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Influence of inorganic, biological and organic manures on nodulation and yield of soybean (*Glycine max* Merril L.) and soil properties

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Abstract

The effect of inorganic, biological and organic manures on nodulation and yield of soybean and soil properties was studied during rainy seasons of 2008 and 2009 in India (Manipur). The experiment consists of nine treatments viz., T_1 - Absolute control, T_2 – FYM (Farmyard manure) at the rate of 5 t ha^{-1}, T_3 -Vermicompost at the rate of 1 t ha^{-1}, T_4 - 100% RDF (Recommended dose of fertilizer), T_5 - 100% RDF + PSB, T_6 - 75% RDF + vermicompost at the rate of 1 t ha^{-1}, T_7 - 75% RDF + vermicompost at the rate of 1 t ha^{-1} + PSB, T_8 - 50% RDF + vermicompost at the rate of 1 t ha^{-1} and T_9 - 50% RDF + vermicompost at the rate of 1 t ha^{-1} + PSB. The experiment was replicated thrice in randomized block design. The results revealed that integration of 75% RDF with vermicompost at the rate 1 t ha^{-1} and PSB produced significantly higher plant height, number of nodules plant, dry weight of nodules plant^{-1}, pods plant^{-1} and seed index than the other treatments. Similarly, significantly higher grain and stover yield were obtained from the application of 75% RDF as inorganic fertilizer in combination with vermicompost at the rate of 1 t ha^{-1} followed by seed inoculation of PSB. The oil and protein content of seed were increased significantly due to the application of 75% RDF coupled with vermicompost at the rate of 1 t ha^{-1} and PSB. The available N, P and K of soil after the harvest of soybean were improved significantly due to the integration of inorganic fertilizers with organic manures. Soil pH and organic carbon were improved due to the application of organic manure. Maximum net return and B: C ratio was also recorded from the integration of 75% RDF coupled with vermicompost at the rate 1 t ha^{-1} and PSB. Thus, it shows the positive impact of biological and organic manure application on reduction of chemical fertilizer use.

Keywords: vermicompost, phosphate solubilizing bacteria, farmyard manure, nodule, nutrient management, soybean.
Abbreviations: N= Nitrogen; P= Phosphorus; K= potassium; RDF = Recommended dose of fertilizer; B: C = Benefit:Cost; FYM= Farmyard Manure; PSB= Phosphate solubilizing bacteria; VC = Vermicompost.

Introduction

Soybean being a high protein and energy crop and its productivity is often limited by the low availability of essential nutrients or imbalanced nutrition forming one of the important constraints to soybean productivity in India. Hence a balanced nutrients application is must to harness the productivity of the crops. The long-term use of inorganic fertilizers without organic supplements damages the soil physical, chemical and biological properties and causes environmental pollution. Organic manures act not only as a source of nutrients and organic matter, but also increase size, biodiversity and activity of the microbial population in soil, influence structure, nutrients get turnover and many other changes related to physical, chemical and biological parameters of the soil (Albiach et al., 2000). Environmental degradation is a major threat confronting the world, and the rampant use of chemical fertilizers contribute largely to the deterioration of the environment through depletion of fossil fuels, generation of carbon dioxide and contamination of water resources. It leads to loss of soil fertility due to imbalanced use of fertilizers that has adversely impacted agricultural productivity and caused soil degradation. Now there is a growing realization that the adoption of ecological and sustainable farming practices can only reverse the declining trend in the global productivity and environment protection (Aveyard, 1988; Wani and Lee, 1992; Wani et al., 1995). Use of organic manures alone or in combination of chemical fertilizers will help to improve physic-chemical properties of the soils, Organic manures provide a good substrate for the growth of microorganisms and maintain a favourable nutritional balance and soil physical properties. One such strategy to maintain soil fertility for sustainable production of soybean is through judicious use of fertilizers (Bobde et al., 1998) coupled with organic resources that to achieve sustainability in production, the use of organic manures alone is not sufficient (Prasad, 1996). It has also been brought out that the use of organic manures in integration with fertilizers meets the need of micronutrients of soybean (Joshi et al., 2000). Lourduraj (2000) has also reported that the combined application of' inorganic and organic manures significantly enhanced the growth attributes and yield of' soybean as compared to the sole application of either of them. Vermicompost is the microbial composting of organic wastes through earthworm activity to form organic fertilizer which contains higher level of organic matter, organic carbon, total and available N, P, K and micronutrients, microbial and enzyme activities (Edwards and Bohlen, 1996; Ranganathan, 2006; Parthasarathi et al., 2007). Vermicompost applications to field soils combined

with 50% of the recommended inorganic fertilizers increased the yields of tomatoes (Kolte et al., 1999). A lower application rate of 1 t ha^{-1} vermicompost plus recommended amounts of inorganic fertilizers, increased tomato yields to a level similar to those of tomatoes in soils treated with vermicompost at the rate 4 t ha^{-1} and 50% of the recommended rates of inorganic fertilizers (Patil et al., 1998). Tuberlets from a true potato seed line produced the greatest marketable yields, after amending the soils with 75% of the recommended inorganic fertilizers and vermicompost at the rate 2.5 t ha^{-1} (Mrinal et al., 1998). Several workers (Kale et al., 1992; Tomati and Galli, 1995; Edwards and Bohlen, 1996; Ghosh et al., 1999; Parthasarathi and Ranganathan, 2002; Ranganathan, 2006; Zaller, 2007; Rajesh Banu et al., 2008) observed that integration of vermicompost with inorganic fertilization tended to increase the yield of crop viz. tomato, potato, rapeseed, groundnut, blackgram, paddy, mulberry and marigold. Soil P dynamics are characterized by physic-chemical and biological processes. P is needed in relatively large amounts by legumes for growth and nitrogen fixation and has been reported to promote leaf area, biomass, yield, nodule number, nodule mass, etc., in a number of legumes (Berg and Lynd, 1985; Pacovsky et al., 1986; Kasturikrishna and Ahlawat, 1999). The large amount of P applied as fertilizer enters in to the immobile pools through precipitation reaction with highly reactive Aluminium (Al^{3+}) and Iron (Fe^{3+}) in acidic, and Calcium (Ca^{2+}) in calcareous or normal soils (Gyaneshwar et al., 2002; Hao et al., 2002). Phosphorus deficiency can limit nodulation by legumes and P fertilizer application can overcome the deficiency (Carsky et al., 2001). Phosphate solubilizing bacteria (PSB) has been used as biofertilizer since the 1950s (Krasilinikov, 1957). Release of P by PSB from insoluble and fixed/adsorbed forms is an import aspect regarding P availability in soils. There are strong evidences that soil bacteria are capable of transforming soil P to the forms available to plant. In this respect, biofertilization technology has taken a part to minimize production costs and at the same time avoids the environmental hazards (Galal et al., 2001). Presently, the chemical fertilizers are the major source of nutrients but escalating costs, coupled with increasing demand of chemical fertilizers and depleting soil health necessitates the safe and efficient use of organics in crop production. These practices were gaining much popularity to enhance and maintain soil organic carbon status for obtaining sustainable crop yields. However, under arable production systems, organic manures suffer from the drawback of slow release of nutrients at initial stages, may cause significant reduction in crop yield and results in lower farm income. The present study was undertaken to develop a suitable fertilizer package of integration of inorganic fertilizers with biological and organic manures on nodulation, yield attributes, yield of soybean and soil properties.

Results

Plant height

Plant height was significantly influenced by the application of inorganic fertilizers, biological and organic manures. Plant height produced by T_7 (41.49 cm), T_6 (38.88cm) and T_9 (38.48cm) were significantly higher than that of all other treatments and the lowest plant height (24.13cm) were in the control. It was observed that organic manure alone had no significant effect on plant height over 100% RDF. But the integration of biological and organic manure with chemical fertilizers had a significant impact on plant height. This clearly indicated the need for adding organic manures to the soil conjunctive with inorganic fertilizers, which increased the availability of nutrients considerably resulting in a positive effect on growth parameters. These findings are in accordance with the results of Babalad (1999) who had observed increased plant height, number of trifoliate leaves per plant and number of branches per plant in soybean due to the application of organic manure and inorganic fertilizers. Similar findings were reported (Sharma and Dixit 1987; Bish and Chandel 1991; Babhulkar 2000 in soybean; Jayabal et al., 2000 in sunflower; Dikshit and Khatik 2002 in sorghum).

Nodulation

The number of nodules per plant and its dry weight were influenced significantly by the different combination of organic and inorganic fertilizers. The number of nodule per plant ranges from 11.67 to 43.00. The maximum nodules per plant (43.00) was found in the integration of 75% RDF with vermicompost at the rate of 1 t ha^{-1} and PSB which was significantly higher than the other treatments (Table 1). Similarly nodule dry weight $plant^{-1}$ was also significantly influenced by the integration of inorganic and organic fertilizers. The treatment 75% RDF with vermicompost at the rate of 1 t ha^{-1} and PSB produced maximum dry weight of nodules per plant (Table 1). The increase in the nodule dry weight might be due to more number of nodules per plant. Phosphorus has a specific role in nodule initiation, growth and function in addition to its role in host plant growth. Microorganisms with phosphate solubilizing potentially increase the availability of soluble phosphate and enhance the plant growth by improving biological nitrogen fixation (Kucey et al., 1989; Ponmurugan and Gopi, 2006). Phosphorus deficiency has been shown to restrict the nodulation process severely in soybean.

Yield attributes and yield of soybean

The results presented in Table 1 show that grain yield was governed by different yield components such as number of pods $plant^{-1}$, number of seeds pod^{-1}, seed index and grain yield. Number of pods $plant^{-1}$ and seeds pod^{-1} was significantly influenced by the integrated application of 75% RDF with vermicompost at the rate of 1 t ha^{-1} and PSB than the rest of the other treatments. The increase in the number of pods $plant^{-1}$ with the integrated application of 75% RDF with vermicompost at the rate of 1 t ha^{-1} and PSB over control and 100% RDF were 172% and 43% respectively. The number of seeds pod^{-1} is perceived a significant constituent that directly imparts in exploiting potential yield recovery in leguminous crops. Significantly the highest number of seeds per pod (2.96) was recorded at 75% RDF along with vermicompost at the rate of 1 t ha^{-1} and PSB as compared to other treatments. This was perhaps due to a continuous supply of nitrogen, phosphorus, potassium to the crop at the early stages and through organic manure at later stages of crop growth, as slow release nutrients. Seed index was maximum (12.86 g) with the integrated application of 75% RDF coupled with vermicompost at the rate of 1 t ha^{-1} and PSB than the rest of the other treatments (Table 1). Vermicompost application delayed leaf senescence and this might be the reason for increased seed weight. Better growth and development of crop plants due to phosphorus supply and nitrogen uptake might have increased the supply of assimilates to seed, which ultimately gained more weight. Similar achievements on hundred seed weight with phosphorus were observed (Kar et al., 1989; Singh and Hiremath 1990; Chauhan et al., 1992

Table 1. Effect of integration of organic and inorganic fertilizer on plant height, nodulation, yield attributes and yield of soybean (mean for of two years)

Treatment	Plant height (cm)	Nodules/ plant at 60 DAS	Nodule dry weight/plant(mg) at 60 DAS	Pods/ plant	Seed/ pod	100 seeds weight (g)	Seed Grain yield (kg/ha) (t/ha)	Stover yield (kg/ha) (t/ha)
Absolute control	24.13^{d}	19.33 11.67^{c}	112.63^{e}	24.19^{f}	1.90^{e}	12.35^{b}	697 0.70^{f}	970 0.97^{f}
FYM @ (5t/ha)	32.70^{c}	21.00^{d}	127.38^{d}	28.52^{e}	2.27^{d}	12.68^{a}	1180 1.18^{e}	1350 1.35^{e}
VC @ (1t/ha)	33.34^{c}	25.00^{c}	130.19^{cd}	32.51^{d}	2.32^{cd}	12.73^{a}	1288 1.29^{d}	1427 1.43^{de}
100% RDF	33.52^{c}	23.00^{c}	132.30^{c}	46.03^{c}	2.30^{cd}	12.75^{a}	1261 1.26^{d}	1573 1.57^{cd}
100% RDF + PSB	35.42^{bc}	25.00^{c}	133.81^{c}	48.44^{c}	2.53^{b}	12.78^{a}	1293 1.29^{d}	1675 1.68^{c}
75% RDF + VC @ (1t/ha)	38.88^{a}	30.67^{b}	141.20^{b}	52.48^{b}	2.60^{b}	12.68^{a}	1792 1.79^{b}	1875 1.84^{b}
75% RDF + VC @ (1t/ha) + PSB	41.49^{a}	43.00^{a}	149.13^{a}	65.68^{a}	2.96^{a}	12.86^{a}	1924 1.92^{a}	2035 2.04^{a}
50% RDF + VC @ (1t/ha)	37.35^{b}	26.00^{c}	138.38^{b}	50.05^{b}	2.58^{b}	12.82^{a}	1426 1.43^{c}	1724 1.72^{b}
50% RDF + VC @ (1t/ha) + PSB	38.48^{a}	31.67^{b}	140.52^{b}	51.06^{b}	2.41^{c}	12.82^{a}	1437 1.44^{c}	1823 1.82^{b}
LSD (p = 0.05)	3.64	3.16	4.51	5.95	0.17	NS	87.06	23.53

* Means followed by same superscripts within the same column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test; FYM = Farmyard Manure; RDF = Recommended dose of fertilizer; VC = Vermicompost; PSB = Phosphate solubilizing bacteria.

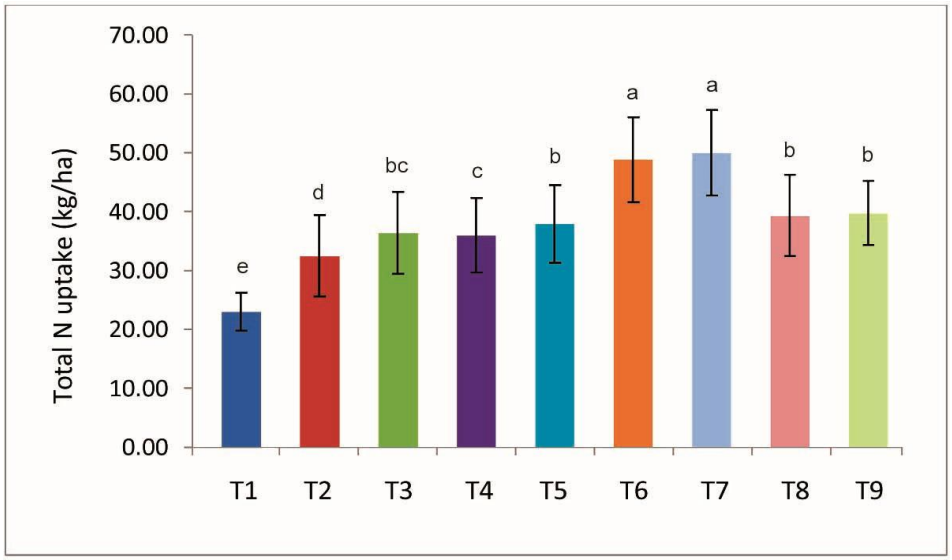

Fig 1. Effect of inorganic fertilizer, biological and organic manures on total N uptake by soybean. Vertical bars at the top of the shaded bars indicate the standard error. Means followed by the same letters are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test.

and Anchal et al., 1997). Integration of inorganic fertilizer with vermicompost and PSB was superior in grain yield than the application of chemical fertilizer or organic manure alone (Table 1). Combination of 75% RDF with vermicompost at the rate of 1 t ha^{-1} and PSB produced significantly higher grain yield (1.92 t ha^{-1}) of soybean than the other treatments (Table 1). The increase in grain yield might be the result of more number of pods per plant and higher seed index. Phosphate solubilizing bacteria enhance the phosphorus availability to plants by mineralizing organic P in the soil and by solubilizing precipitated phosphate (Chen et al., 2006; Kang et al., 2002; Pradhan and Sukla, 2005). Badret (1986), Dubey et al. (1997) have also reported significant increases in grain yield of soybean due to co-inoculation of phosphorus solubilizers. Higher crop yields resulted from solubilization of fixed soil P and applied phosphates by PSB (Zaidi, 1999). Phosphorus has important effects on photosynthesis, nitrogen fixation, root development, flowering, seed formation, fruiting and improvement of crop quality (Brady, 2002). The lowest seed yield (0.70 t ha^{-1}) was observed from the control. Again 100% RDF also produced a lower seed yield (1.26 t ha^{-1}) as compared to the integration of inorganic fertilizers with biological and organic manures. This might be due to the lesser availability of nutrients, especially nitrogen to the crop at the later stages of crop growth when the root nodules degenerate and the nitrogen supply falls short of crop

Table 2. Effect of integration of organic and inorganic fertilizers on oil and protein content of soybean and economics (mean for of two years).

Treatment	Oil content (%)	Oil yield (kg/ha) (t/ha)	Protein content (%)	Protein yield (kg/ha) (t/ha)	Cost of cultivation (Rs/ha) (AUD/ha)	Net return (Rs/ha) (AUD/ha)	B: C ratio
Absolute control	13.81^{f}	96.29 0.10^{f}	32.42^{d}	226.08 0.23^{f}	15000 270^{g}	16380 291^{f}	1.09 1.08^{f}
FYM @ (5t/ha)	16.28^{e}	192.16 0.19^{e}	34.40^{c}	405.92 0.41^{e}	15000 450^{f}	28100 499^{e}	1.12 1.11^{e}
VC @ (1t/ha)	16.67^{d}	214.59 0.21^{de}	34.80^{c}	448.21 0.45^{d}	17000 378^{d}	30960 658^{d}	1.15 1.74^{d}
100% RDF	17.20^{c}	216.87 0.22^{de}	35.43^{c}	446.67 0.45^{d}	20195 364^{e}	36535 650^{d}	1.81 1.79^{c}
100% RDF + PSB	17.42^{c}	225.27 0.23^{d}	35.77^{b}	462.62 0.46^{d}	20295 365^{e}	37905 675^{d}	1.87 1.85^{c}
75% RDF + VC @ (1t/ha)	18.18^{b}	325.76 0.33^{b}	36.23^{a}	649.27 0.65^{b}	27146 448^{b}	53494 993^{b}	1.97 2.22^{b}
75% RDF + VC @ (1t/ha) + PSB	18.61^{a}	358.04 0.36^{a}	36.71^{a}	706.36 0.71^{a}	27246 450^{a}	59349 1097^{a}	2.18 2.44^{a}
50% RDF + VC @ (1t/ha)	17.25^{c}	245.92 0.25^{cd}	35.76^{b}	510.01 0.51^{c}	22098 425^{c}	42073 722^{c}	1.90 1.70^{d}
50% RDF + VC @ (1t/ha) + PSB	18.11^{b}	260.34 0.26^{c}	36.19^{a}	519.92 0.52^{c}	22198 426^{c}	42453 729^{c}	1.91 1.71^{cd}
LSD (p = 0.05)	0.10	15.48	0.07	31.01	3816	3918	0.17

* Means followed by same superscripts within the same column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test; RDF = Recommended dose of fertilizer; VC = Vermicompost; PSB = Phosphate solubilizing bacteria; FYM = Farmyard Manure; Price of FYM = Rs.500 AUD 8.930/card load; Vermicompost = Rs. 6 AUD 0.107/kg; Prevailing market price of soybean = Rs. 45 AUD 0.803/kg; RDF = Recommended dose of fertilizer; VC = Vermicompost.

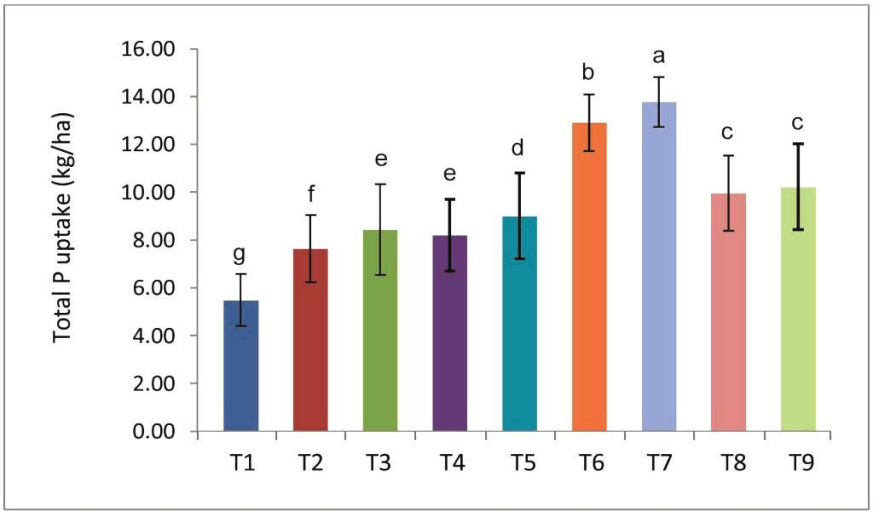

Fig 2. Effect of inorganic fertilizer, biological and organic manures on total P uptake by soybean. Vertical bars at the top of the shaded bars indicate the standard error. Means followed by the same letters are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test.

requirements during the pod development phase of the crop. Similar results were also reported in soybean (Ranjit Singh and Rai 2004; Damodar Reddy 1998; Aruna and Narsareddy, 1999). Significantly higher stover yield (2.04 t ha^{-1}) was produced by the integration of 75% RDF with vermicompost at the rate of 1 t ha^{-1} and PSB and the lowest (0.97 t ha^{-1}) from control. The increase in stover yield might be due to the delayed senescence of leaves with the application of vermicompost.

Oil and protein content of seed

The oil and protein contents in soybean seed were strongly influenced by integrated nutrient management. Between various treatments, integration of 75% RDF with vermicompost at the rate of 1 t ha^{-1} and PSB produced significantly higher oil and protein content of soybean seed (Table 2).

Table 3. Effect of integration of organic and inorganic fertilizers on soil properties after two years.

Treatment	Available nutrient content in soil (kg/ha)			Soil	Organic Carbon
	N	P_2O_5	K_2O	pH	(%)
Absolute control	101.18[e]	8.55[c]	116.32[e]	5.40[b]	0.45[c]
FYM @ (5t/ha)	132.90[d]	10.98 11.31[b]	162.86[d]	5.56[a]	0.52[a]
VC @ (1t/ha)	157.89[b]	12.46[a]	181.30[b]	5.60[a]	0.52[a]
100% RDF	156.36[b]	11.48[b]	165.69[d]	5.40[b]	0.48[b]
100% RDF + PSB	159.75[b]	12.35[a]	177.25[c]	5.43[b]	0.48[b]
75% RDF + VC @ (1t/ha)	162.35[a]	12.57[a]	190.72[a]	5.60[a]	0.52[a]
75% RDF + VC @ (1t/ha)+ PSB	168.12[a]	14.56[a]	194.41[a]	5.60[a]	0.53[a]
50% RDF + VC @ (1t/ha)	137.73[d]	11.41[b]	179.11[c]	5.60[a]	0.52[a]
50% RDF + VC @ (1t/ha) + PSB	143.21[c]	12.41[a]	183.83[b]	5.60[a]	0.52[a]
LSD (p = 0.05)	5.95	0.26	4.24	0.05	0.01

* Means followed by same superscripts within the same column are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test; RDF = Recommended dose of fertilizer; VC = Vermicompost; PSB = Phosphate solubilizing bacteria; FYM = Farmyard Manure.

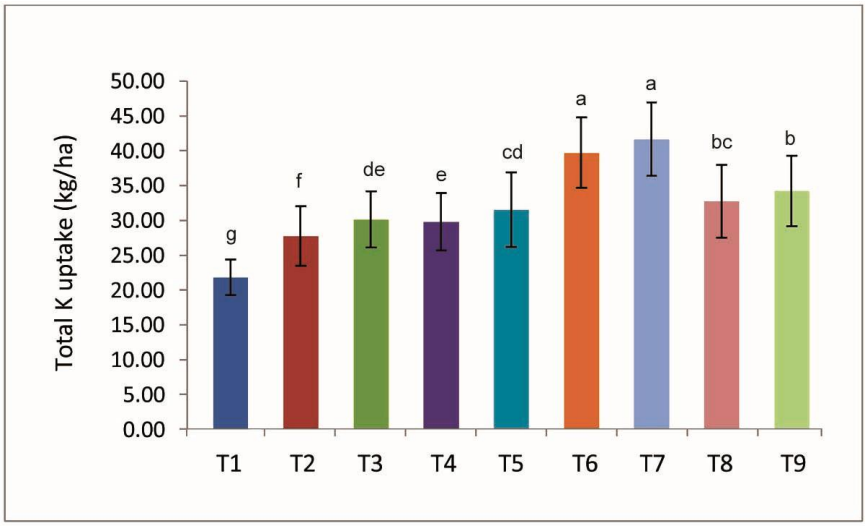

Fig 3. Effect of inorganic fertilizer, biological and organic manures on total K uptake by soybean. Vertical bars at the top of the shaded bars indicate the standard error. Means followed by the same letters are not significantly different at the 5% level of probability based on Duncan's Multiple Range Test.

This could be due to better availability of desired and required nutrients in the crop root zone resulting from its solubilisation caused by the organic acids produced from the decaying organic matter and also the increased uptake by soybean root due to their association with mycorrhizal filaments increasing the ascribing area of roots. The presence of sulphur in SSP was also involved in the synthesis of fatty acids and increases the protein quality through the synthesis of certain amino acids such as cysteine, cystine and methionine. It is evident from the results (Table 2) that sulphur had a remarkable influence on oil and protein content. Similar findings were also reported (Havlin et al., 1999; Kandpal and Chandel, 1993). Similarly, oil yield and protein yield were also observed in the same trend. The relative increase in oil yield by the integrated application of 75% RDF with vermicompost at the rate of 1 t ha^{-1} and PSB over control and 100% RDF were 260% and 63.64% respectively. Similarly, the increase in protein yield over control and 100% RDF were 209% and 58%, respectively.

Economics

The beneficial effect of combined application of inorganic fertilizers with biological and organic manure manifest in net return and B: C ratio. Net return and B: C ratio was significantly higher in the integrated application of 75% RDF coupled with vermicompost at the rate of 1 t ha^{-1} and PSB over other treatments as it could be able to increase the yield level of soybean in addition to the increased cost of production. The cost of vermicompost was compensated with the higher yield of soybean. Application of 100% RDF alone gave a net return lower than the integration of inorganic fertilizer with biological and organic manures. It might be due to lower yield of soybean when only inorganic fertilizers are applied. The increase in B:C ratio with the integrated application of 75% RDF with vermicompost at the rate of 1 t ha^{-1} and PSB over control and 100% RDF were 126% and 36% respectively.

Nutrient uptake

The uptake of N, P ad K by soybean was significantly influenced by different treatments. The N, P and K uptake increase with the combination of inorganic fertilizers with biological and organic fertilizers. The N uptake varied from 23.05 to 49.99 kg $ha^{-1}$the highest uptake being recorded in the T_6 and T_7 which was significantly different from other treatments (Fig.1). The ranking of the treatments in respect of

total N uptake was in the order $T_7 > T_6 > T_9 > T_8 > T_5 > T_3 > T_4 > T_2 > T_1$ (Fig.1). Verma et al (2006) also found a significantly higher NPK uptake by maize-wheat cropping system by the application of 100% NPK + FYM 10 t ha^{-1}. Kumar and Sharma (2004) reported a maximum nutrient uptake in cabbage and tomato with FYM + 150 % NPK treatment. The uptake of N, P, K and Mg by rice plant was highest when fertilizer was applied in combination with vermicompost (Jadhav et al., 1997). The maximum P uptake was noted when 75% RDF with vermicompost at the rate of 1 t ha^{-1} and PSB followed by the integration of 75% RDF with vermicompost at the rate of 1 t ha^{-1} (Fig.2). Yadav et al., (2005) also reported that the maximum P uptake was noted when 25% N was substituted by green leaf (sesbania) manure. Recommended NPK + FYM 10 t ha^{-1} followed by 50% recommended NPK + FYM 10 t ha^{-1} resulted in higher nutrient uptake compare to the recommended rate of NPK alone (Chaturvedi and Chandel, 2005). The highest K uptake (41.68 kg ha^{-1}) was observed in T_7 followed by T_6 (39.72 kg ha^{-1}) (Fig.3). In barley, the highest K uptake was found due to an addition of vermicompost at 4.5 t ha^{-1} along with 60 kg N ha^{-1} (Kumawat and Jat, 2005) which partly support our findings. The uptake of nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) by rice (*Oryza sativa*) plant was highest when fertilizer was applied in combination with vermicompost (Jadhav et al., 1997).

Soil properties

Available nitrogen, phosphorus and potassium of soil

Data in Table 3 shows that the available nitrogen status of the soil increased significantly with the integrated use of inorganic fertilizers and organic manures. Application of 75% RDF with vermicompost at the rate of 1t ha^{-1} and PSB and 75% RDF with vermicompost at the rate of 1t ha^{-1} recorded significantly higher soil available nitrogen over 100% RDF. The increment was due to slow release of nutrients through organic manures and enriching the available pool of nitrogen (Bharadwaj and Omanwar, 1994). The increase in available N status in T_6 and T_7 was 60 and 66 % over the control while the corresponding increase over 100% RDF was 3.83 and 7.52 % respectively. The increase in available nitrogen status under integrated treatment might also be attributed to a greater multiplication of soil microbes as a result of which organically bound nitrogen was converted to inorganic form of nitrogen (Bharadwaj and Omanwar, 1994). The lower values for available nitrogen with 100% RDF was attributed to maximum utilization of applied nutrients by the crop (Uma Reddy, 1999) which are in readily available form. The available phosphorus in the soil after the harvest of soybean was significantly lower in the treatments received inorganic alone compared to the integration of inorganic with organic fertilizers. It may be due to lack of addition of organic matter and thereby depletion of native pool of available P by plants which was mineralized by the buildup of microflora. The buildup of available phosphorus was higher in the integration of 75% RDF as inorganic fertilizer with organic manure and PSB treated plots (Table 3). It might be due to release of organic acid during microbial decomposition of organic matter which might help in increasing solubility of native phosphates, thus increased available phosphorus pool in the soil (Khan et al., 1984). In addition, the organic anions compete with phosphate ions for the binding sites on the soil colloids. The complex organic anions chelate $A1^{3+}$, Fe^{3+} and Ca^{2+} and thus decrease the phosphate precipitating power of these cations and thereby increase in the phosphorus availability with vermicompost (Reddy et al., 1990 and Pawar, 1996). Integrated use of inorganic fertilizers and organic manures enriched the fertility status of soil in respect of available K content. There were 67%, 19% and 17% increment in the available K content by integrated application of 75% RDF as inorganic fertilizer with vermicompost and PSB over control, FYM at the rate of 5 t ha^{-1} and 100% RDF (Table 3). It may be due to the beneficial effects of organic manures affecting clay-oregano interaction and direct K_2O additions widening available K pool of soil. Similar beneficial effect of organic manures on the available K_2O content of the soil was reported earlier in case of vermicompost (Pawar, 1996). Significantly higher available K_2O content in soil was recorded in treatments with integration of inorganic fertilizer, vermicompost and PSB due to beneficial effect of organic manures through slow release and rapid mineralization and buildup of microflora. The results are in conformity with Laxminarayan and Patiram (2006).

Soil pH and Organic carbon

The soil pH was largely maintained in manure treated plots (Table 3). The plots receiving only 100% RDF gave the maximum reduction in soil pH value (5.40%). Maximum increased in soil pH (5.60) was recorded from the integration of inorganic fertilizers with organic manures. The organic carbon was found to vary from 0.45% to 0.53% having the highest in T_7 (0.53%). The initial organic carbon of the soil was 0.50% which was reduced to 0.48% in control where no manure or fertilizer was applied (Table 3). However, the organic carbon was maintained at around 0.52% in a combined application of inorganic fertilizers with organic manures. Singh et al. (1999) reported a drastic reduction in organic carbon concentration on a continuous application of chemical fertilizer where addition of 5 t FYM ha^{-1} along with fertilizer N helped in maintaining the original organic matter status in soil.

Materials and methods

Experimental site and soil characteristics

The experiment was undertaken in the field during the rainy season (June- October) of 2008 and 2009 under All India Coordinated Research Project on Soybean at the Research Farm, College of Agriculture, Central Agricultural University, Imphal, India (24°45′ N, 93°56′ E; altitude 774.5m above mean sea level). The soil was clay loam in texture with pH of 5.5, low in organic carbon (0.50%), available nitrogen (212 kg ha^{-1}), available P_2O_5 (18.5 kg ha^{-1}) and available K_2O (192 kg ha^{-1}).

Treatments

The experiment consists of nine treatments viz., T_1 - Absolute control, T_2 - FYM at the rate of 5 t ha^{-1}, T_3 - Vermicompost at the rate of 1 t ha^{-1}, T_4 - 100% RDF, T_5 - 100% RDF + PSB, T_6 - 75% RDF + vermicompost at the rate of 1 t ha^{-1}, T_7 - 75% RDF + vermicompost at the rate of 1 t ha^{-1} + PSB, T_8 - 50% RDF + vermicompost at the rate of 1 t ha^{-1} and T_9 - 50% RDF + vermicompost at the rate of 1 t ha^{-1} + PSB. The experiment was laid out in randomized block design with three replications. The recommended dose of fertilizer (100% RDF) used for soybean was N: P_2O_5: K_2O:: at the rate of 40 : 60 : 20

kg ha^{-1}. Nitrogen, phosphorus and potash were applied as basal as per treatment in the form of urea, single superphosphate and muriate of potash respectively. Soybean seeds were inoculated with the phosphate solubilizing bacterial (PSB) strain *Pseudomonas striata* culture at 5 g kg^{-1} seed as per treatment. The N, P, K content of the applied vermicompost and FYM were 1.8%, 1.2%, 1.7% and 0.5%, 0.5%, 1.4% respectively. These organic manures were applied fifteen days before sowing to the respective plots as per treatment.

Variety and agronomic practices

Soybean variety JS-335 is a medium duration, high yielding variety, widely cultivated in India. The crop was sown in the first week of June and harvested at second week of October in all the experimental years at 30 cm row spacing and 10 cm. between plants. Hand weeding was done once at 35 days after sowing.

Sampling procedures and observations

Data on nodulation were recorded from five randomly selected plants at 60 days after sowing. Five plants were carefully uprooted randomly from each plot so that no nodules were left in the soil. The roots were thoroughly washed in water and the nodules from the roots of each plant were separately collected and counted. The nodules were air dried in the oven at 65 °C for 72 hours. Then the dry weights of the nodules were recorded. Plant height was recorded at the time of maturity. Number of pods $plant^{-1}$ and number of seeds pod^{-1} were counted from 10 plants selected randomly from each plot at harvest. Harvested soybean was threshed, grains were cleaned and recorded the yield.

Chemical analysis

Foliar diagnosis was in the fully youngest expanded leaf picked at the crop flowering. Leave and grain samples from each plot were dried at 70^{o}C for constant weight and ground for determination of total nitrogen, phosphorus, potash and oil contents. Soil samples were collected, dried and ground for chemical analysis. Soil pH was determined by using a glass electrode pH meter (Jackson, 1973) and organic carbon by wet oxidation method (Walkley and Black, 1935). The total N content of the soil was determined by Kjeldahl method (Jackson, 1973), available P by ascorbic acid and blue colour method (Watanabe and Olsen, 1965) and available K by flame photometer (Jackson, 1973). Concentrated nitric acid was used for digestion of plant samples. Total P concentration was determined by Vanadomolybdate yellow colour method (Jackson, 1973), K concentration by Flame photometer method (Jackson, 1973). The oil content of soybean seeds was estimated by adopting a Soxhlet Ether Extraction method (Sadasivam and Manickam 1996). Protein content was calculated by multiplying the total nitrogen content with dry matter-based factor 5.71 to determined total protein content (Sadasivam and Manickam, 1996). Nutrient uptake was calculated by multiplying the N, P and K content of soybean grain and stover with their respective yield. The total nutrient uptake was obtained by summation of the nutrient uptake of grain and stover.

Statistical analyses

All the data were subject to analysis of variance (ANOVA) for three replications in randomized block design by using MSTAT C software (CIMMYT, Mexico City), and the significance was tested by the variance ratio (i.e. *F*-value) at $p = 0.05$ (Gomez and Gomez, 1984). The least significant difference (LSD) was calculated for comparing the treatment means at the 5% level of probability based on Duncan's Multiple Range Test.

Conclusion

From the above study it can be concluded that integration of inorganic fertilizers with biological and organic manure enhanced the growth parameters like plant height and yield attributes such as number of pods $plant^{-1}$, number of seeds pod^{-1} and seed index . The highest grain yield and stover yield were recorded in the treatment 75% RDF through chemical fertilizers coupled with vermicompost at the rate of 1 t ha^{-1} and PSB (1.92 t ha^{-1} and 2.04 t ha^{-1}) respectively. Similarly, the highest benefit: cost (2.44) was also obtained from the integration of 75% RDF through chemical fertilizers with vermicompost at the rate of 1 t ha^{-1} and PSB which accounted for 110% and 30% increase over control and 100% RDF respectively. The available N, P and K content of soil after the harvest of soybean were increased significantly with the integrated application of 75% RDF through chemical fertilizers with vermicompost at the rate of 1 t ha^{-1} and PSB. The soil pH and organic carbon after the harvest of soybean was also increased with the combined application of inorganic fertilizers with biological and organic manure. Thus the objective of maximizing yields as well as maintaining soil health and productivity can be furnished by a balanced use of inorganic fertilizers conjunctively with biological and organic manure.

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