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Research Paper

Productivity, nutrient uptake, energy indices and profitability of soybean (*Glycine max*) as influenced by planting methods, *Bradyrhizobium* and plant growth promoting rhizobacteria

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ABSTRACT

A field experiment was conducted during rainy season (*kharif*) of 2014 and 2015 at Punjab Agricultural University, Ludhiana, Punjab to study the effect of planting methods, viz. Happy seeder sowing, straw chopper + zero tillage sowing and conventional sowing and biofertilizers, viz. *Bradyrhizobium*, plant growth promoting rhizobacteria (PGPR) and *Bradyrhizobium* + PGPR on nutrient uptake, energy indices, productivity and profitability of soybean [*Glycine max* (L.) Merrill). Results showed significantly higher seed yield, gross returns, net returns and benefit: cost ratio with happy seeder sowing as compared to straw chopper + zero tillage sowing and conventional sowing. N, P and K uptake by seed and straw were significantly higher in happy seeder sowing than straw chopper + zero tillage sowing and conventional sowing. Happy seeder sowing recorded the lowest energy input and the highest energy-output, net energy, energy-use efficiency and energy productivity. Seed inoculation with *Bradyrhizobium* and/or PGPR did not influence N, P and K uptake by seed and straw and energy indices significantly. However, combined inoculation of *Bradyrhizobium* and PGPR recorded the highest gross returns, net returns and benefit: cost ratio. Zero tillage with happy seeder sowing was found promising with the highest net returns and energy-use efficiency.

Key words : Biofertilizers, Economics, Energy indices, Happy seeder, Nutrient uptake, Seed yield, Soybean

In Indo-Gangetic Plains of India, rice–wheat cropping system is most important. It produces a lot of crop residues each year. Burning or removal of crop residues causes loss of organic matter and nutrients from soils (Singh *et al*., 2009). Retention of crop residues with zero tillage helps in moisture conservation and reduction of evaporation and soil temperature by modifying the thermal regime (Aulakh *et al*., 2012). Many studies have shown higher nutrient uptake by soybean in zero tillage with or without crop residue (Singer *et al*., 2008; Duseja and Dennis, 2010 and Aulakh *et al*., 2012). Application of crop residues (wheat + soybean) significantly increased the NPK uptake by soybean–wheat system as compared to no residue (Karunakaran and Behera, 2016).

Monetary returns from soybean production was higher in no tillage production system. Sowing of wheat with happy seeder (zero tillage) also saved time and money over the rotavator (reduced tillage) and fuel, time and money over farmer's practice (conventional tillage). Moreover, happy seeder treatment recorded higher net returns than conventional tillage and rotavator (Singh *et al*., 2013). The happy seeder machine cuts and manages the standing stubble and loose straw in front of the furrow openers, retaining it as surface mulch while sowing (Sidhu *et al*., 2007). Application of crop residues as a mulch improved yield and economic returns in soybean (Sekhon *et al*., 2005 and Karunakaran and Behera, 2016). No tillage in soybean recorded higher profitability due to lower cost of production by reducing some mechanized operations (fuel, machinery maintenance and manpower economy) (Santos *et al*., 2015).

Soybean can meet up to 80% of its total nitrogen requirement from biological nitrogen fixation (BNF) (Salvagiotti *et al*., 2008). Biofertilizers help in increasing crop productivity by way of increasing BNF, increasing availability or uptake of nutrients, improving soil fertility and have been proven to be an environmentally sound

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option. Thus, biofertilizers play a crucial role in sustainable crop production.

Plant growth promoting rhizobacteria (PGPR) can play an important role in plant nutrition, plant protection and growth stimulation. They may fix atmospheric nitrogen and supply it to plants; synthesize siderophores which can sequester iron from the soil and provide it to plant cells as a siderophore-iron complex; synthesize phytohormones such as auxins, cytokinins and gibberellins, which may enhance or regulate various stages of plant growth; and solubilize minerals such as phosphorus, making them more readily available for plant growth (Bashan and de-Bashan, 2010).

Many researchers have reported that inoculation of soybean seed with *Bradyrhizobium* enhanced N, P and K uptake by seed in soybean (Fakkar *et al*., 2010 and Rawat *et al*., 2013). Though a lot of information is available on the use of *Bradyrhizobium*, very little information is available on the effects of PGPR in soybean. The information on direct drilling of soybean with happy seeder in wheat crop residues and combined use of biofertilizers (*Bradyrhizobium* and PGPR) in India is still lacking. Moreover, the presence of wheat crop residue may influence the microclimate and consequently affect the performance of biofertilizers. Therefore, this experiment was carried out to study the effect of retention of crop residue with zero tillage and biofertilizers (*Bradyrhizobium* and PGPR) on productivity, nutrient uptake, energy indices and economics of soybean production.

MATERIALS AND METHODS

A study was conducted at Punjab Agricultural University, Ludhiana (30°54' N latitude, 75°48' E longitude with an altitude of 247 metre above mean sea level) during rainy season (*kharif*) of 2014 and 2015. The soil of the experimental site was loamy sand in texture with normal soil reaction (*p*H 7.5) and electrical conductivity (0.27 dS/m), low in organic carbon (0.29%), available nitrogen (131.8 kg/ha), medium in phosphorus (19.6 kg/ha) and potassium (157.4 kg/ha). The total rainfall of 426.3 and 580.5 mm during 2014 and 2015, respectively, was recorded during the soybean growing season against the normal value of 585.4 mm.

The preceding winter wheat crop was sown according to the layout of experiment used for soybean (fixed plots). The wheat crop was harvested with a combine at a stubble height of 30–40 cm to keep the residue within the plot in the treatments of happy seeder sowing and straw chopper + zero tillage sowing, and wheat was manually harvested in conventional sowing treatment. The wheat crop residue was about 9 and 6 t/ha during 2014 and 2015 respectively.

In happy seeder treatment, the sowing of soybean was done after combine harvested wheat in the standing stubbles of wheat after pre-sowing irrigation without any field preparation. In straw chopper + zero tillage sowing treatment, the preceding wheat crop was harvested with a combine harvester and the left over wheat residue was chopped with straw chopper to the size of about 10–20 cm and then the soybean crop was sown without any field preparation with zero-till drill after pre-sowing irrigation. In conventional sowing, a primary tillage operation was done with tractor drawn disc harrow and then pre-sowing irrigation was applied to ensure adequate moisture in the soil profile at the time of sowing. When the field attained proper moisture condition, a fine seedbed was prepared by giving two cultivators each followed by planking and soybean was sown with conventional seed drill.

Experiment was laid out in factorial randomized complete block design (RCBD) replicated 4 times. Soybean 'SL 958' was sown on June 5 during both the years as per treatments at 40 cm rows with happy seeder and at 45 cm rows in zero-till drill and conventional drill using 75 kg seed/ha. Soybean seed was inoculated with two microbial cultures – *Bradyrhizobium* (LSBR 3) and PGPR (*Burkholderia arbosis*) (containing 1×10^8 cells/g of carrier) as per the treatments of biofertilizers before sowing. Seed was spread on a polythene sheet and moistened by sprinkling water. Each culture was added @ 10 g/kg of seed to give a fine coating to the entire lot of seed. The treated seed was dried in the shade and used for sowing.

The recommended dose of nitrogen (39.1 kg/ha) as urea and phosphorus (60 kg P_2O_5/ha) as single superphosphate (SSP) was applied at the time of sowing. The harvesting of soybean was done manually on November 3, 2014 and November 2, 2015 from the net plot area. The harvested crop was kept for sun drying and then the threshing was carried out. Threshing was done with an engine operated thresher. Plant samples were analyzed for of nitrogen, phosphorus and potassium content using standard laboratory procedures. An their uptake was calculated by multiplying the per cent of nutrient content in seed and straw with their respective yields on dry weight basis and expressed in kg/ha.

The energy values for various inputs and outputs were computed as suggested by Singh and Mittal (1992) (Table 1). The total energy input was calculated by adding the energy requirement for human labour, diesel, seed, biofertilizers, herbicides, irrigation and fertilizers used. The energy output was calculated by the energy value of seed yield and straw yield. The energy input and output were expressed as Mega Joule (MJ). The net energy, energy-use efficiency and energy productivity were computed as follows.

Net energy (MJ/ha) = Output energy – input energy

Table 1. Energy equivalents for various sources of energy

Particular	Units	Equivalent energy (MJ)
Inputs		
Human labour	Man-hour	1.96
Seed	kg	14.7
Superior chemicals (Herbicides, insecticides)	kg	120
Diesel	Litre	56.31
Electricity	KWh	11.93
Chemical fertilizers		
N	kg	60.60
P_2O_5	kg	11.10
K_2O	kg	6.70
Biofertilizers	kg	10
Man	Man-hour	1.96
Electricity	KWh	11.93
Submersible pump	HP	68.4
Output		
Seed	kg	14.7
Straw	kg	12.5

$$\text{Energy-use efficiency} = \frac{\text{Energy output}}{\text{Energy input}}$$

$$\text{Energy productivity (kg/MJ)} = \frac{\text{Seed yield}}{\text{Energy input}}$$

The cost of cultivation was worked out on the basis of prevailing market prices of inputs and outputs (Table 2). Gross returns were calculated by multiplying the price of soybean (₹36,000 and ₹38,000/t during 2014 and 2015 respectively) with their seed yield and expressed as ₹/ha. Net returns were calculated by subtracting total cost of production (Table 2) from the gross returns and expressed as ₹/ha. Benefit: cost ratio was calculated by dividing the net returns with total cost of production treatment-wise. The data collected on various aspects of the investigations were statistically analyzed and the comparisons were made at 5% level of significance.

RESULTS AND DISCUSSION

Productivity and economics

Seed yield was significantly higher in happy seeder

Table 2. Costs (₹/ha) of different operations and price of inputs and outputs (₹/kg)

Treatment	Operation	Mechanical labour (hrs)*	Human labour (hrs)**	2014	2015
Planting methods					
Happy seeder	Sowing	3 hr 20 min	3 hr 20 min × 2	1,484	1,466
				1,484	1,466
Straw chopper	Straw chopper	3 hr 20 min	3 hr 20 min	1,367	1,333
ZT	Sowing	2 hr 30 min	2 hr 30 min × 2	1,113	1,100
				2,480	2,433
CT	Disc 1	2 hr 30 min	2 hr 30 min	1,025	1,000
	Cultivator 2	3 hr 20 min	3 hr 20 min	1,367	1,333
	Planking 2	2 hr 30 min	2 hr 30 min	1,025	1,000
	Sowing	2 hr 30 min	2 hr 30 min × 2	1,113	1,100
				4,530	4,433
Inputs		*Particulars*			
Seed		Soybean		50	50
Biofertilizers		*Bradyrhizobium*		100	100
		PGPR		100	100
Fertilizers		Urea		5.40	5.44
		SSP		8.20	8.20
Herbicides		Stomp 30 EC (pendimethalin)		450/L	450/L
		Parimaze 10 SL (imazethapyr)		1,500/L	1,500/L
Insecticides		Polo 50 WP (difenthiuron)		7,000/L	7,000/L
		Ekalux 25 EC (quinalphos)		480/L	500/L
Irrigations				37	40
Human labour (hrs.)				35	40
Output					
		Seed		36	38

*Mechanical labour @ ₹375 and 360/h during 2014 and 2015 respectively; **Human labour @ ₹35 and 40/h during 2014 and 2015 respectively sowing than straw chopper + zero tillage sowing and conventional sowing (Table 3). Happy seeder sowing registered 14.6 and 17.0% higher seed yield than straw chopper + zero tillage sowing and conventional sowing, respectively. The seed yield of Straw chopper + zero tillage sowing was statistically at par with conventional sowing. Application of crop residues as surface mulch is known to improve soil nutrient status, modify the hydrothermal regimes of the soil surface by reducing the temperature (Aulakh *et al.,* 2012; Kumar *et al.,* 2013 and Prasad *et al.,* 2014), improve the soil physico-chemical and biological environment in the soil through addition of nutrients and enhanced microbial activity (Babujia *et al.,* 2010). Therefore, higher seed yield observed with the retention of crop residues as surface mulch might be due to improvement in soil physical structure, chemical and microbial status and thereby providing favourable environment for establishment, growth and development of the crop. Sekhon *et al.* (2005) also reported that wheat straw mulching increased soybean yield by 4.4 to 68.3% due to lowering of soil temperature and reducing evaporation loss. Inoculation of biofertilizers did not influence the seed yield significantly.

The gross returns, net returns and benefit: cost ratio were significantly influenced by different planting methods. Happy seeder sowing recorded significantly higher gross returns as compared to straw chopper + zero tillage sowing and conventional sowing, which might be due to more seed yield. However, gross returns obtained from straw chopper + zero tillage sowing were statistically at par with conventional sowing, which could be due to similar seed yields in these treatments.

Happy seeder sowing recorded significantly higher net returns as compared to straw chopper + zero tillage sowing and conventional sowing. However, net returns obtained from Straw chopper + zero tillage sowing were statistically at par with conventional sowing but, straw chopper + zero tillage sowing gave numerically higher net returns to the tune of ₹3,827/ha over conventional sowing. This, apart from higher seed yields, might be due to fewer field operations under happy seeder sowing compared to straw chopper + zero tillage sowing and conventional sowing, which resulted in lower fuel and labour cost. Similar results have also been reported in wheat (Singh *et al*., 2013) and soybean (Santos *et al*., 2015).

Significantly higher benefit: cost ratio of 2.59 was recorded in happy seeder sowing as compared to 2.03 in straw chopper + zero tillage sowing and 1.77 in conventional sowing, which might be due to reduction in cost of cultivation incurred on land preparation. Similarly, Karunakaran and Behera (2016) also reported higher benefit: cost ratio in zero tillage than conventional tillage in soybean–wheat system.

Combined inoculation of *Bradyrhizobium* and PGPR recorded the highest gross returns, net returns and benefit: cost ratio (Table 3). However, net returns were non-significantly affected by different biofertilizer treatments. Higher net returns under dual inoculation of biofertilizers have also been reported by Tairo and Ndakidemi (2013) in soybean. Different biofertilizer inoculations treatments did not influence the benefit: cost ratio significantly. However, the benefit: cost ratio was higher in dual inoculation of soybean seed with *Bradyrhizobium* + PGPR than single inoculation of *Bradyrhizobium* or PGPR, which might be due to higher seed yield.

Table 3. Effect of planting methods and biofertilizers on seed yield, economics and energy indices of soybean (pooled data of 2 years)

Treatment	Seed yield (t/ha)	Gross returns ($\times 10^3$ ₹/ha)	Net returns ($\times 10^3$ ₹ /ha)	Benefit: cost ratio	Energy input ($\times 10^3$ MJ/ha)	Energy output ($\times 10^3$ MJ/ha)	Net energy	Energy-use efficiency ($\times 10^3$ MJ/ha)	Energy productivity (kg/MJ)
Planting methods									
Happy seeder sowing	2.73	100.61	72.61	2.59	13.9	104.68	90.73	7.51	0.19
Straw chopper + zero tillage sowing	2.38	87.85	58.85	2.03	14.0	91.91	77.81	6.52	0.17
Conventional sowing	2.33	86.07	55.02	1.77	15.0	87.69	72.62	5.82	0.15
SEm±	0.071	2.65	2.65	0.09	–	1.78	1.78	0.12	0.005
CD (P=0.05)	0.144	5.32	5.32	0.18	–	3.57	3.57	0.24	0.01
Biofertilizer									
Bradyrhizobium	2.42	89.24	59.91	2.05	14.3	93.63	79.26	6.54	0.17
PGPR	2.48	91.50	62.17	2.13	14.3	94.28	79.91	6.58	0.17
Bradyrhizobium + PGPR	2.54	93.79	64.41	2.21	14.3	96.37	81.99	6.73	0.18
SEm±	0.071	2.65	2.65	0.09	–	1.78	1.78	0.12	0.005
CD (P=0.05)	NS	NS	NS	NS	–	NS	NS	NS	NS

PGPR, Plant growth promoting rhizobacteria

Nutrient uptake

The nitrogen content in seed was not influenced significantly by different planting methods. However, nitrogen content in straw was significantly higher in happy seeder sowing and straw chopper + zero tillage sowing than conventional sowing (Table 4). The nitrogen uptake by seed was significantly higher in happy seeder sowing (170.1 kg/ha) than straw chopper + zero tillage sowing (148.4 kg/ha) and conventional sowing (144.1 kg/ha). Similarly, the N uptake by straw (46.2 kg/ha) was significantly higher in happy seeder sowing than straw chopper + zero tillage sowing (40.4 kg/ha) and conventional sowing (37.3 kg/ha). Higher nitrogen uptake in seed and straw of soybean in happy seeder sowing may be due to wheat straw mulching, which modified the hydrothermal regime of the soil and resulted in better growth and productivity of the crop (Behera *et al.,* 2007). Furthermore, it may not only be due to higher seed and straw yield but also better growth environment by straw mulching that increased nodulation (Sekhon *et al.,* 2005) and probably more amount of nitrogen fixation (Kitou and Yoshida, 1994) and consequently more availability of nitrogen. Duseja and Dennis (2010) also reported higher nitrogen uptake by the soybean seed in no tillage than conventional tillage. Aulakh *et al.* (2012) reported higher uptake of nitrogen by soybean in crop residue amended treatments of both conventional tillage and conservation agriculture in soybean.

The phosphorus content in seed and straw were similar in different planting methods. Significantly higher phosphorus uptake by seed was recorded in happy seeder sowing (19.9 kg/ha) than straw chopper + zero tillage sowing (17.4 kg/ha) and conventional sowing (16.9 kg/ha) (Table 4). Similarly, phosphorus uptake by straw in happy seeder sowing (12.8 kg/ha) was significantly higher than straw chopper + zero tillage sowing (11.3 kg/ha) and conventional sowing (10.5 kg/ha). This might be due to higher seed and straw yield and production of organic acids as a result of higher microbial activity (Babujia *et al.,* 2010), which solubilized phosphate and resulted in more availability of phosphorus for its uptake by the crop. Seed phosphorus uptake was greater in no tillage compared with mould-board plough and conventional tillage (Singer *et al.,* 2008) in soybean.

The potassium content in seed and straw were not influenced significantly by different planting methods. The happy seeder sowing showed significantly higher K uptake by seed (53.9 kg/ha) as compared to straw chopper + zero tillage sowing (47.1 kg/ha) and conventional sowing (45.7 kg/ha). Similarly, happy seeder sowing showed significantly higher K uptake by straw (43.6 kg/ha) as compared to straw chopper + zero tillage sowing (38.5 kg/ha) and conventional sowing (35.7 kg/ha) (Table 4). Signifi-

Table 4. Effect of planting methods and biofertilizers on nutrient content and their uptake by seed and straw in soybean (pooled data of 2 years)

Treatment	Nitrogen content (%)		Phosphorus content (%)		Potassium content (%)		Nitrogen uptake (kg/ha)		Phosphorus uptake (kg/ha)		Potassium uptake (kg/ha)	
	Seed	Straw	Seed	Straw	Seed	Straw	Seed	Straw	Seed	Straw	Seed	Straw
Planting method												
Happy seeder sowing	6.24	0.90	0.73	0.25	1.97	0.84	170.1	46.2	19.9	12.8	53.9	43.6
Straw chopper + zero tillage sowing	6.24	0.89	0.73	0.25	1.97	0.84	148.4	40.4	17.4	11.3	47.1	38.5
Conventional sowing	6.17	0.87	0.73	0.24	1.95	0.83	144.1	37.3	16.9	10.5	45.7	35.7
SEm±	0.09	0.01	0.004	0.004	0.02	0.01	4.2	0.8	0.5	0.2	1.4	1.1
CD (P=0.05)	NS	0.02	NS	NS	NS	NS	8.5	1.7	1.1	0.5	2.9	2.3
Biofertilizer												
Bradyrhizobium	6.21	0.88	0.73	0.25	1.96	0.84	150.2	41.0	17.6	11.5	47.6	38.9
PGPR	6.22	0.89	0.73	0.25	1.96	0.84	154.1	41.1	18.0	11.4	48.8	38.9
Bradyrhizobium + PGPR	6.23	0.89	0.73	0.25	1.97	0.85	158.3	41.9	18.6	11.7	50.2	40.0
SEm±	0.09	0.01	0.004	0.004	0.02	0.01	4.2	0.8	0.5	0.2	1.4	1.1
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

cantly higher K uptake by seed in zero tillage has also been reported in soybean by Singer *et al*. (2008).

The nitrogen, phosphorus and potassium content in seed and straw were non-significantly influenced by different biofertilizer treatments (Table 4). Similarly, inoculation of seed with *Bradyrhizobium* and/or PGPR did not affect the nitrogen, phosphorus and potassium uptake by seed and straw significantly which might be due to similar seed and straw yield. However, dual inoculation of seed with *Bradyrhizobium* and PGPR recorded the highest nitrogen, phosphorus and potassium uptake by seed and straw, which might be due to synergistic effect of *Bradyrhizobium* and PGPR on seed yield as a result of production of plant growth hormones like auxins, gibberellins and cytokinins; siderphore production, phosphate solubilization and nitrogen fixation in soybean (Bashan and de-Bashan, 2010). There was no difference in nitrogen, phosphorus and potassium content in seed and straw but higher seed yield in dual inoculation of *Bradyrhizobium* and PGPR resulted in higher uptake.

Energy indices

The energy input was higher in conventional sowing than happy seeder and straw chopper + zero tillage sowing (Table 3). The input energy requirement was less in happy seeder and straw chopper + zero tillage sowings due to no energy expenditure on the seedbed preparation. The energy output was significantly higher in happy seeder sowing than straw chopper + zero tillage and conventional sowings which might be due to high seed yield. The net energy was significantly higher in happy seeder sowing than the other methods, which might be due to less expenditure of input energy and higher seed yield. However, energy input and output were non-significantly influenced by different biofertilizer treatments.

Energy-use efficiency (Table 3) was significantly higher in happy seeder sowing (7.5) and straw chopper + zero tillage sowing (6.5) than conventional sowing (5.8). Higher energy use efficiency in happy seeder and straw chopper + zero tillage sowings might be due to less input energy and high output energy. Karunakaran and Behera (2016) also reported highest energy use efficiency with zero tillage due to less energy used for seed-bed preparation, and slightly higher yield. However, energy use efficiency was not influenced significantly by different biofertilizer treatments.

Energy productivity was recorded significantly higher in happy seeder sowing (0.19) and straw chopper + zero tillage sowing (0.17) than conventional sowing (0.15), which could be due to higher seed yield and less energy input (Table 3). Single or dual inoculation with biofertilizers did not influence the energy productivity significantly, which might be due to higher seed yield.

It may be concluded that happy seeder sowing with higher seed yield, gross returns, net returns, benefit: cost ratio, less energy input, highest energy output, net energy, energy-use efficiency and energy productivity is superior and more promising as compared to straw chopper + zero tillage sowing and conventional sowing soybean production. Although single or dual inoculation of *Bradyrhizobium* and PGPR in soybean recorded almost similar benefits, dual inoculation of *Bradyrhizobium* and PGPR slightly improved the gross returns, net returns and benefit: cost ratio.

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