Chickpea					*Isabgol*		
Organic manures	1.73 (-3.0)	1.48 (-2.6)	1.72 (-1.7)	1.89 (+4.2)	1.70	1.18 (-2.5)	1.12 (-2.9)	1.22 (+9.4)	1.24 (+11.2)	1.19
Fertilizers	1.79	1.52	1.75	1.81	1.71	1.21	1.16	1.12	1.12	1.15
Integrated (50:50)	1.89	1.57	1.79	2.05	1.83	1.26	1.20	1.23	1.22	1.23
SEm±	0.05	0.03	0.03	0.08		0.03	0.02	0.02	0.02	
CD (P=0.05)	NS	NS	NS	NS		NS	NS	0.05	0.06	

*Per cent reduction/increase compared to the chemical fertilizers.

Table 4. Total system productivity expressed in terms of soybean equivalent yield (t/ha) and economics (Rs/ha/annum)**

Treatment	2004-05	2005-06	2006-07	2007-08	Cost of cultivation	Net returns	B : C ratio
Nutrient management							
Organic manures	2.96 (-5.8)*	3.51 (-4.8)	3.69 (+3.6)	3.45 (+6.2)	21,037	44,307	2.10
Fertilizers	3.15	3.69	3.56	3.25	22,012	44,458	2.01
Integrated (50:50)	3.33	3.77	3.78	3.54	21,525	47,455	2.20
SEm±	0.11	0.07	0.03	0.06			
CD (P=0.05)	0.31	0.20	0.11	0.18			
Cropping system							
Soybean-*durum* wheat	3.79	4.33	4.43	4.34	23,683	56,421	2.38
Soybean-mustard	2.94	3.55	3.56	3.24	20,550	43,318	2.10
Soybean-chickpea	3.12	3.42	3.56	3.50	20,983	44,307	2.11
Soybean-*isabgol*	2.72	3.32	3.16	2.59	20,716	36,402	1.75
SEm±	0.11	0.08	0.06	0.07			
CD (P=0.05)	0.31	0.23	0.19	0.22			

*Per cent reduction/increase compared to the chemical fertilizers; ** Mean of 4 years duce.

Nutrient uptake

The N, P and K uptake of soybean was not affected significantly due to either nutrient management or cropping systems (Table 6). However, the pooled uptake of soybean and *rabi* crops was the highest in INM (188.4, 28.7 and 142.1 kg/ha of N, P and K, respectively). Application of chemical fertilizers recorded significantly higher total uptake of N (181.7 kg/ha) than in organic manure treatment (174.7 kg/ha) but the uptake of P and K was on par between the two treatments. Among the cropping systems, soybean-*durum* wheat recorded the highest uptake of nutrients (226.7, 31.2 and 157.6 kg/ha of N, P and K, respectively) followed by soybean-mustard, soybean-chickpea and soybean-*isabgol* cropping systems.

Soil fertility

Organic manures application resulted in significantly higher soil organic carbon (0.71 %), soil available N (189.5 kg/ha), P (27.66 kg/ha) and K (611 kg/ha) to the chemical fertilizers but was on par with the integrated nutrient management. Among the cropping systems, soybean-*durum* wheat recorded the highest soil organic carbon (0.71 %), available N, P and K (193.2, 33.45 and 624 kg/ha, respectively) followed by soybean-mustard, soybean-chickpea and soybean-*isabgol* cropping systems (Table 6).

The increase in soil organic carbon with the application of organic manures can be attributed to addition of higher biomass to the soil as of crop stubbles and residues especially in cropping systems involving *durum* wheat and mustard where crop biomass is relatively higher than the systems involving chickpea and *isabgol*. Similar results were also reported by Badanur *et al.* (1990) and Tiwari *et al.* (2002). The increase in available P might be due to the organic acids, which were released during microbial decomposition of organic matter which helped in the solubility of native phosphates as a result of which the available P content increased. Applied organic matter leads to the formation of a coating on the sesquioxides and a reduction in the phosphate fixing capacity of soil in manure treated plots. Similar results were reported by Subramanian and Kumarswamy (1989) and Bhardwaj and Omanwar (1994). The higher availability of K may be due to beneficial effect of organic manures on the reduction of potassium fixation; direct effect of addition of K through manures, higher CEC and exchangeable K. Bulluck *et al.* (2002) also reported that K concentration in soil amended with organic wastes increased compared to soils fertilized with chemical fertilizers.

Table 5. Interaction effect of nutrient management and cropping system on system productivity (t/ha)*

Treatment	Soybean-*durum* wheat	Soybean-mustard	Soybean-chickpea	Soybean-*isabgol*	Mean
Organic manures	3.89	3.18	3.35	3.04	3.40
Fertilizers	4.23	3.30	3.25	2.92	3.41
Integrated (50:50)	4.54	3.49	3.57	2.94	3.61
Mean	4.22	3.32	3.40	2.95	
	Nutrient management		Cropping system		Interaction
SEm±	0.05		0.07		0.08
CD (P=0.05)	0.16		0.20		NS

*Pooled data of 4 years.

Table 6. Total uptake of nutrients (soybean and system), soil organic carbon (SOC), available N, P and K of soil at the end of the cropping cycle

Treatment	Total uptake of nutrients (kg/ha/annum)			Soil organic carbon (%)	Soil available nutrients (kg/ha)		
	N	P	K		N	P	K
Nutrient management							
Organic manures	100.7 (174.7)	11.3 (22.6)	72.7 (126.4)	0.71	189.5	27.66	611
Fertilizers	99.2 (181.7)	11.1 (24.9)	71.6 (130.2)	0.55	175.1	20.85	580
Integrated (50:50)	100.2 (188.4)	11.2 (28.7)	72.3 (142.1)	0.67	186.3	24.44	599
SEm±	0.3 (2.0)	0.3 (0.8)	0.6 (1.5)	0.02	3.1	1.40	6
CD (P=0.05)	NS (6.1)	NS (2.4)	NS (4.6)	0.06	9.2	4.09	18
Cropping system							
Soybean-*durum* wheat	107.5 (226.7)	12.1 (31.2)	77.6 (157.6)	0.71	193.2	33.45	624
Soybean-Mustard	100.2 (188.3)	11.3 (24.9)	72.3 (139.4)	0.68	184.3	25.66	598
Soybean-Chickpea	98.6 (165.6)	11.1 (23.5)	71.2 (124.2)	0.62	187.4	20.78	589
Soybean-*Isabgol*	97.7 (145.8)	10.9 (22.2)	70.6 (110.5)	0.57	169.3	17.77	575
SEm±	3.4 (4.7)	0.6 (2.5)	2.4 (3.4)	0.02	4.5	1.61	8
CD (P=0.05)	NS (13.6)	NS (7.4)	NS (9.9)	0.07	13.2	4.73	23
Initial soil fertility				0.53	154.2	12.77	530

*Figures in parenthesis are systems uptake

Economics

Higher net returns and benefit: cost ratio were recorded in the integrated nutrient management practice than either fertilizers or organic manure treatments (Table 4). These economic returns were almost similar between the treatments receiving organic and chemical fertilizers. Since the cost of cultivation was less in the treatment receiving organic manures, the benefit: cost ratio was slightly higher when compared to the chemical fertilizers. Among the cropping systems, soybean-*durum* wheat recorded the highest net return and benefit: cost ratio, even though the cost of cultivation was more. These economic returns were favurable in the order of: soybean-chickpea > soybean-mustard > soybean-*isabgol* cropping systems.

It can be concluded from the study that integrated nutrient management is the best option for higher productivity of soybean-based cropping systems and organic nutrient management gave comparable yields from the third year onwards besides improving soil fertility.

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