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Research Paper

Production potential, soil health and economics of soybean (*Glycine max*)-linseed (*Linum usitatissimum*) cropping system under various nutrient-management protocols

A.B. SINGH[1], B.P. MEENA[2], B.L. LAKARIA[3], J.K. THAKUR[4], K. RAMESH[5], P.S. RAJPUT[6] AND A.K. PATRA[7]

ICAR-Indian Institute of Soil Science, Bhopal, Madhya Pradesh 462 038

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ABSTRACT

The field experiment was conducted during the rainy (*kharif*) season of 2015 to winter (*rabi*) season of 2020–21 at the research farm of the ICAR-Indian Institute of Soil Science, Bhopal, Madhya Pradesh, to investigate the performance of soybean [*Glycine max* (L.) Merr.]-linseed [*Linum usitatissimum* (L.)] cropping sequence and its effect on soil health. The treatments consisted of 6 nutrient- management protocols, *viz*. 100% organic, 75% organic + innovative, 50% organic + 50% inorganic, 75% organic + 25% inorganic, 100% inorganic and state recommendations, laid out in a randomized block design with 4 replications in permanent plots. Soybean cv. 'JS 335' and linseed cv. 'JL 9' were grown with a recommended dose of N : P : K as 30 : 26.2 : 16.6 and 60 : 17.5 : 0 kg/ha respectively. Cattle dung manure (CDM), vermicompost and poultry manures were used to supply nitrogen in organic nutrient-management in 1 : 1 : 1 proportion and chemical fertilizers were applied as per treatments details. In the innovative practice, 10% vermiwash and 10% cow urine were sprayed at 30 and 45 days after sowing (DAS). In integrated nutrient-management, nitrogen (N) was supplied through organic sources and remaining amount of N was broadcasted through chemical fertilizer. The pooled data revealed that, the soybean and linseed yields were 18.5 and 12.7% higher under organic nutrient management than the inorganic practices. The integrated nutrient-management practices (50% organic + 50% organic) also registered 6.7 and 5.1% higher yield of soybean and linseed than the recommended dose of fertilizer application respectively. The organic nutrient-management was reflected as economically viable practice as evident from benefit : cost ratio. The organic nutrient-management also showed significant increase in soil organic carbon (SOC) and soil biological properties. Thus, the results indicated that the organic nutrient-management improved the soil health and increased the crop yield of soybean-linseed cropping system.

***Key words*:** Cattle dung manure, Linseed, Nutrient management, Soybean, Soil health, Yields

Soybean [*Glycine max* (L.) Merr.] is an important oilseed crop and finds an important place in crop rotations of Central India. Soybean fixes atmospheric nitrogen, thus enriches the soil and partially fulfil the nitrogen requirement of succeeding crops for higher productivity (Jaybhay *et al*., 2015). Similarly, linseed (*Linum usitatissimum* L.) occupies the second position among the winter *(rabi)* season oilseed crops next to rapeseed-mustard. It is a valuable crop with high content to linolenic acid and omega-3 fatty acid which has medicinal value. Among the various factors affecting the growth and yield of crops, nutrient management plays an important role in plant growth and development for higher biomass production (Lal *et al*., 2019). India is the second largest consumer of fertilizers in the world, after China. The fertilizer production (N+P) in India accounted 18.5 million tonnes during 2019–20. The fertilizer consumption reached a record growth. The total estimated nutrient consumption (N + P_2O_5 + K_2O) was 29.04 million tonnes during 2019–20 as against 27.23 million tonnes in the previous year recording a growth of 6.7% during 2019–20 (MoAFW, 2019). The fertilizer consumption in India has generally exceeded domestic production in both, nitrogenous and phosphatic fertilizers except, for few years. The entire requirement of potassic fertilizers is met through imports as India does not have commercially viable sources of potash. India imported about 10.49 million tonnes (about 36% of total consumption) of NPK fertilizer nutrients in 2019–20 (MoAFW, 2019). Lack of

[2]**Corresponding author's Email:** bharat.meena@icar.gov.in; bharatmeena24@gmail.com

[1]Principal Scientist and Head, Soil Biology Division, [2,4]Scientists, [3]Principal Scientist, [6]Senior Research Fellow, [7]Director; [5]Principal Scientist, Directorate of Oilseed Research, Hyderabad, Telangana 500 030

availability of chemical fertilizer with rising demand, increases the cost of cultivation of the farmers warrants the search for alternate nutrient-management options, including organic sources. The chemical fertilizers might play an important role to meet nutrient requirement of the crop but their continuous imbalanced use may have deleterious effects on physical, chemical and biological properties of soil which does not support higher yield in long run (Meena *et al.*, 2019a). Judicious application of nutrient especially organic manures not only improves the productivity (Meena *et al.*, 2019b) and quality but also makes cultivation sustainable because it is the basic source of soil organic matter. Soil organic matter plays a pivotal role in several processes of the soil ecosystem including nutrient cycling, soil-structure formation, carbon sequestration, water retention and energy supply to microorganisms (Lal *et al.*, 2019). But changing the conventional farming into organic farming is a challenge because of the setback in crop yields in the initial few years. In this context, integrated nutrient-management (INM) is a great way to push the production and profitability of crops and helps in maintaining the soil healthy. In India, there is sufficient availability of organic manures (million tonnes) like animal dung manure, crop residues, green-manure, rural compost, city compost and biofertilizer (Bhattacharya and Chakraborthy, 2005), and these may become a good source to substitute the chemical fertilizer for nutrient supply to the crops. These organic manures influence soil productivity through their effect on soil physical, chemical and biological properties (Shirale *et al.*, 2017). The improved soil biological activity is also known to play a key role in suppressing pest and disease problems in crops. In the present investigation, an attempt was made to evaluate the different nutrient-management practices with respect to growth and yield attributes of soybean and linseed; and soil health in a Vertisols of central India.

MATERIALS AND METHODS

The field experiment was conducted from rainy *(kharif)* season of 2015 to winter *(rabi)* 2020-21 at the research farm of the ICAR Indian Institute of Soil Science, Bhopal (23° 18" N, 77° 24" E, 485 m above mean sea-level), Madhya Pradesh. The soil of experimental site is clayey in texture (Typic Heplustert), slightly alkaline (*p*H 7.85), non-saline (electrical conductivity 0.32 dS/m) with medium organic carbon content (0.53%). The initial available soil nitrogen, phosphorus and potassium were 154, 12.7 and 530 kg/ha respectively. The experiment consisted of 6 nutrient-management protocols, viz. 100% organic, 75% organic + innovative, 50% organic + 50% inorganic, 75% organic + 25% inorganic, 100% inorganic and state recommendations, were laid out in a randomized block design with 4 replications (plot size 15 m × 6 m). Soybean (cv. 'JS 335') in the rainy season and linseed (cv. 'JL 9') in the winter season were cropped continuously for 5 years, with a recommended dose of 30 : 26.2 : 16.6 and 60: 17.5 : 0 kg/ha (N : P : K) respectively. In the organic nutrient-management practices, nutrients were applied in the form of cattle dung manure (CDM) in soybean crop and one-third each of CDM, vermicompost and poultry manure in linseed crop on nitrogen (N)-equivalent basis. Weeds were managed with manual weeding, while insect-pests were kept below economic threshold level (ETL) using neem oil (0.03%) spray at 30, 45 and 60 days after sowing (DAS) of soybean and linseed for organic nutrient-management treatments. In the innovative treatment, 75% nutrients were supplied through organic manures, while 10% vermiwash and 10% cow urine were sprayed at 30 and 45 days after sowing (DAS). In state recommendations, nutrients were supplied through chemical fertilizers in soybean and linseed crop with a recommended dose of 30 : 26.2 : 20 and 60 : 20 : 20 kg/ha (N : P : K), respectively. In 100% inorganic nutrient management practice, nutrients were also supplied through the chemical fertilizers (urea, single super phosphate and muriate of potash). Trizophos (40% EC) was sprayed to manage the pests as and when required. In integrated nutrient-management practices (50% organic + 50% inorganic and 75% organic + 25% inorganic), nutrients were supplied through organic manures and chemical fertilizers. The yield and yield-attributing parameters of soybean and linseed such as pods/plant, seeds/pod, capsules/plant, seeds/capsule, seed yields, total biomass and test weight were recorded every year. The total biomass and seed yield (kg/ha) were calculated on the basis of total weight of harvested dry matter and seed yield of soybean from the experimental plots. Harvest index was calculated as the ratio of seed yield to above-ground biomass yield.

Soil samples were collected at the end of annual cycle in each year from 0–15 cm depth. The composite soil sample was used for determination of soil properties. Soil organic carbon (SOC) was determined by the Walkley and Black (1934) method. Soil-available N, P and K were determined by standard laboratory protocols. Soil microbial properties were assessed by estimation of dehydrogenase (Casida *et al.*, 1964), fluorescein diacetate (Adam and Duncan, 2001) and phosphatase (Tabatabai and Bremner, 1969) activities in soil. The data were analysed statistically and treatment means were compared using LSD techniques at 5% probability.

RESULTS AND DISCUSSION

Effect of nutrient management on yield attributes and yield of soybean

The yield-attributing parameters of soybean such as pods/plant, seed yield and total biomass were found significantly higher in organic nutrient management over the other nutrient management pratices (Table 1). The highest seed yield was recorded in 100% organic nutrient managerment (1,226 kg/ha), being significantly higher than either 50% organic + 50% inorganic nutrient management (1,104 kg/ha) or 100% inorganic nutrient management (1,035 kg/ha), although 50% organic + 50% inorganic and 100% inorganic nutrient management remained at par. Organic nutrient management ensued significantly higher number of pods/plant and seed yield than inorganic and integrated practices (Shirale *et al.*, 2017). Crop with organic sources showed about 18.5% increase in yield over inorganically managed crop, which might be owing to application of organic sources of nutrients (Jaybhay *et al.,* 2015).

Effect of nutrient management on yield attributes and yield of linseed

Seed yield and total biomass of linseed significantly responded to the nutrient-management practices but yield-attributing parameters of linseed, viz. capsules/plant, seeds/capsule, test weight remained statistically at par. Seed yield (1,602 kg/ha) and total biomass (4,703 kg/ha) under 100% organic nutrient management were significantly higher over integrated (75 % organic + 25 % inorganic, 50% organic + 50% inorganic) and inorganic treatment (100 % inorganic, state recommendation) (Table 1). The yield advantage with the application of organic sources of nutrients was owing to addition of secondary and micronutrients (Meena *et al*., 2013). Jat *et al.* (2012) also confirmed that, vermicompost or farmyard manure resulted in the maximum grain yield owing to their residual effects on the component crops in the cropping system. Meena *et al*. (2019a) also reported that, FYM appeared to play a beneficial role in improving the physical and biological properties of the soil.

Soil pH and electrical conductivity

The mean changes in soil *p*H showed a significant variation among different treatments (Table 2). The changes in *p*H varied from 7.68 to 7.77, being significantly lower *p*H (7.68) in the treatment receiving organic manures. The pH of the soil decreased slightly with the addition of organic manures. A slight decrease in soil *p*H with the addition of FYM has already been reported earlier (Chaudhary *et al*., 1981; Meena *et al.,* 2019; Oueriemmi *et al*., 2021). Such decrease might be explained by the production of H^+ ions and subsequently release of H^+ ions in the soil solution resulting from the heavy application of organic manures to the soil (Shirale *et al*., 2018). The electrical conductivity of soil found statistically at par with respect to the nutrient management.

Soil organic carbon

The result indicated that, manure application increased the soil organic carbon content of soils (Table 2). Soil organic carbon (SOC) increased with the application of organic manures (0.93%) compared to inorganic nutrient-management practice (0.63%). The SOC was higher in organic and integrated nutrient-management practices, which is attributed to more amount of carbon entering in to soil through organic manure addition. Panwar *et al*. (2010) and Lakaria *et al*. (2012) reported that, the regular organic additions (manures and root biomass) have the largest effect in soil organic carbon. Adekiya *et al.* (2018) reported increased SOC content in organic and/or integrated management systems compared to chemical management practice. Organic management practice plays as a key for soil restoration to maximize the retention and recycling of organic matter and plant nutrients.

Soil-available nitrogen, phosphorus and potassium

Soil-available N did not found significantly across the treatments, whereas available P and K were found

Table 1. Performance of soybean and linseed under various nutrient management (pooled data of 5 years; 2015–20) practices

Treatment	Soybean					Linseed				
	Pods/ plant	Seeds/ pod	Test weight (g)	Total biomass (kg/ha)	Seed yield (kg/ha)	Capsules/ plant	Seeds/ capsule	Test weight (g)	Total biomass (kg/ha)	Seed yield (kg/ha)
100% organic	44.8	3.6	11.1	3,825	1,226	99.8	9.2	7.0	4,703	1,602
75% organic + innovative	42.0	3.3	11.0	3,660	1,168	94.5	8.9	6.9	4,383	1,531
50% organic + 50% inorganic	41.0	3.4	10.9	3,535	1,104	93.1	8.7	6.9	4,246	1,494
75% organic + 25% inorganic	43.3	3.2	10.9	3,720	1,181	96.1	9.1	7.0	4,616	1,585
100% inorganic	36.8	3.0	10.7	3,321	1,035	86.5	8.4	6.8	3,782	1,422
State recommendation	37.6	3.2	10.8	3,380	1,048	87.3	8.5	6.9	3,856	1,406
SEm±	1.6	0.14	0.42	110	35	2.9	0.28	0.22	199	46
CD (P=0.05)	4.9	NS	NS	333	106	8.6	NS	NS	600	139

Table 2. Effect of nutrient management on soil properties

Treatment	*p*H	Electrical conductivity (dS/cm)	Soil organic carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
100% organic	7.68	0.20	0.93	227.0	94.0	603.1
75% organic + innovative	7.71	0.20	0.91	205.4	87.2	596.5
50% organic + 50% inorganic	7.72	0.21	0.79	216.0	77.8	571.4
75% organic + 25% inorganic	7.70	0.20	0.80	217.6	80.3	611.7
100% inorganic	7.77	0.23	0.63	202.3	58.7	556.3
State recommendation	7.75	0.22	0.63	203.1	40.6	556.0
SEm±	0.23	0.01	0.03	6.30	2.50	13.6
CD (P=0.05)	NS	NS	0.07	NS	7.7	42.0

significantly higher in organic nutrient-management practice than either inorganic or integrated management practice (Table 2). The available phosphorus in the soil was significantly lower in the treatments that received inorganic source of nutrient alone (58 kg/ha) as compared to the 100% organic (94 kg/ha) management practices. The lower value of soil-available P in inorganic management was mainly attributed to lack of addition of organic matter and thereby depletion of native pool of available P by plants which was mineralized by the build-up of microflora. The increase in available P in organic treatment might be owing to the organic acids, which were released during microbial decomposition of organic matter, which helped in the solubility of native phosphate (Meena *et al.*, 2020). Adekiya *et al.* (2020) also confirmed that, the organic system improved the soil fertility in terms of organic matter content and available N, P, K, Ca and Mg contents of the soil (Shirale *et al.*, 2018). The available K was higher in organic management practice (603 kg/ha) than inorganic management practice (556 kg/ha). Majumdar *et al.* (2005) also observed that, K concentration in soil amended with organic wastes increased compared to soils supplied with chemical fertilizers. The beneficial effect of organic matter on available K mainly attributed to the release of K to organic colloids with greater cation-exchange sites that attract K from the non-exchangeable pool and applied K, which ultimately favoured the available K (Shirale *et al.*, 2018). Panwar *et al.* (2010) reported higher soil-available N, P and K in the plots receiving cattle dung manure applied on nitrogen-equivalent basis.

Nutritional quality parameters of soybean

Different sources of nutrient application did not significantly influence the nutritional quality constituents such as protein, oil and methionine determined in soybean seeds. However, the higher values of protein, oil and methionine were recorded in 100% organic treatment than others (Table 3). In contrast, Adekiya *et al.* (2020) reported significant improvement in quality parameters of soybean and wheat upon organic application as compared to the chemical fertilizers. This might be owing to the supply of all growth-promoting substances, like enzymes, hormones, growth-regulators etc. besides all the essential plant nutrients from the manures (Walia and Patidar 2021; Meena *et al.*, 2021). Also, this might have been instrumental in effective regulation of the metabolic functions leading to better synthesis of proximate constituents and consequent improvement in the crop quality.

Soil-enzyme activity

Biological activities, i.e. fluorescein diacetate (FDA), dehydrogenase (DHA) and alkaline phosphatase, were determined in soil as influenced by different nutrient-management practices. All the 3 enzyme activities were higher in 100% organic nutrient management, followed by integrated and inorganic nutrient management (Fig. 1). The FDA,

Table 3. Seed quality of soybean under various nutrient-management practices

Treatment	Protein (%)	Oil (%)	Methionine (g/16 g N)
100% organic	35.96	18.26	1.73
75% organic + innovative	35.64	18.11	1.71
50% organic + 50% inorganic	35.42	18.09	1.69
75% organic + 25% inorganic	35.79	18.19	1.70
100% inorganic	35.12	18.00	1.66
State recommendation	35.06	17.96	1.67
SEm±	1.3	0.47	0.04
CD (P=0.05)	NS	NS	NS

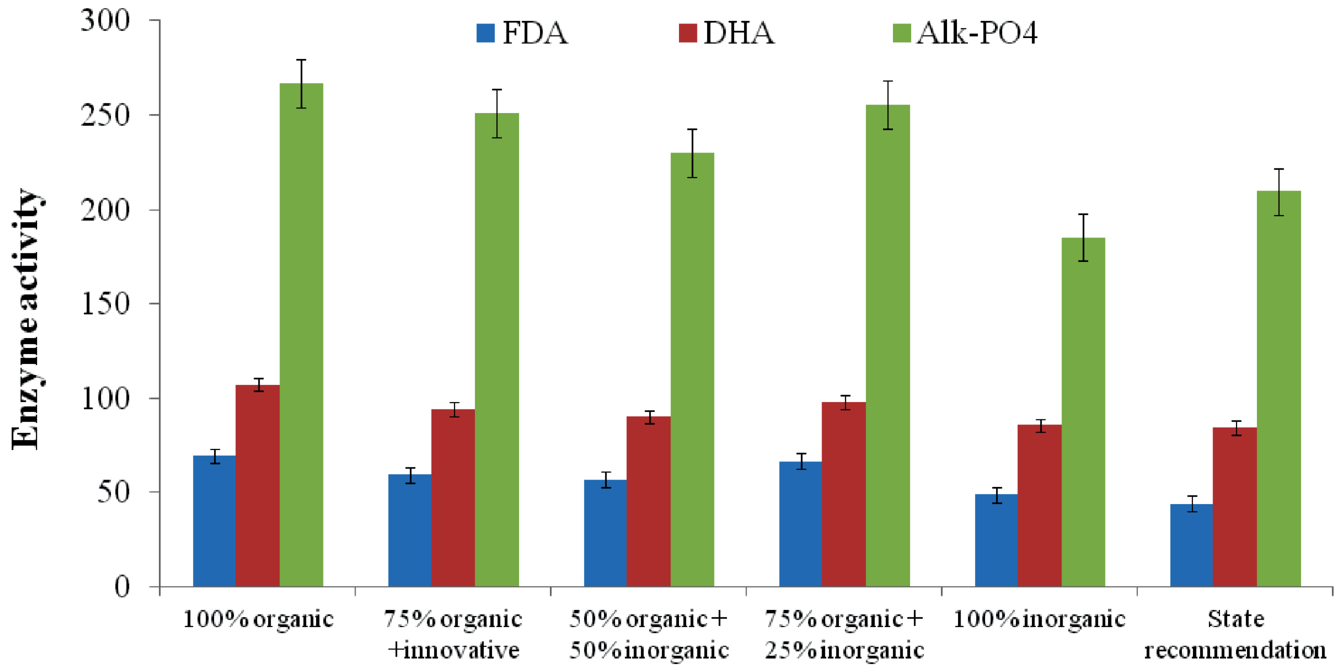

Fig. 1. Effect of nutrient management on soil-enzyme activity (FDA in µg fluorescein/g/soil/h; DHA in µg TPF/g soil/day; Alk-PO_4 in µg PNP/g soil/h; CD (≤P=0.05): FDA-6; DHA-11; Alk-PO_4-25; Error bars indicate Standard Error of Mean-SEm)

DHA and alkaline phosphatase activity in soil were found in the range of 44.4–69.4 µg fluorescein/g soil/h, 84.51–107.1 µg TPF/g soil/day and 185.4–267 µg PNP/g soil/h respectively. These enzymes followed the trend organic 100% organic >75% organic + 25% inorganic >75% organic + innovative >50% organic + 50% inorganic >100% inorganic > state recommendation. Bowles *et al.,* (2014) also reported the higher enzyme activities under organic nutrient management. Soil-enzyme activity is an indirect indication of the activities of microbes which is directly correlated with soil microbial dynamics. Enzyme activity in the soil environment is considered to be a major contributor of overall soil microbial activity (Meena *et al*., 2019a). The enzyme activity in the soil is directly related to the soil microbial population and soil organic carbon (Lal *et al*., 2019). Lower enzyme activities in inorganic and state recommendation soil might be due to inadequate or lower levels of organic carbon compared to the other treatments and also possibly dues to reduced *p*H because of ammonium-based fertilizers. The addition of organic substances to the soil served as a carbon source that enhanced microbial biomass and enzyme activity (Antonious *et al*., 2020). The higher enzyme activities in soil enhanced the nutrient mineralization as evident from soil- nutrient values (Table 3).

Economic returns

Considering the soybean-based cropping system as an annual cycle, organic management recorded higher gross returns of (₹129,339), higher net returns (₹75,568) and higher benefit: cost ratio (2.4) as compared to chemical treatment (Table 4).

This was owing to higher soybean as well as soybean-equivalent yield and reduced cost of cultivation in organic as compared to the other management systems. Ramesh

Table 4. Economics of soybean-linseed cropping system under various nutrient-management practices

Treatment	Productivity in terms of SEY (kg/ha)			Gross returns (₹/ha)	Cost of cultivate on (₹/ha)	Net returns (₹/ha)	Benefit: cost ratio
	Rainy season	Winter season	Total				
100% organic	1,226	2,222	3,448	129,319	53,751	75,568	2.4
75% organic + innovative	1,168	2,123	3,291	123,408	52,779	70,629	2.3
50% organic + 50% inorganic	1,104	2,072	3,176	95,275	52,734	42,541	1.8
75% organic + 25% inorganic	1,181	2,226	3,407	102,221	53,861	48,361	1.9
100% inorganic	1,058	1,972	3,029	90,884	51,596	39,288	1.8
State recommendation	1,063	1,950	3,013	90,400	51,862	38,538	1.7

SEY, Soybean-equivalent yield

et al. (2010) also found highest gross returns, net returns and benefit: cost (B : C) ratio (2.22) with combined application of cattle dung manure + vermicompost + poultry manure as compared to either chemical fertilizers or the control under soybean –wheat cropping system in Vertisols. Similarly, Ram *et al.* (2013) and Ransing and Tomar (2019) documented better economics of different crops with the application of organic manures either alone or in combination with chemical fertilizers than chemical fertilizers alone. The B : C ratio of organic nutrient management was significantly higher which is attributed to higher gross returns and lower cost of cultivation (Table 4).

It was concluded that yield, yield attributes of soybean and linseed responded positively to organic nutrient-management practice. Seed yield and total biomass were significantly higher in organic nutrient-management as compared to intigrated and inorganic nutrient-management practices. Organic farming systems improved the soil fertility by enhancing soil biological activities and increasing the plant-available nutrients in soil.

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