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Shrila Das
Indian Agricultural Research Institute

Ruma Das
Indian Agricultural Research Institute

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Long term impact of nutrient management options on yield, and nutrient uptake by soybean and soil properties under soybean (*Glycine max*) - wheat (*Triticum aestivum*) cropping system in the Indian Himalayas

SHRILA DAS[1], N KUMAR[2], RUMA DAS[3] and KAUSTAV ADITYA[4]

Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263 145

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ABSTRACT

Long term effect of nutrient management practices in wheat (*Triticum aestivum* L.) -soybean [*Glycine max* (L.) Merr.] cropping system were monitored after 7 years on the changes of different chemical and microbiological properties of soil (Mollisols) at Norman E Borloug Crop Research Centre, Pantnagar, Uttarakhand (Himalayan region, India). The experiment was laid out in a randomized block design with four nutrient management options with four replications with soybean variety PS 1347. Results recorded that the integrated use of organic and inorganic sources of nutrients (50% organic + 50% inorganic) showed highest grain (1.81 t/ha) and straw (3.11 t/ha) yield, and N (121.61 and 58.12 kg/ha) and P (11.85 and 13.83 kg/ha) uptake in grain and straw, respectively when compared with rest of the treatments (100% organic treatment, 100% inorganic treatment and INM (Integrated Nutrient Management) + IPM (Integrated Pest Management). The treatment 50% organic + 50% inorganic sources of nutrient also showed 56.4% significantly higher nodule number than with 100% organic treatment at 60 DAS (days after sowing) which recorded lowest nodule number (24.6/plant). Though, INM + IPM treatment was better than 100% organic treatment with respect to nodulation, yield, nutrient concentration and uptake, but microbial biomass and dehydrogenase activity were significantly higher in 100% organic treatment than the other treatments. Therefore, 50% organic + 50% inorganic treatment was found best for most of the symbiotic, plant growth and yield parameters of soybean possibly by saving water, energy and nutrient resources which would help in maintaining the sustainability of the production system over the years.

Key words: Grain yield, Integrated nutrient management, Microbial biomass carbon, Nodulation, Soybean

Intensive agriculture with very high nutrient turnover in soil plant system coupled with indiscriminate and imbalanced use of chemical fertilizers results in deterioration of native soil fertility and poses a serious threat to mankind for maintaining long term sustainability of crop production. Therefore, an integrated approach of using chemical, organic and biological sources of nutrients and their management has shown promise in sustaining productivity and better soil health (Zerihun and Haile 2017). The research related to Integrated Nutrient Management (INM) techniques in cereal crops has been gaining importance because most of the Indian farmers are benefitted with the adaption of these techniques throughout the country. In agricultural ecosystem, nodulated legumes are undoubtedly prominent nitrogen fixers. Among legumes, soybean [*Glycine max* (L.) Merrill] is considered to be a 'Wonder legume' as it augments protein and oil to human diet. The importance of soybean in Indian agriculture to narrow down oil and protein gap in diet has now been well recognized. Moreover, soybean crop has the ability to fix N through symbiosis (Revellin *et al*. 2018) which gets reduced at seed development stage when the requirement of N is maximum. It is well documented that organic manures are good complimentary sources of nutrients and improve the efficiency of the applied nutrients on one hand and also improve soil physical and biological properties on the other hand (Singh and Ryan 2015). Hence, the INM is need of the hour to increase the productivity in a sustainable manner by maintaining the soil health. Moreover, soil and crop management practices that utilize organic amendments, such as animal and crop residues have the potential to increase the organic carbon and microbial activities in the soil besides increasing crop productivity and sustainability. The productivity of soybean can be increased by inoculation with bio-agents such as *Rhizobium japonicum* and phosphate solubilising bacteria (PSB). Co-inoculation of these bio-cultures has shown encouraging results in improving the crop productivity and

[1] Scientist (e mail: shrila34040@gmail.com), [3]Scientist (e mail: rumadas13@gmail.com), SSAC, ICAR-Indian Agricultural Research Institute, Pusa, New Delhi 110 012. [2]Professor (e mail: nk5278@rediffmail.com), Department of Soil Science, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263 145. [4]Scientist (e mail: katu4493@gmail.com), Division of Sample Survey, ICAR-Indian Agricultural Statistics Research Institute, Pusa, New Delhi 110 012.

sustaining soil fertility (Bhardwaj *et al*. 2014). Therefore, an experiment was conducted to study the effect of different nutrient management practices on the growth and yield of soybean in relation to soil properties.

MATERIALS AND METHODS

The field experiment was initiated at the Norman E. Borloug Crop Research Centre, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, District Udham Singh Nagar, Uttarakhand in 2002. The centre is located in the *Tarai* region of Uttarakhand foothills of Shiwalik range of Himalayas. Geographically it lies between 28°52′ to 29°25′ N latitude, 75^0 58′ to 79^0 42′ E longitude and at an altitude of 243.8 m above the mean sea level. The soil of the experimental field was silty clay loam in texture. The experimental soil was alkaline in nature with pH 7.71, electrical conductivity of 0.29 dS/m, medium in organic carbon and low in available nitrogen, medium in phosphorus and potassium content.

The treatments comprised four nutrient management options, which are given below.

Organic (100%): FYM @ 10 t/ha + remaining quantity of P_2O_5 through rock phosphate, inoculation with *Bradyrhizobium japonicum* and PSB. Seed treatment with *Trichoderma harzianum* + *Pseudomonas fluorescens* @ 5 g/kg seed.

Inorganic (100%): A uniform basal dose of N (20 kg/ha), P (60 kg P_2O_5/ha) and K (40 kg/ha) was applied through urea, single super phosphate (SSP) and muriate of potash (MOP), respectively prior to sowing without inoculation.

Organic (50%) + Inorganic (50%): FYM @ 5 t/ha and rock phosphate + 50% of Recommended Dose of Fertilizers (RDF), inoculation with *Bradyrhizobium japonicum* and PSB. Seed treatment with *Trichoderma harzianum* + *Pseudomonas fluorescens* @ 5 g/kg seed. Weed control through pre-emergence herbicide Lasso @ 0.2% + 1 hand weeding at 25-30 DAS and plant protection measures through IPM (Integrated Pest Management) practices.

INM+IPM: In Integrated Nutrient Management (INM), recommended dose of fertilizers (60%) + organic sources of nutrients through FYM (40%) were applied. In case of Integrated Pest Management (IPM), one spray of trizophos @ 0.15% and remaining through *Trichoderma harzianum* + *Pseudomonas fluorescens* @ 5 g/kg seed.

The experiment was conducted with soybean variety PS 1347 in a randomized block design with four replications. The soybean crop was harvested in December. Plants nodulation and plant biomass were recorded at 30, 60 and 90 days after sowing and yield at after harvest respectively from each treatments. Nitrogen content in straw and grain of soybean was estimated after fine grinding (40 mesh) in a mechanical grinder and digestion of 0.2 g sample with concentrated H_2SO_4 by Micro – Kjeldahl method as described by Page (1982) and concentration of phosphorus in straw and grain of soybean was determined by molybdovandate phosphoric acid yellow colour method after wet digestion in tri-acid (Page *et al*. 1982). The uptake of nutrient by plant and grain was computed as described below:

Nutrient uptake in straw (t/ha) = Straw yield (t/ha) × Nutrient content (%) × 10

Nutrient uptake in grain (t/ha) = Grain yield (t/ha) × Nutrient content (%) × 10

Collected soil samples after crop harvest were processed and analysed for bulk density and it was determined by drawing samples by core sampler (Black and Hartge 1971). The organic carbon was determined by $K_2Cr_2O_7$ oxidizing method of Walkley and Black (1934), available N was determined by alkaline potassium permanganate method (Subbiah and Asija 1956). Available P was extracted from soil with 0.5 M $NaHCO_3$ (pH 8.5) as described by Olsen *et al*. (1954) and available potassium by ammonium acetate method (Hanway and Heidal 1952). Pour plate serial dilution method (Subba Rao 1986) was used for estimating the population of soil rhizobia, total bacteria, fungi and phosphate solubilising bacteria (PSB). Microbial biomass in soil was determined in terms of biomass carbon according to the fumigation extraction method (Vance *et al*. 1987). Dehydrogenase activity in soil was measured using colorimetric procedure of Tabatabai (1994). Collected data were analysed through analysis of variance (ANOVA). Duncan's multiple range test was used as a post hoc mean separation test ($P< 0.05$) using SPSS.

RESULTS AND DISCUSSION

Nodulation

Different treatments significantly influenced the nodule number/plant only at 60 DAS and the highest nodule number (38.5/plant) was recorded with 50% organic + 50% inorganic treatment. This treatment showed 56.4% higher nodule number than with 100% organic treatment which recorded lowest nodule number of 24.6/plant (Table 1) though, the numbers of nodules did not vary significantly with inorganic (100%) and INM+IPM treatments. The overall nodule number increased up to 60 DAS then it declined subsequently. Although the treatments did not varied significantly with each other for nodule number, but 50% organic + 50% inorganic treatment showed highest nodule number/plant when compared with the rest of treatments at 30 and 90 DAS. This treatment also registered 10.93 and 12.44% higher nodule number/plant in comparison to 100% inorganic treatment at 30 and 90 DAS respectively. 50% organic + 50% inorganic treatment also recorded 38.33 and 23.36% more nodules/plant over INM + IPM treatment, respectively at 30 and 90 DAS.

The nodule dry weight was affected significantly with different treatments at 30 and 60 DAS, however, there was not any significant difference at 90 DAS (Table 1). The highest nodule dry weight was recorded with 50% organic + 50% inorganic treatment at all the three stages, whereas 100% organic treatment showed the lowest nodule dry weight. At 30 DAS, 50% organic + 50% inorganic treatment gave 28.80% and at 60 DAS, 25.30% significantly higher nodule dry weight than 100% organic

Table 1 Effect of nutrient management on nodule number, nodule dry weight and plant dry weight of soybean

Treatment	Nodule number/plant			Nodule dry weight (mg/plant)			Plant dry weight (g/plant)			Grain yield (t/ha)	Straw yield (t/ha)
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS		
Organic (100%)	11.37[a*]	24.62[b]	15.50[a]	62.50[b]	136.87[b]	89.37[a]	3.90[b]	17.49[a]	31.97[b]	0.88[b]	1.77[b]
Inorganic (100%)	12.62[a]	27.87[ab]	19.12[a]	67.62[ab]	147.50[ab]	101.00[a]	3.96[b]	18.01[a]	34.39[ab]	1.34[ab]	2.30[b]
Organic (50%) + Inorganic (50%)	14.00[a]	38.50[a]	21.50[a]	80.50[a]	171.50[a]	162.00[a]	5.16[a]	21.28[a]	40.94[a]	1.81[a]	3.11[a]
INM+IPM	10.12[a]	35.37[ab]	17.12[a]	65.62[ab]	143.50[ab]	111.37[a]	4.69[a]	18.99[a]	36.16[ab]	1.07[b]	2.12[b]

*Means followed by the same lower case letter within a parameter indicate that they are not significantly different ($P<0.05$).

treatments, respectively while 100% inorganic and INM + IPM treatments were at par in both the cases. 50% organic + 50% inorganic treatment also showed significant increase of 22.67 and 19.51% in nodule dry weight in comparison to INM + IPM treatment at 30 DAS and 60 DAS, respectively while at 90 DAS, the non-significant increase in nodule dry weight was 45.46%.

The maximum number of nodules was recorded in the treatment with 50% organic + 50% inorganic might possibly be due to increased bradyrhizobia growth and activity in soil because of more availability of nutrients which also helped in growth of plant and nodule development on roots. The decrease in nodule number at 90 DAS was due to nodule senescence with the decreasing nodule number and nodule size. Shiva Kumar and Ahlawat (2008) found the beneficial effect of integrated nutrient management along with biofertilizers on nodulation of soybean. They concluded that improved soil fertility and microflora activity in the rhizosphere with the application of organic sources of nutrients and recommended dose of fertilizers (RDF) resulted in improved nodulation in soybean plant. This finding corroborates with Sharma *et al*. (2018). The findings of their two years of experiment on soybean alluded that application of Vermicompost @ 1.5 t/ha enriched with PSB and *Rhizobium* + Remaining of RDF through chemical fertilizer recorded significantly higher number of root nodules, dry weight of root nodules and grain and stover yield.

Plant biomass

Plant dry weight varied significantly under different treatments at 30 and 90 DAS, whereas there was not any significant difference among the treatments at 60 DAS interval. The values of plant dry weight ranged from 3.90 to 5.16, 17.49 to 21.28 and 31.97 to 40.94 g/plant at 30, 60 and 90 DAS, respectively (Table 1). There was not any significant effect between the 100% organic and 100% inorganic treatments for plant dry weight at 30 and 60 DAS, whereas the treatment with INM + IPM showed 20.3 and 13.1% higher plant dry weight than 100% organic treatment at 30 and 90 DAS, respectively. 50% organic + 50% inorganic treatment showed highest plant dry weight at all the stages. This treatment also showed significant increase of 32.30 and 28.05% in plant dry weight over 100% organic treatment at 30 and 90 DAS respectively. Highest plant dry weight was observed in 50% organic + 50% inorganic treatment at all the stages. This finding corroborates with More *et al*. (2008) who concluded that optimum supply and availability of nutrients through inorganic and organic sources helped in better uptake of nutrients resulting into more synthesis of nucleic and amino acids, amide substances in growing region and meristematic tissue ultimately enhancing cell division and thereby increased growth of soybean plants. This is in conformity with the findings of Singh *et al*. (2016, 2017).

Yield

Grain yield (kg/ha) of soybean showed significant response to nutrient management (Table 1). The highest grain yield of 1.81 t/ha was obtained from 50% organic + 50% inorganic treatment which was significantly more than all other treatments. The lowest grain yield (0.88 t/ha) was given by 100% organic treatment. The magnitude of increase was 47.48% in 100% inorganic treatment followed by 21.38% in INM + IPM treatment over the 100% organic treatment. The maximum straw yield of 3.11 t/ha was obtained from 50% organic + 50% inorganic treatment which was significantly more than all other treatments (Table 1). This treatment also showed 76.05 and 36.87% significantly higher straw yield when compared with 100% organic and 100% inorganic treatments, respectively. 100% inorganic and INM + IPM treatments gave 28.62 and 20.12% higher straw yield than 100% organic treatment, respectively. In case of yield, the treatment supplied balanced amount of nutrients to plant favourably increased the grain as well as straw yields. Similar findings were documented by More *et al*. (2008) who reported that the increase in grain yield of soybean could be attributed to cumulative effect of better growth that produced more number of pods and more grain yield/plant which ultimately increased the seed yield per hectare. Besides, co-inoculation of biofertilizers produced heavier seeds, which might be accorded to the better translocation of photosynthates. Whereas, in 100% organic treatment the nutrient release was slow in comparison to 100% inorganic treatment. That's why yield was more in 100% inorganic treatment due to more availability of nutrients. The higher straw yield due to inorganic and in combination with organic sources along with biofertilizer might be due to sustained nutrient supply and also as a result of better utilization of applied nutrient through improved microbial activity that involved in nutrient transformation and fixation. These findings were in corroboration with Singh *et al*. (2017) who observed that application of FYM + vermicompost in combination with inorganic fertilizers showed synergistic effect in the growth as well as yield attributes of soybean crop.

Nutrient uptake

The highest uptake of N (121.61 kg/ha) by grain was recorded in the treatment with 50% organic + 50% inorganic, being significantly higher than all other treatments (Fig 1). 100% inorganic treatment showed 53.12% significantly higher uptake than 100% organic treatment. The 50% organic + 50% inorganic treatment accounted for 129.10 and 49.62% significantly higher grain N uptake than 100% organic and 100% inorganic treatments, respectively. This treatment also recorded 73.70% significantly higher grain N uptake in comparison to INM + IPM treatment. The highest N uptake by straw of 58.12 kg/ha was registered by 50% organic + 50% inorganic treatment which was significantly higher than all other treatments. This treatment also gave 171.46 and 96.95% more straw N uptake, respectively, over 100% organic and 100% inorganic treatments. The N uptake by straw was 37.83% significantly more in 100% inorganic treatment over 100% organic treatment. 100% inorganic treatment and INM + IPM treatments were comparable with each other both in grain and straw N uptake.

The P uptake by grain was significantly affected by the given treatments (Fig 2). 50% organic + 50% inorganic treatment showed highest P uptake of 11.85 kg/ha by grain which was significantly more than all other treatments. 100% inorganic and INM + IPM treatments gave significantly 74.65 and 52.28% respectively, more uptake of P by grain than 100% organic treatment. The highest P uptake (13.83 kg/ha) by straw was recorded in 50% organic + 50% inorganic treatment which was significantly 126.72, 60.81 and 57.33% more than 100% organic, 100% inorganic and INM + IPM treatment, respectively. 100% inorganic treatment showed 40.98% significantly higher straw P uptake in comparison to 100% organic treatment. INM + IPM treatment did not differ significantly with 100% inorganic treatment but registered 44.09% significantly more P uptake by straw than 100% organic treatment.

The highest N uptake in grain and straw in 50% organic + 50% inorganic treatment was possibly due to more availability of N to plant which was translocated to straw and grain. It might also be due to the addition of organic manure along with biofertilizer and application of recommended dose of NPK and formation of more nodules by rhizobia which fixed more nitrogen in plant so, nitrogen concentration in plant has increased. The results were also in agreement with the findings of Kumar (2002) who found that application of enriched compost increased nitrogen in straw and grain. The increase in P uptake in grain and straw might be due to increase in available P by the fertilizers application and further addition of FYM increased microbial population in soil which produced organic acids and increased available P in soil. Similar results were obtained by Singh and Rai (2004). The treatment having 100% inorganic showed 53.12% significantly higher uptake than 100% organic treatment due to more availability of N and more uptake by plant which was translocated to grain. The increased uptake of N by grain was due to more availability and translocation of N in grain by increasing plant growth. This was possibly due to improvement in physico-chemical properties of soil along with increased mineralization of nutrients which resulted in the more nutrients uptake. The increased uptake of P by straw and grain was due to more availability of P and more uptake by plant and translocated to grain by increasing plant growth. Similar results

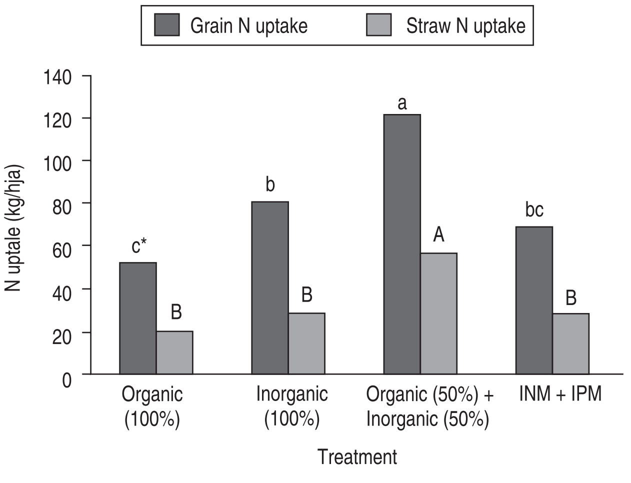

Fig 1 Effect of nutrient management on N uptake (kg/ha) in grain and straw of soybean.

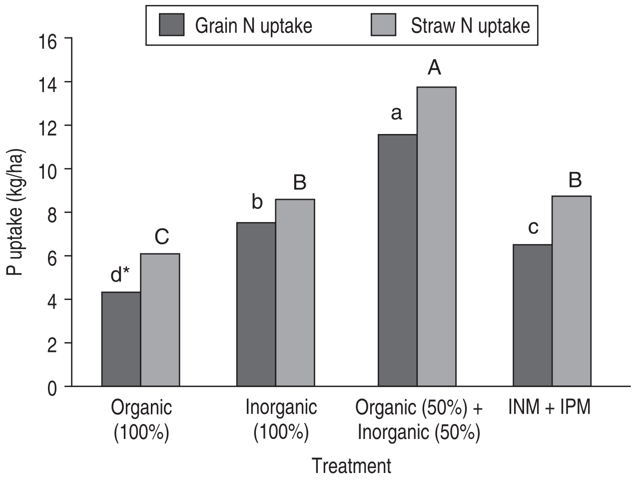

Fig 2 Effect of nutrient management on P uptake (kg/ha) in grain and straw of soybean.

were obtained by Singh and Rai (2004) who reported that the highest P uptake was obtained in the treatment receiving combined application of NPK fertilizers, FYM, biofertilizers and crop residues. This could be explained on the basis of better availability of phosphorus in crop-root zone resulting from its solubilization caused by the organic acids produced from decaying organic matter and also the increased uptake by the soybean roots. Therefore, in 50% organic + 50% inorganic treatment, the combined application of chemical fertilizers along with enough bulk of FYM has always stimulated the uptake of nutrients and partly by because of stimulated microbes flush and improved root growth due to congenial soil physical, chemical and biological condition. Apart from that application of N fixing biofertilizers enhances the soil N and PSM produces the organic acids which may partly by responsible for quick release of nutrients which resulted into more content of nutrients in grain as well as in straw. Thus, improvement in uptake of N and P might be attributed to their respective higher concentration in grain and straw and associated with higher grain and straw yields. The results of present investigation are also in close agreement with the findings of Tatpurkar *et al*. (2014) and Vallabh *et al*. (2015).

Soil properties

The organic carbon in soil was significantly affected by the given treatments, ranged from 0.62 to 0.71% (Table 2). The lowest organic carbon was found in 100% inorganic treatment, while the treatment with 50% organic + 50% inorganic recorded highest organic carbon. Organic carbon in soil was higher in the treatments which contained organic matter in comparison to 100% inorganic treatment. In case of soil organic carbon, our findings were in agreement with the findings of Sharma *et al*. (2015), and it was attributed to addition of more biomass. Similar results were obtained by Singh and Rai (2004) who reported that the organic carbon content (%) showed increasing trend with the integration of inorganic fertilizers with the organic sources.

The given treatments showed significant affect on soil bulk density (Table 2). 100% inorganic treatment recorded the highest bulk density of 1.42 Mg/m^3 which was significantly more than 100% organic treatment. 100% inorganic treatment also showed 3.65% higher bulk density over 50% organic + 50% inorganic treatment. The treatment having INM +IPM also was statistically at par with other treatments. The bulk density of soil decreased with the addition of organic matter when compared with 100% inorganic treatment, because incorporated organic matter made soil more porous while the soil without organic matter became compact. The results were also in agreement with Singh and Rai (2004).

Available nutrients

The perusal of the data indicated that available N in soil was significantly affected by given treatments (Table 2). 50% organic + 50% inorganic treatment showed the highest available N (286.94 kg/ha) in soil. This treatment recorded 13.11% significantly more N than 100% inorganic treatment. 100% organic treatment gave 4.46% more N in soil in comparison to 100% inorganic treatment. Available nitrogen was more in integrated treatments as compared to organic treatments (Yaduvanshi *et al*. 2013). It might be due to fact that integration of organic and chemical fertilizer has increased the mineralization owing to narrow C/N ratio as compared to organic treatments. In chemical fertilizers, applied treatment low available nitrogen is owing high mineralization and low organic matter caused nutrients mining. The N slowly mineralized in the treatment with organic matter and remained in soil for longer time, because some part of N in the form of ammonium was fixed on soil colloids and organic matter. Similar results were observed by Singh *et al*. (2016) who reported that the highest available N status of soil was registered by the integration of inorganic fertilizers with the organic sources. The added nitrogen only through inorganic sources were low in soil which could be lost by leaching due to heavy rainfall or volatilization processes or might be utilized rapidly by the crop which were in readily available form, because of rapid mineralization due to higher microbial activity which provided readily available nutrients to plants.

The soil available P was not significantly affected by the given treatments (Table 2). However, highest soil available P (23.46 kg/ha) was found in 50% organic + 50% inorganic treatment. 100% organic treatment showed lowest soil available P (21.11 kg/ha) while 100% inorganic treatment showed 8.14 and 5.25% higher soil available P over 100% organic and INM +IPM treatments,

Table 2 Effect of nutrient management on soil organic carbon, bulk density, available N, available P and available K at harvest of soybean

Treatment	Organic carbon (%)	Bulk density (Mg/m^3)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
Organic (100%)	0.67^{a*}	1.32^{a}	264.99^{ab}	21.11^{a}	133.82^{ab}
Inorganic (100%)	0.62^{b}	1.42^{b}	253.66^{b}	22.83^{a}	126.03^{b}
Organic (50%) + Inorganic (50%)	0.71^{a}	1.37^{ab}	286.94^{a}	23.46^{a}	139.03^{a}
INM+IPM	0.67^{a}	1.40^{ab}	260.28^{b}	21.69^{a}	131.61^{ab}

*Means followed by the same lower case letter within a parameter indicate that they are not significantly different ($P<0.05$).

respectively. However, available phosphorus status of soil remained unaffected might be due to medium level of phosphorus available in soil, however slight increased phosphorus level was observed under integrated approach. Higher soil available P was recorded with 100% inorganic treatment because in this treatment P was in available form while in 100% organic treatment, P was in bound form in organic matter which was very slowly available to plants in the later stages. That's why the available P was low in 100% organic treatment. Kler and Walia (2007) also observed positive balance of available P with the combination of organic sources of nutrients in soybean-wheat cropping system. Improved nodulation, nitrogeanse and nitrate-reductase activity and N-fixation by *Rhizobium* and improved solubilization of P through secretion of organic acids and activity of phosphatase enzyme by PSB and their combined influence might have resulted in improved soil N and P status at harvest (Govindan and Thirumurugan 2005). The applied treatments also significantly affected the amount of soil available K (Table 2). 50% organic + 50% inorganic treatment recorded 139.03 kg/ha of highest available soil K and this treatment also registered 3.89 and 5.63 per cent increased amount soil available K in comparison to 100% organic and INM +IPM treatments, respectively and it might be due to more available K pool of the soil besides reducing the K fixation and releasing K on interaction of FYM and organic matter with clay (Sharma and Namdeo 1999). It also recorded 10.31% significantly more soil available K over 100% inorganic treatment. 100% organic treatment showed an increase of 6.18% in soil available K over 100% inorganic treatment. The beneficial effect of integrated use of fertilizers and organic treatments on available K may be ascribed to the direct potassium addition in the potassium pool of the soil (Dutt *et al*. 2013). Besides addition to this carbon dioxide and organic acids released during the process of decomposition FYM which increase the availability of nutrients from native as well as applied fertilizers. *Rhizobium* fixed the atmospheric nitrogen and phosphobacteria solubilized the fixed phosphate by secretion of organic acids and phosphate enzymes. These all might have contributed towards increased available status of soil with respect to these nutrients. The results of present investigation are also in line with the findings of Choudhary *et al*. (2011) and Vallabh *et al*. (2015). Singh *et al*. (2016) also found similar result and opined that increase in microbial population and enzymatic activity on the addition of manure and fertilizers resulted in greater mineralization of added substrates, hence increased organic carbon and available nutrients in soil.

Soil biological properties

Microbial population: It is interesting to note that after harvesting of crop, maximum number of soil bacteria 29.60 × 10^7 CFU/g soil was recorded in 100% organic treatment followed by 50% organic + 50% inorganic treatment (27.01 × 10^7 CFU/g soil) (Table 3). A significant increase of 48.67% in bacterial population was given by 100% organic treatment over 100% inorganic treatment. This treatment also recorded 7.12 and 23.23% higher bacterial population than 50% organic + 50% inorganic and INM + IPM treatment, respectively. The treatment having 50% organic + 50% inorganic recorded 38.77% significantly higher population than 100% inorganic treatments.

The maximum fungal population (13.75 × 10^5 CFU/g soil) was recorded in 50% organic + 50% inorganic treatment after harvest which was significantly more than 100% inorganic treatment (Table 3). 100% organic treatment gave 9.53% more fungal population than 100% inorganic treatment and 6.08% higher than INM +IPM treatment. 50% organic + 50% inorganic treatment showed 36.00 and 48.97% more fungal population, respectively than 100% organic and 100% inorganic treatments.

The maximum rhizobial population (31.97 × 10^6 CFU/g soil) was recorded by 100% organic treatment after harvest (Table 3). 100% organic and 50% organic + 50% inorganic treatments performed significantly better than INM +IPM treatment. The treatments having 100% organic and 50% organic + 50% inorganic showed numerically more population of rhizobia in soil in comparison to 100% inorganic treatment.

100% organic treatment was significantly better than 100% inorganic treatment by showing 25.86% more number of PSB in soil after harvest of soybean (Table 3). Similarly, 50% organic + 50% inorganic treatment gave 22.50% higher number of PSB in comparison to

Table 3 Effect of nutrient management on total microbial population of soil at harvest of soybean

Treatment	Total bacteria (× 10^7 CFU/g soil)	Total fungi (× 10^5 CFU/g soil)	Total rhizobia (× 10^6 CFU/g soil)	Total PSB (× 10^4 CFU/g soil)	Soil microbial biomass carbon (µg/g)	Dehydrogenase activity (µg TPF/g soil/24 h)
Organic (100%)	29.60^{a*}	10.11^{ab}	31.97^{a}	57.72^{a}	380.30^{a}	177.36^{a}
Inorganic (100%)	19.91^{b}	9.23^{b}	30.85^{ab}	45.86^{b}	321.57^{c}	132.30^{b}
Organic (50%) + Inorganic (50%)	27.63^{a}	13.75^{a}	31.45^{a}	56.18^{ab}	358.25^{ab}	151.23^{b}
INM+IPM	24.02^{ab}	9.53^{ab}	26.31^{b}	61.15^{a}	342.98^{bc}	142.84^{b}

*Means followed by the same lower case letter within a parameter indicate that they are not significantly different (P<0.05).

100% inorganic treatment. Maximum PSB population was recorded in the treatment with INM +IPM; however, 100% organic and 50% organic + 50% inorganic treatments were statistically comparable with INM +IPM treatment, whereas INM +IPM treatment treatment was significantly better than 100% inorganic treatment.

In case of soil microbial community, the majority of the soil bacteria are heterotrophic in nature depending on the C supply, energy and nutrient supply and in 50% organic + 50% inorganic and 100% organic treatments, the effect of added organic matter in soil provided the energy as well as carbon to the bacterial population for their cell component synthesis resulting in higher bacterial population. The results corroborated with the findings of Kibunja *et al*. (2010) who stated that treatments with farmyard manure supported higher number and activity of various groups of microorganisms probably due to higher SOC content. Chemical fertilizers alone on the other hand did not enhance SOC build up but instead raised the soil pH, which probably explains the low numbers recovered from the treatments with chemical fertilizers. Moreover, fungal populations require more carbon than the bacterial population due to more cytoplamic mass, these are also heterotrophic in nature. That's why higher fungal population was observed in 100% organic treatment due to more carbon when compared with 100% inorganic treatment. Similar results were also found by Das and Dkhar (2011) who observed that the number of fungi was significantly greater in vermicompost (25.23×10^3 CFU/g soil) followed by integrated plant compost (23.54×10^3 CFU/g soil) and the least was observed in control (11.37×10^3 CFU/g soil). The total rhizobial population in soil was higher in all the treatments than INM +IPM treatment, because rhizobia are also heterotrophic in nature and depend on the availability of organic carbon and nutrients in soil. The possible reason of increased PSB population in INM +IPM treatment might be due to the increased availability of organic carbon and P to the PSB resulting in higher PSB population which was due to added organic matter in these treatments. Furthermore, Bhatt *et al*. (2016) suggested that continuous use of FYM over the years in combination with optimum chemical fertilizers supplied large amount of readily available carbon in soil resulting into more microbial population as compared to application of chemical fertilizers alone. Most of the soil microorganisms, being chemoheterotrophs, obtain carbon for synthesis of cellular constituents and energy by the oxidation of organic substances. In addition, incorporation of organic matter improves the soil physical environment, making it more congenial for microorganisms.

Soil microbial biomass carbon (SMBC): The highest soil microbial biomass carbon (380.30 µg/g) was found in 100% organic treatment, while 100% inorganic treatment recorded the lowest microbial biomass carbon of 321.57 µg/g after harvest (Table 3). 100% organic treatment gave 18.26% significantly higher soil microbial biomass carbon than 100% inorganic treatment. The treatment having 50% organic + 50% inorganic also registered 11.40% significantly higher microbial biomass carbon over 100% inorganic and a numerical increase of 4.45% of higher microbial biomass carbon over INM +IPM treatment. 100% organic treatment also recorded 6.15% higher microbial biomass carbon than 50% organic + 50% inorganic treatment. The possible reason of improved microbial biomass was the increased availability of organic carbon to the soil microorganism which accumulated in the microbial protoplasm and increased microbial population. That's why 100% inorganic treatment showed lowest microbial biomass carbon. Addition of farmyard manure usually increases microbial biomass and soil enzyme activities (Canarutto *et al*. 1995) over soils that have not received any organic or inorganic amendments. Thus management practices that increase incorporation of organic residue typically increase biological activity. Use of inorganic fertilizer can increase the plant biomass production which in turn increases the amount of residue returned to the soil and stimulates biological activity (Balota *et al*. 2003). The lack of response or decrease in microbial biomass and activity could be due to acidifying effect of the fertilizers and the resultant impairment of the survival capacity of many of the soil microorganisms. Nakhro and Dkhar (2010) concluded that under paddy field condition the application of organic fertilizers increased the organic carbon content in the soil and thereby increasing the microbial counts and microbial biomass carbon of the soil. Singh *et al*. (2012, 2017) also reported that microbial biomass carbon was higher in the treatments where the combination of organic and inorganic fertilizers was applied.

Dehydrogeanse activity (DHA): The dehydrogenase activity was affected significantly by given treatments after harvest (Table 3). The maximum activity (177.36 µg TPF/g soil/24 h) was recorded in 100% organic treatment which was 34.05% more than 100% inorganic treatment. This treatment also recorded 17.27% more dehydrogenase activity when compared with 50% organic + 50% inorganic treatment. On the other hand, the treatment with 50% organic + 50% inorganic recorded 14.30 and 5.87% more dehydrogenase activity than 100% inorganic and INM +IPM treatments, respectively. Dehydrogenase activity is related with the soil microbial population and activities. When microbial population was more, dehydrogenase activity was also increased depending on the organic matter content of the soil. The dehydrogenase and nitrogenase activities indicate the enhanced microbial activity of soil and serve as an index of microbial biomass. The results also corroborated with the findings of Verma and Mathur (2009) who reported that integrated use of FYM with chemical fertilizer increased this activity. Further, addition of nitrogen in the farmyard manure and biofertilizers increased the dehydrogenase activity than the alone chemical fertilizer treatment might be due to more availability of substrate for dehydrogenase enzyme (Singh *et al*. 2016).

It can be concluded that integrated use of organic and inorganic source significantly enhanced nodulation and yield of soybean. This treatment also improved the soil properties as compared to other integrated nutrient options. Therefore, integrated use of 50% organic and + 50% inorganic source of nutrient was found best for most of the symbiotic, plant growth and yield parameters of soybean. Therefore, proper nutrient management practices improve overall quality of soil which will help to maintain the sustainability of the production system of soybean-wheat over the years.

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