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Symbiotic Efficiency, Productivity and Profitability of Soybean as Influenced by Liquid Bio-inoculants and Straw Mulch

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ABSTRACT

A field experiment was conducted at College of Agriculture (RVSKVV), Indore during *kharif* (July–October) 2019 to study on physiological parameter, symbiotic efficiency, productivity and profitability of soybean as influenced by liquid bio-inoculants and mulch under Vertisols in relation to ten treatments. Results revealed that the higher growth attributes, physiological parameters and symbiotic parameters were recorded under *Rhizobium*+phosphours solubilizing bacteria (PSB)+mulch+foliar spray of Plant Growth Promoting Rhizobacteria (PGPR) @ 20 ml l^{-1} water in comparison to other treatments. The highest seed yield (1232 kg ha^{-1}), straw yield (1537 kg ha^{-1}), protein content (41.72%) and protein yield (51628 kg ha^{-1}) were obtained under *Rhizobium*+PSB (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1})+foliar spray of PGPR @ 20 ml lml l^{-1} water (at 35 days and flowering stage), which was at par with *Rhizobium*+mulch+foliar spray of PGPR @ 10 ml l^{-1} water, PSB +mulch+foliar spray of PGPR @ 15 ml l^{-1} water and *Rhizobium*+PSB +mulch. The maximum gross returns (₹ 48768 ha^{-1}), net returns (₹ 20762 ha^{-1}), B:C ratio (1.74), production efficiency (14.0 kg ha^{-1} day^{-1}) and economic efficiency (₹ 235.93 ha^{-1}) were also recorded under above treatment. Significantly higher nutrient uptake (82.61 and 35.31 kg N, 4.72 and 8.49 kg P, 24.17 and 41.27 kg K by seed and straw, respectively) were obtained under *Rhizobium*+PSB+mulch +foliar spray of PGPR @ 20 ml l^{-1} water.

KEYWORDS: Bio-inoculants, nutrient uptake, physiological parameters, symbiotic efficiency, yield

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1. INTRODUCTION

Soybean (*Glycine max* L. Merrill) being a leguminous crop, is capable to fix atmospheric nitrogen through biological nitrogen fixation and originated from China (Tomar et al., 2018 and Rahangdale et al., 2021). It is basically a legume crop, however, nowadays it is gaining popularity as an oilseed crop. Soybean grains are important as protein meal and vegetable oil (Virk et al., 2018a). Among the essential nutrients, macro-nutrients such as nitrogen, phosphorus and potassium play a crucial role in improving plant growth and yield (Singh et al., 2020). Soybean crop played a pivotal role in solving the problem of malnutrition as it contains about 20 percent oil and 40 percent high quality protein. Its protein is rich in valuable amino acid lycine (5%), in which, most of the cereals are deficient (Kumawat et al., 2019). In addition, it is an important source of K, Ca, Zn, Fe, B, and P. Its oil containing saturated fatty acids, like palmitic (12–13% of total oil) and stearic (3–4%) and unsaturated fatty acids such as oleic (19-23%), linoleic (48–58%) and linolenic (5–8%) (Khandkar et al., 2019). World soybean production is 341.76 million tonnes which is 4.17% less than the last year's soybean production (Anonymous, 2019–20). India ranks 6th rank in the world with respect to production after Brazil, United States, Argentina, China and Paraguay. In India it is cultivated in 10.16 million hectares, producing 8.35 million tonnes with average productivity of 822 kg ha^{-1}. Madhya Pradesh is the leading state in India grown on an area of 5.01 million hectares and production of 5.40 million tonnes with productivity of 858 kg ha^{-1} (Anonymous, 2018). Madhya Pradesh has substantial contribution around 60% of total area and production of India, which is why it is also known, as "Soya State" (Tomar et al., 2018).

The productivity of soybean can be increased by inoculation of bio-fertilizers and which have shown better results in sustaining the crop productivity and improving soil fertility (Kumar et al., 2020a). *Rhizobium* can add 20-200 kg N ha^{-1} under optimum soil conditions and thereby increased crop yield by 15-25% of crop yield (Htwe et al., 2019 and Singh et al., 2020). PGPRs improve the growth either through using their self metabolism (solubilizing phosphates, producing hormones or fixing nitrogen) or directly affecting the plant metabolism (enhancing the uptake of nutrients and water), enhanced root system, increasing the enzymatic activities or "helping" other beneficial micro-organisms to improves their action on the plants. It's may also promote plant growth by suppressing plant pathogens (Kumawat et al., 2017 and Kumar et al., 2021). Mulching is a desirable management practice which regulates farm environment and thereby enhances crop production through regulating soil temperature by reducing leaching and evapotranspiration, by increasing the soil organic matter content and by reducing nutrient loss due to run off (Sikka et al., 2018, Virk et al., 2018b and Virk et al., 2019). Organic mulches like wheat straw are easily available in nature at affordable prices and are easily degradable in nature after their use. Application of mulches good source of crop nutrition over a period in crop growth, suppress weeds and reduces evaporation loss in the aerobic system (Praharaj et al., 2017 and Kumar et al., 2020b). Mulches can improve water productivity and yields through an increase in the water holding capacity of soils (Rinku et al., 2016 and Jadav et al., 2021). It improve the moisture availability period, reduce evaporation loss and also stabilize soil temperature (Dhyani et al., 2016, Kumawat et al., 2020, Praharaj et al., 2020 and Kumawat et al., 2021). So, keeping in view the above observations, present investigation on the physiological parameter, symbiotic efficiency, productivity and profitability of soybean as influenced by liquid bio-inoculants and mulch under Vertisols has been undertaken.

2. MATERIALS AND METHODS

A field experiment was carried out at Research Farm, College of Agriculture (RVSKVV), Indore situated at 75° 48' East longitude and 22° 43' North latitude with an altitude of 567 meters above mean sea level during *kharif* season of (July to October) 2019 on a medium to black soil with pH of 7.8 and organic carbon 0.34 percent. The soil was low in available nitrogen (245.0 kg ha^{-1}) medium in available phosphorus (12.30 kg ha^{-1}) and high in potassium (480.2 kg ha^{-1}). The treatment were laid out in RBD in three replications with twelve treatments *viz*., T_1: Control, T_2 : *Rhizobium* (seed inoculation), T_3: PSB (seed inoculation), T_4: *Rhizobium*+PSB (seed inoculation), T_5: *Rhizobium* (seed inoculation) +mulch (wheat straw @ 5.0 t ha^{-1}), T_6: PSB (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1}), T_7: *Rhizobium*+PSB (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1}), T_8: *Rhizobium* (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1})+foliar spray of PGPR @ 10 ml l^{-1} water (at 35 days and flowering stage), T_9: PSB (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1})+foliar spray of PGPR @ 15 ml l^{-1} water (at 35 days and flowering stage) and T_{10}: *Rhizobium*+PSB (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1})+foliar spray of PGPR @ 20 ml l^{-1} water (at 35 days and flowering stage). Seeds of the crop (JS-20 34) were sown on 30 June 2019 and harvested on 25 September 2019. The recommended dose of fertilizer (30 kg N+60 kg P_2O_5+ 30 kg K_2O ha^{-1}) was applied to the soybean. A full dose of N, P_2O_5 and K_2O were applied at the time of sowing. Recommended local crop management practices, weed control measures and plant protection measures were done in the crops. Various growth and yield attributes were observed at harvest following the standard procedure. The net plot seed yield was converted to seed yield in terms of kg ha^{-1}. Protein content in seed was worked out by multiplying the nitrogen content in the seed with the factor by (Anonymous, 1960). Protein harvest was determined by multiplying the protein content in seed and straw with their respective yield. Prevailing market prices of inputs as per treatments of each crop was considered for working out the cost of cultivation. Net returns (₹ ha^{-1}) was calculated by deducting the cost of cultivation (₹ ha^{-1}) from gross returns, while B:C ratio were worked out as a ratio of gross return (₹ ha^{-1}) to cost of cultivation (₹ ha^{-1}) suggested by Kumawat et al. (2015).

Nitrogen fixation capacity was computed by the formula given Carter and Rennie (1984) which is expressed as:

Nitrogen fixation capacity =(TNCIP-TNCIC)/TNCIP)×100

Where:

TNCIP=Total nitrogen content in inoculated plant

TNCIC=Total nitrogen content in control plant

Nutrient uptake by seed and straw of crop was calculated in kg ha^{-1} in relation to dry matter production/ha by using the formula.

Nutrient uptake (kg ha^{-1})=(Nutrient content (%)× yield (seed/straw in kg ha^{-1})×100

Production efficiency and economic efficiency were calculated as following the formula suggested by Kumar et al. (2014a).

Production efficiency (kg ha^{-1} day^{-1})=Seed yield (kg ha^{-1})/ The total duration taken crop (days)

Economic efficiency (₹ ha^{-1} day^{-1})= Net return (₹ ha^{-1})/ Total duration taken crop (days)

All the data obtained from the trial was statistically analyzed using the F-test (Gomez and Gomez 1984). Critical difference (CD) values at p=0.05 were used to determine the significance of differences between mean values of treatments.

3. RESULTS AND DISCUSSION

3.1. Growth and physiological parameters

The growth characters (plant height, branches $plant^{-1}$, dry matter accumulation $plant^{-1}$) and physiological parameters (leaf area, leaf area index, CGR, RGR, chlorophyll content) were significantly affected by liquid bio-inoculants and mulching during the investigation (Table 1). Significantly

Table 1: Effect of liquid bio-inoculants and mulch on growth and physiological parameters of soybean

Treatments	Plant height (cm)	Branches $plant^{-1}$	Dry matter accumulation $plant^{-1}$	Leaf area (cm^2)	Leaf area index	CGR (g $plant^{-1}$ day^{-1})	RGR (g g^{-1} $plant^{-1}$)	Chlorophyll content (SPAD value) at 60 DAS
T_1	41.95	4.03	17.80	47.86	0.120	0.078	0.022	37.99
T_2	44.90	4.38	20.17	48.81	0.122	0.082	0.025	39.27
T_3	43.77	4.24	19.33	48.63	0.122	0.082	0.025	39.13
T_4	45.17	5.00	21.10	50.33	0.126	0.092	0.030	40.53
T_5	46.80	5.65	21.53	52.73	0.132	0.092	0.030	41.67
T_6	46.74	5.62	21.48	52.48	0.131	0.092	0.030	42.31
T_7	48.82	6.05	22.80	53.52	0.134	0.093	0.030	43.31
T_8	49.08	6.10	23.50	54.21	0.136	0.094	0.031	44.63
T_9	48.89	6.02	23.48	54.14	0.135	0.096	0.032	44.09
T_{10}	49.55	6.33	24.24	54.54	0.136	0.098	0.034	44.46
SEm±	1.59	0.33	1.27	1.64	0.004	0.01	0.003	1.50
CD (p=0.05)	4.73	0.97	3.78	4.86	0.012	0.02	0.009	4.47

T_1: Control; T_2: *Rhizobium* (seed inoculation); T_3: PSB (seed inoculation); T_4: *Rhizobium*+PSB (seed inoculation); T_5: *Rhizobium* (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1}); T_6: PSB (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1}); T_7: *Rhizobium*+PSB (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1}); T_8: *Rhizobium* (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1})+foliar spray of PGPR @ 10 ml l^{-1} water (at 35 days and flowering stage); T_9: PSB (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1})+foliar spray of PGPR @ 15 ml l^{-1} water (at 35 days and flowering stage); T_{10}: *Rhizobium*+PSB (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1})+foliar spray of PGPR @ 20 ml l^{-1} water (at 35 days and flowering stage) higher plant height (49.55 cm), branches plant^{-1} (6.33) and dry matter accumulation plant^{-1} (24.24 g) were found with the application of *Rhizobium*+PSB+mulch (wheat straw @ 5.0 t ha^{-1})+foliar spray of PGPR @ 20 ml l^{-1} water (T_{10}) which was at par with all the treatments except control, *Rhizobium* and PSB alone. Similarly, the maximum leaf area (54.54 cm^2), leaf area index (0.136), RGR (0.034 g g^{-1}plant^{-1}) and chlorophyll content (44.46 SPAD value) were observed under *Rhizobium*+PSB+wheat straw mulch @ 5.0 t ha^{-1}+foliar spray of PGPR @ 20 ml l^{-1} water (T_{10}) which was statistically at par with rest of the treatments except control, *Rhizobium* and PSB alone. The increase in growth parameters may be due to the factor of photosynthesis production which was higher due to increased levels of inoculation. The inoculated produced more and healthy nodules which in turn translocation nitrogen from, the lower to the growing tips and enlarged the height of the plant. The combined application of bio-inoculants and mulch provided nutrients to the plants and mulch helps in maintaining adequate soil moisture which helps in reduces stomatal closure; this opens the pathway for the exchange of water, carbon dioxide and oxygen, resulting in increases in photosynthetic rate and thereby increasing vegetative growth of plants. These results are in accordance with the findings of Arora et al. (2011), Jain (2015), Kumar et al. (2020) in pea and Rahangdale et al. (2021) in soybean.

3.2. *Symbiotic parameters*

The symbiotic parameter (total nodules, effective nodules, fresh and dry weight of nodules plant^{-1}) was significantly influenced by liquid bio-inoculants and mulch (Table 2). The total number of nodules plant^{-1} (26.17), effective nodules plant^{-1} (19.69), fresh weight of nodules plant^{-1} (703.33 mg) and dry weight of nodules plant^{-1} (132.45 mg) were highest in (T_{10}) *Rhizobium*+PSB+mulch @ 5.0 t ha^{-1}+foliar spray of PGPR @ 20 ml l^{-1} water which was on par with rest of the treatments (except T_1, T_2, T_3 and T_4) while minimum values these parameters were observed in control (T_1) where the recommended dose of fertilizer (RDF) was applied. The significantly higher nitrogen fixation capacity was also recorded with the application of *Rhizobium*+PSB+mulch @ 5.0 t ha^{-1}+foliar spray of PGPR @ 20 ml l^{-1} followed by PSB+wheat straw mulch @ 5.0 t ha^{-1} along with foliar spray of PGPR @ 15 ml l^{-1} water and *Rhizobium*+mulch @ 5.0 t ha^{-1}+foliar spray of PGPR @ 10 ml l^{-1} as compared to other treatments. The conjunction of bio-inoculants with

Table 2: Effect of liquid bio-inoculants and mulch on symbiotic parameters, yield and quality of soybean

Treatments	Total nodules plant^{-1}	Effective nodules plant^{-1}	Fresh weight of nodules plant^{-1} (mg)	Dry weight of nodules plant^{-1} (mg)	Nitrogen fixation capacity (%)	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Protein content (%)	Protein yield (kg ha^{-1})
T_1	19.33	13.80	473.33	93.67	0.00	864	1336	36.74	31808
T_2	20.17	14.50	483.33	101.00	2.27	899	1343	37.44	33655
T_3	19.83	13.83	480.00	103.33	1.90	888	1336	37.40	33128
T_4	21.67	16.17	573.33	109.81	4.00	937	1376	38.17	35941
T_5	23.60	17.87	663.33	124.92	7.21	994	1382	39.29	39060
T_6	23.43	17.62	660.67	124.54	6.33	983	1375	39.00	38350
T_7	24.00	19.43	687.67	129.75	8.69	1071	1457	39.94	42800
T_8	25.33	19.93	696.67	131.45	11.16	1177	1519	40.92	48035
T_9	25.00	19.47	687.33	129.14	10.38	1166	1510	40.57	47352
T_{10}	26.17	19.69	703.33	132.45	12.64	1232	1537	41.72	51628
SEm±	0.92	0.65	24.22	4.65	0.23	50	50	1.18	2662
CD (p=0.05)	2.73	1.94	71.97	13.82	0.69	149	148	3.51	7910

T_1: Control; T_2: *Rhizobium* (seed inoculation); T_3: PSB (seed inoculation); T_4: *Rhizobium*+PSB (seed inoculation); T_5: *Rhizobium* (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1}); T_6: PSB (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1}); T_7: *Rhizobium*+PSB (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1}); T_8: *Rhizobium* (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1})+foliar spray of PGPR @ 10 ml l^{-1} water (at 35 days and flowering stage); T_9: PSB (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1})+foliar spray of PGPR @ 15 ml l^{-1} water (at 35 days and flowering stage); T_{10}: *Rhizobium*+PSB (seed inoculation)+mulch (wheat straw @ 5.0 t ha^{-1})+foliar spray of PGPR @ 20 ml l^{-1} water (at 35 days and flowering stage) mulch had a favourable effect on soybean nodulation was increased by 8–220% in different cropping seasons (Shekon et al., 2005). Similar results were also reported by Kumar et al., (2010), Bhanwaria et al., (2013), Kumar et al., (2014b) and Singh et al., (2020).

3.3. Productivity

Seed yield and straw yield of soybean as affect by various bio-inoculants and straw mulching (Table 2). Highest seed yield (1232 kg ha^{-1}) and straw yield (1537 kg ha^{-1}) was recorded under T_{10} treatment where *Rhizobium*+PSB+mulch @ 5.0 t ha^{-1}+foliar spray of PGPR @ 20 ml l^{-1} water and it was closely followed by *Rhizobium* +mulch @ 5.0 t ha^{-1} along with foliar spray of PGPR @ 10 ml l^{-1} water (1177 and 1519 kg ha^{-1}), PSB+mulch along with foliar spray of PGPR @ 15 ml l^{-1} water (1166 and 1510 kg ha^{-1}) and *Rhizobium*+PSB +mulch @ 5.0 t ha^{-1}) (1071 and 1457 kg ha^{-1}) were registered 39.12, 36.22, 34.95 and 23.96 percent higher seed yield and 15.04, 13.69, 13.02 and 9.06 percent over control, respectively. It is clear that bio-inoculants (*Rhizobium*, PSB and PGPRs) solubilize the native sparingly soluble phosphates as well as nutrients in the soil which that might have enhanced the availability of plant nutrients and reducing the fixation in the soil. Thus, greater assimilation of photosynthates and their subsequent partitioning between vegetative and reproductive structures might have helped in enhancing the yield attributing characters and finally yields of soybean. These findings are corroborated with the results of Jain (2015), Tomar et al. (2018), Verma et al. (2017) and Htwe et al. (2019).

3.4. Quality parameters

Protein content and their yield were affected by bio-inoculants and straw wheat straw mulch (Table 2). The higher protein content (41.72%) was obtained with the application of *Rhizobium*+PSB+mulch @ 5.0 t ha^{-1}+foliar spray of PGPR @ 20 ml l^{-1} water, it was at par with each other and significantly superior to control, *Rhizobium*, PSB and *Rhizobium*+PSB. Similarly, maximum protein yield was recorded with *Rhizobium*+PSB+mulch @ 5.0 t ha^{-1}+foliar spray of PGPR @ 20 ml l^{-1} water, it was found closely followed *Rhizobium*+wheat straw mulch @ 5.0 t ha^{-1}+foliar spray of PGPR @ 10 ml l^{-1} water and PSB+wheat straw mulch @ 5.0 t ha^{-1} along with foliar spray of PGPR @ 10 ml l^{-1} water. The protein content in the seed is essentially a manifestation of N content. Increased N content due to seed inoculation with bio-inoculants and mulching resulted in higher protein content because of their beneficial role in enhancing N content in seed. The protein yield is related to seed yield and protein content, seed yield and protein content increased naturally increased the protein yield. Similar, findings have also been reported by Siczek et al. (2015), Htwe et al. (2019) and Rahangdale et al. (2021) in soybean.

3.5. Profitability

The economics of soybean were influenced significantly by bio-inoculants, mulch and PGPRs (Table 3). Among the various treatment, maximum gross returns (₹ 48,768), net returns (₹ 20,762 ha^{-1}), B:C (1.74) ratio, production efficiency (14.0 kg ha^{-1}day^{-1}) and economic efficiency (235.93 ₹ ha^{-1} day^{-1}) were recorded with the supplementation of *Rhizobium*+PSB+mulch @ 5.0 t ha^{-1}+foliar spray of PGPR @ 20 ml l^{-1} water. This was mainly due to higher seed yield, straw yield and net returns and relatively low

Table 3: Effect of liquid bio-inoculants and mulch on economics of soybean

Treatments	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio	Production efficiency (kg ha^{-1} day^{-1})	Economic efficiency (₹ ha^{-1} day^{-1})
T_1	34722	10736	1.45	9.82	121.99
T_2	36026	11980	1.50	10.21	136.14
T_3	35607	11561	1.48	10.09	131.38
T_4	37503	13397	1.56	10.64	152.23
T_5	39624	13078	1.49	11.29	148.61
T_6	39232	12686	1.48	11.17	144.15
T_7	42661	16055	1.60	12.17	182.44
T_8	46692	19346	1.71	13.37	219.84
T_9	46266	18560	1.67	13.25	210.90
T_{10}	48768	20762	1.74	14.00	235.93
SEm±	1888	1888	0.07	0.57	21.46
CD (p=0.05)	5610	5610	0.22	1.70	63.76

1US$=INR 71.02 (Average value for the month October, 2019) cost of biofertilizers and micronutrients. The additional cost of organic manures was compensated by the additional yield of soybean. This might be the improvement in growth and yield attributes and the ultimate increase in seed yield could be the reason for enhanced economic parameters in the above treatment. These findings are in conformity with Kumar et al. (2014a), Kalegore et al. (2018) and Jadav et al. (2021).

3.6. Nutrient uptake

The nutrients uptake by seed and straw (N, P and K) were significantly influenced due to different treatments (Figure 1). Significantly highest N, P and K uptake by seed and straw were recorded in the treatment T_{10} (*Rhizobium*+PSB+mulch @ 5.0 t ha^{-1}+foliar spray of PGPR @ 20 ml l^{-1} water), which was statistically at par with *Rhizobium*+mulch @ 5.0 t ha^{-1}+foliar spray of PGPR @ 10 ml l^{-1} water and *Rhizobium*+mulch @ 5.0 t ha^{-1}+foliar spray of PGPR @ 15 ml l^{-1} over the rest of the treatments. The *Rhizobium*, PSB and PGPR along with mulch enhanced the availability of nutrients to the plants which might have utilized in greater root development and nodulation which in turn resulted in higher nitrogen fixation in the soil by nodules. Thus, increased availability of macro and micro-nutrients resulted in greater uptake by the plants and ultimately increased their content in plants. Our findings are in agreement with those reported earlier (Kumar et al., 2014b, Rinku et al., 2016 and Kumawat et al., 2020).

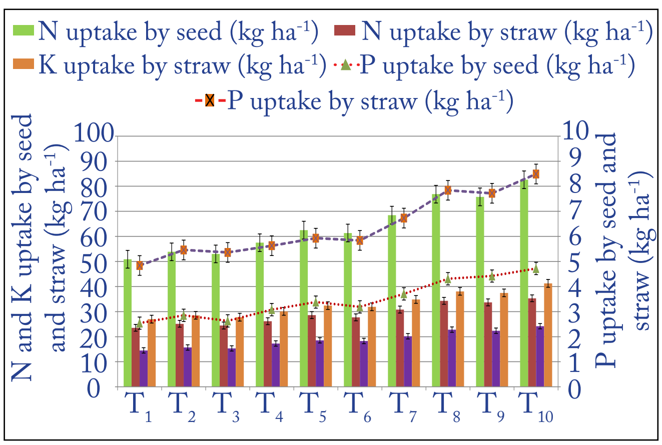

Figure 1: Effect of liquid bio-inoculants and mulch on nutrients uptake by seed and straw

4. CONCLUSION

Dual seed inoculation (*Rhizobium*+PSB)+wheat straw mulch @ 5.0 t ha^{-1} along with two foliar sprays of PGPR @ 20 ml l^{-1} water at 35 DAS and the flowering stage was beneficial and advisable for obtain higher growth parameters (plant height, branches and drymatter), yield attributes, yields, net returns, B:C ratio, protein content in seed and nutrient uptake of soybean under black cotton soils of Madhya Pradesh.

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