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Evaluation of partial factor productivity for soybean (*Glycine max* L. Merrill)

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ABSTRACT

A research trial was carried out during *kharif* season of 2019-20, 2020-21 and 2021-22 at the AICRP on Soybean Farm, School of agricultural Sciences, Nagaland University to evaluate the production factors of soybean and their effects on growth, yield and economics. The experiment was laid out in Randomized Block Design with 7 treatments replicated thrice. The treatments comprised of T₁-full package (seed treatment, seed inoculation, RDF, weed management, insecticide, ridge furrow), T₂-full package - seed treatment, T₃-full package - seed inoculation, T₄-full package - RDF, T₅-full package - weed management, T₆-full package - insecticide and T₇-full package - ridge furrow. Pooled results revealed that soybean grown with full package of practices gave highest growth and yield attributes and produced highest yield. Seed yield reduction of 91.24% and 69.90% with omission of weed management and RDF, was observed compared to full package of practice. Maximum yield gap was obtained with full package of practice excluding weed management and RDF. Partial factor productivity and Agronomic efficiency for NPK was higher with full package of practices.

Keywords: Factor productivity, Nutrient management, Soybean, Weed management, Yield

INTRODUCTION

Soybean is a protein rich oilseed crop cultivated over an area of 11 million ha in India yielding production of about 11.53 million tonnes. Soybean, also known as miracle crop or golden bean is a highly nutritious crop and has about 20% oil content, where it meets the shortage of edible oils and also serves as a major source of protein in several countries including India. Additionally, soybean protein contains 5% of lysine, a substance that is lacking in most cereals and gives the flour an added nutritional boost (Raghuveer and Keeerti, 2017).The by-

products of soybean in the form of oilcake and oil meal are either being exported or used as feed for livestock (Chand, 2007). The crop has its highest production in the state of Madhya Pradesh followed by Maharashtra, Rajasthan, Karnataka, Chhattisgarh and Telangana. The crop can be grown in most parts of India, and states like northeast states, Himachal Pradesh and Jharkhand, have good potential of soybean (Agarwal *et al.*, 2013).

The high yield of the soybean crop is the result of several interdependent variables. In order to complete its growth and development, soybean needs an ideal weather conditions, fertile and nutrient rich soil, optimum cultivation and management techniques (Agarwal *et al.*, 2013). Lack of seed treatment to seeds before sowing with fungicide, insecticide and bio fertilizers, lack of weed management due to unavailability of labour or continuous rain, lack of sufficient soil moisture due to long dry spells during crop growth period, imbalanced nutrition, improper insect and disease management etc., affect the seed yield and productivity of soybean (Jaybhay *et al.*, 2018). The production of soybeans can be strengthened to meet future demand for soybean crops by making sensible variety selections, employing sound agronomic techniques, and finding creative ways to deal with yield limits. Of late factor productivity appears to be declining owing to several factors, such as indiscriminate use of chemical fertilizers, over exploitation of land beyond their capability, decline in natural resources and change in climate. Therefore, there is a need to increase the productivity of crop per unit area, which can be done through the use of proper inputs such as seeds and their varieties, selection of suitable land, proper and right use of chemicals as well as labour. In terms of Soybean and all crops in general, application of nutrients in optimum amount at the right time and with the right method can increase and sustain crop production.

The way to get greater output from the same amount of inputs is the key to increase the efficiency of crop production. This is done through measures like total factor productivity, which is an indicator of how efficiently agricultural land, labour, capital and materials are used to produce an output. Partial factor productivity (PFP) calculated as the ratio of total output to total agricultural area is a useful measure of nutrient use efficiency as it provides an integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the system (Yadav, 2003). PFP is usually used as a measure of land and labour productivity because they are easier to estimate and shows higher rates of growth than TFP. Partial factor productivity is generally low due to inefficient use of nutrients, incidence of pest and diseases and other biotic

factors. If a unit of fertilizer does not increase the yield enough to pay for its cost, its application will not be economical and will not return profit even after a constant increase in the yield (Singh, 2004). In order to achieve optimum profitability, one must not only utilize fewer inputs per unit of land but also increase crop yields while decreasing production costs per unit of land. Economic analysis is therefore required to make recommendations for farmers based on experimental results.

MATERIALS AND METHODS

Experimental site

The experiment was carried out at the AICRP Soybean Project Farm, School of agricultural Sciences, Nagaland University, Medziphema during the *kharif* seasons of 2019-20, 2020-21 and 2021-22. Geographically situated at 20°45'43" N latitude and 93°53'04" E longitude at an altitude of 310 m above mean sea level. The region lies in a sub-tropical zone having hot and humid summers and cold winters. Throughout the study period from July to October, the amount rainfall received was 964 mm in 2019, 613.5 mm in 2020 and 656.4 mm in 2021. Average maximum temperature recorded was 32.52 C in 2019, 32.55 C in 2020 and 32.54 C in 2021 while average minimum temperature was 17.62 C in 2019, 24.2 C in 2020 and 23.19 in 2021. Relative humidity ranged from a minimum of 62 %-97 %, 52 %-97 % and 49 %-97 % during 2019, 2020 and 2021 respectively. The experimental soil was found to be sandy loam, very strongly acidic in nature with a pH of 4.55, low in available nitrogen (201.6 kg/ha), medium in available phosphorus (15.7 kg/ha) and potassium (150.8 kg/ha).

Treatment details

The experiment was laid out in Randomized Block Design (RBD) with 7 treatments replicated thrice. The treatments comprised of T₁-full package (seed treatment, seed inoculation, RDF, weed management, insecticide, ridge furrow), T₂-full package - seed treatment, T₃-full package - seed inoculation, T₄-full package - RDF, T₅-full package - weed management, T₆-full package - insecticide and T₇-full package - ridge furrow. Manure and fertilizers were applied as FYM @ 5t ha⁻¹, N @ 25 kg ha⁻¹, P₂O₅ @ 100 kg ha⁻¹ and K₂O @ 50 kg/ha. Soybean variety JS 97-52 was used as a test crop with spacing of 45x10 cm. Seeds were sown on 20th June, 2019, 17th July, 2020 and 12th July, 2021. One hand weeding at 30-45 days after sowing (DAS) was done to control weeds. Chlorpyrifos 20 EC @0.2% was applied before sowing as a means to control termites, while cypermethrin @1.5% was sprayed at flowering stage to check blister beetle. Seed

treatment with thiram 75WP + carbendazim 50WP (2:1) at 3g/kg seed and blanket spray of carbendazim @ 1.5g/kg seed was given at 45 DAS to reduce the incidence of diseases. Seed inoculation with Bradyrhizobium at 5g/kg seed was done just before planting under shade to maintain the viability of bacterial cells.

Observations recorded

The data on yield and its attributes was recorded at the time of harvest whereas, observations on growth attributes was recorded at 30, 45 and 60 days after sowing (DAS). Partial factor productivity (PFP) and agronomic efficiency (AE) for N/P/K was determined as per the formula given by Mengel and Kirkby (2001)

$$\text{PFP for N/P/K} = \frac{\text{Seedyield (kg ha}^{-1}\text{)}}{\text{Rate of nutrient applied (kg ha}^{-1}\text{)}}$$

$$\text{AE for N/P/K} = \frac{\text{Seedyield (kg ha}^{-1}\text{) in nutrient applied plot} - \text{seed yield (kg ha}^{-1}\text{) in control plot}}{\text{Nutrient applied (kg ha}^{-1}\text{)}}$$

Economics

The total cost for the system was calculated separately by taking into account all investments (labour and inputs) at prevailing market prices. The value of the main products and by-products in terms of monetary value was calculated separately based on prevailing market price and was recorded on unit area basis. Net return was calculated by subtracting the cost of cultivation from the corresponding gross returns and expressed as ₹ ha⁻¹. The benefit cost ratio (BCR) was calculated by following the formula

$$\text{B: C ratio} = \frac{\text{Net returns}}{\text{Cost of cultivation}} \times 100$$

Statistical analysis

Average values were worked out from the three years of trial and all the data's collected were analyzed in randomized block design using the technique of analysis of variance suggested by Gomez and Gomez (1984).

RESULTS

Growth attributes of soybean

Significant differences were observed during the study period in plant dry weight at 45 DAS, crop growth rate at 30-45 DAS and number of branches/plant at harvest due different crop

production practices. Pooled data of three years mentioned in Table 1 revealed that the treatment T₁-full package increased the dry weight of plant (4.34 g/plant), CGR (0.23 g/m²/day) and no. of branches/plant (3.75/plant) and it was found to remained at par with other treatment. The lowest dry weight of 2.33 g/plant, CGR of 0.09 g/m²/day and no. of branches of 2.50/plant was recorded in T₄i.e., full package excluding application of recommended dose of fertilizer. However, plant height and relative growth rate were not affected significant by the treatment.

Yield attributes and yield of soybean

Table 2 represents the pooled data of yield attributes and yield of soybean. A significant influence on yield attributes was recorded by practicing crop production factors where maximum pods/plant of 48.87 and seed index of 10.69 was obtained with T₁-full package and T₂-full package excluding seed treatment respectively while T₅-full package-weed management produced significantly lower values of pods/plant of 15.37 and seed index of 8.29.

Similarly, during the three years of experiment, cultivation of soybean by practising different crop production factors significantly affected the seed, straw and biological yield and harvest index. Soybean grown with full package of practices produces highest seed yield (1175.31 kg/ha), straw yield (1796.40 kg/ha) and biological yield (2971.70 kg/ha) and it was statistically at par with T₂ and T₇. Compared to other treatments, T₅-full package excluding weed management recorded significantly lowest seed yield (103.01 kg/ha), straw yield (304.03 kg/ha) and biological yield (407.04 kg/ha). Seed yield reduction of 91.24% and 69.90% in T₅ and T₄, respectively was observed compared to T₁. In case of harvest index, treatment T₃ recorded highest harvest index (40.08%) whereas the lowest value (25.23 %) was obtained with T₅.

Economics analysis

Economics of soybean crop under different crop production factors computed based on prevailing market price are presented in Table 3. The highest cost of cultivation (Rs 33109/ha) among the treatment was observed under treatment T₁ consisting of full package of practices while the lowest (Rs 25371/ha) was recorded with T₄ i.e., full package excluding RDF. The gross returns ranged from Rs. 6180.53/ha with treatment T₅ to Rs. 70518.47/ha with treatment T₁. Considering the inputs and the gross returns, treatment T₁ which consisted of the full package practices obtained the highest net returns of Rs. 37409.47/ha. The particular treatment also gave a benefit cost (B: C) ratio of 1.13 indicating that adopting the package practices could yield a higher return. The highest B: C ratio of 1.20 was, however, showed by treatment T₇ with full

package excluding ridge furrow along with net returns of Rs. 37039.33/ha, followed with a slight decrease by treatment T₂ with B:C ratio 1.15. It is also evident that treatments T₄ and T₅ showed a negative B:C ratio which is below the margin and profitable value, calling for incorporating other practices in addition to just RDF and weed management. Looking at the results, treatments T₃ and T₆ also showed a low non-profitable B: C ratio of 0.94 and 0.49, respectively.

The yield gap with reference to yield reduction per hectare over treatment T₁ was worked out where maximum yield gap was obtained under T₅ (1072.30 kg/ha) and T₄ (821.54 kg/ha) and the least gap was recorded under T₂ (41.95 kg/ha) and T₇ (42.84 kg/ha). Maximum value of differential yield per hectare depending on yield gap was found highest in treatment T₅ (Rs 64337.93/ha) and T₄ (Rs 49292.60/ha). Treatment T₄ (Rs 7738.00/ha) resulted in highest differential cost compared to T₁ consisting of full package while the least was observed in T₃ (Rs 220.00/ha). The highest incremental benefit cost ratio was obtained when soybean crop was grown with full package of practices excluding seed inoculation i.e., T₃ (30.37) compared to the rest of the treatment.

Partial factor productivity and Agronomic efficiency

Data with regard to partial factor productivity and agronomic efficiency for NPK presented in Table 4 showed that soybean crop grown with full package of practices resulted in maximum partial factor productivity of applied nutrients with nitrogen of 47.01 kg/ha, phosphorus of 11.75 kg/ha and potassium of 23.51 kg/ha. This was followed by T₂ with full package excluding seed treatment and T₇ with full package excluding ridge furrow. Decrease in PFP for NPK of 4.12 kg/ha, 1.03 kg/ha and 2.06 kg/ha respectively was observed in treatment T₅-full package-weed management compared to other treatment.

Pooled data on agronomic efficiency of applied nutrients to soybean indicated that treatment T₁ with full package of practices recorded higher agronomic efficiency with nitrogen of 32.86 kg/ha, phosphorus of 8.22 kg/ha and potassium of 16.43 kg/ha followed by treatment T₂ and T₇. The least agronomic efficiency was obtained in T₅-full package excluding weed management with nitrogen of 10.03 kg/ha, phosphorus of 2.51 kg/ha and potassium of 5.02 kg/ha.

DISCUSSION

Soybean crop grown with full package of practices resulted in highest dry weight of plants, crop growth rate and number of branches/plant. The increased in growth attributes might

be due to the inclusion of all agronomic practices such as seed treatment, seed inoculation, recommended dose of fertilizer, weed management, insecticides and ridge furrow. Similar finding was reported by Getachew and Abeble (2021) about the effect of seed treatment on the growth parameters of soybean. The effect of using N fertilization on nodule formation and BNF depends, e.g., on the amount of application and the timing of fertilization. High N concentrations can inhibit soy nodule formation and N fixation, while low N concentrations promote root nodules and biological nitrogen fixation as described by Lyu *et al.* (2019) and Ono *et al.* (2021). Inoculation of seeds with *Bradyrhizobium* along with optimal level of fertilization might have increased biological nitrogen fixation and improved soil fertility which enhanced the activities of meristematic tissues of the plant, increase in number and size of the cell and the efficient utilization of nutrients uptake. This, in turn encourage the emergence of branches and ultimately increased the crop growth rate and dry weight of plants. This finding aligns with the previous studies reported by Marinkovic *et al.*(2017).

The current study revealed that yield attributes such as number of pods/plants and seed index were increased when soybean cultivation was done following the full package of practices (T₁). Higher yield parameters can be attributed to several factors like seed treatment, seed inoculation, application of recommended dose of fertilizers, timely weed and insect pest management and ridge furrow planting. *Bradyrhizobium*, a bacterial strain used for soybean seed inoculation plays a pivotal role in the nitrogen cycle by infecting the roots of soybean plants and inducing the formation of nitrogen fixing nodules. These nodules might have provided an appropriate environment for atmospheric nitrogen fixation and its conversion into ammonium by nitrogenase activity (NA) which is a form of nitrogen available to the plant. Novytska *et al.* (2020), Jarecki (2023) and Krok *et al.* (2023) also reported a positive effect on the yield components with increased in N fertilization and higher N fixation caused by inoculation of seeds with *Bradyrhizobium* bacteria. Additionally, balanced application of fertilizers which increased their availability in soil along with effective weed management during critical period of crop-weed competition might have reduced the utilization of resources by weeds like moisture, nutrients, light and space and enhanced the nutrient uptake by crop resulting into better growth and yield attributing parameters. Suryawanshi *et al.* (2006) also documented higher number of pods/plant with 100% NPK application.

Higher seed and straw yield in treatment T₁-full package could be the result of maximum number of pods/plant obtained under this treatment due to the supply of all inputs and optimum management practices required for obtaining higher yield. Increase in seed yield of 22.72 % and 20.52 % under full package compared to full practice excluding RDF and full practice excluding weed management was observed by Jaybhay *et al.* (2022). A study by Lakshmyet *al.* (2020) also showed that foliar application of RDF gave a better yield and overall performance of soybean. In contrast, the lowest yield was observed in treatment T₅-full package excluding weed management followed by T₄-full package excluding RDF and T₆-full package excluding insecticide application. The findings demonstrated that, in comparison to the other crop management techniques, the lack of RDF to supplement the nutrients, unremoval of weeds that compete for resources and no insecticide application to manage the insect pests all contribute to maximum yield loss and evidenced the importance of individual cultivation practice to obtained higher yield. Increment in soybean seed yield due to high input system was supported by the findings of Marburger *et al.* (2016).

Economic evaluation of different treatments presented in Table 3 showed a negative B: C ratio which is below the margin and profitable value when the crop was grown with full package excluding RDF and weed management under treatment T₄ and T₅. This might be due to reduced grain and straw yield as a result of lower nutrient uptake and full season weed infestation. Although the cost of cultivation is higher in treatment T₁, it also gave a higher net returns and a profitable B: C ratio. For a more cost effective outcome, doses of chemical fertilizers can be reduced and integrated with organic manures. The least yield gap obtained in T₂ and T₇ demonstrated that seed treatment and ridge furrow has least effect on soybean seed yield compared to other management practices. Similar findings were reported by Jaybhay *et al.* (2022). Partial factor productivity is a measure of efficiency that includes production per unit of nutrient applied as described by Rose *et al.* (2012). Higher partial factor productivity and agronomic efficiency of applied nutrient to soybean crop obtained in treatment T₁: full package might be due to enhanced uptake and more utilization of indigenous nutrients and increased efficiency of applied nutrients which are taken up by the crop and utilized to produce seed. In contrast, decline in PFP and AE under treatment T₅: full package excluding weed management may be attributed to higher weed infestation and more nutrient uptake by weeds. The results are in agreement with McLaughlin *et al.* (2011), Patra *et al.* (2012) and Jaybhay *et al.* (2022).

CONCLUSION

Based on the pooled data of three years experiment, it can be concluded that inclusion of all agronomic practices such as seed treatment, seed inoculation, RDF, weed management, insecticide and ridge furrow proved best in enhancing the yield and yield attributes of soybean. Maximum partial factor productivity was also observed in the same treatment with 1175.31 kg ha⁻¹ of seed yield. While highest B: C ratio of 1.20 was obtained by treatment T₇: full package excluding ridge furrow.

Table 1. Effect on growth attributes due to different treatments

Treatment	Plant height at 60 DAS (cm)	Plant Dry weight (g/plant)			CGR (g/m ² /day)		RGR (g/g/day)		No of branches/plant at harvest
		30 DAS	45 DAS	60 DAS	30-45 DAS	45-60 DAS	30-45 DAS	45-60 DAS	
T ₁ - Full package (Seed treatment, seed inoculation, RDF, weed management, insecticide, Ridge furrow)	59.40	0.90	4.37	7.45	0.23	0.21	0.105	0.035	3.75
T ₂ - Full package – seed treatment	56.20	0.96	4.02	7.28	0.20	0.22	0.095	0.040	2.67
T ₃ - Full package – seed inoculation	54.93	0.91	2.97	6.27	0.14	0.22	0.078	0.051	3.00
T ₄ - Full package – RDF	58.10	0.91	2.33	6.14	0.09	0.25	0.068	0.065	3.50
T ₅ - Full package – weed management	55.87	0.79	2.38	5.69	0.11	0.22	0.073	0.059	2.50
T ₆ - Full package – insecticide application	55.67	0.76	3.44	6.86	0.18	0.23	0.100	0.046	2.50
T ₇ - Full package – Ridge furrow	59.47	0.80	2.94	6.51	0.14	0.24	0.087	0.053	3.50
SEm±	3.74	0.10	0.32	0.35	0.03	0.03	0.015	0.007	0.25
CD (P=0.05)	NS	NS	0.98	NS	0.08	NS	NS	NS	0.77

Table 2. Effect on yield and yield attributes due to different treatments

Treatment	Pods/ plant	Seed index	Seed yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	HI (%)	% decrease in yield compared to T₁
T ₁ - Full package (Seed treatment, seed inoculation, RDF, weed management, insecticide, Ridge furrow)	48.87	10.51	1175.31	1796.40	2971.70	39.67	-
T ₂ - Full package – seed treatment	43.24	10.69	1133.36	1785.16	2918.51	38.90	3.57
T ₃ - Full package – seed inoculation	43.43	10.62	1063.96	1613.94	2677.90	40.08	9.47
T ₄ - Full package – RDF	21.63	9.89	353.76	896.98	1250.74	27.55	69.90
T ₅ - Full package – weed management	15.37	8.29	103.01	304.03	407.04	25.23	91.24
T ₆ - Full package – insecticide application	36.30	10.23	779.33	1352.23	2131.56	36.71	33.69
T ₇ - Full package – Ridge furrow	46.15	10.28	1132.47	1742.74	2875.21	39.51	3.64
SEm±	3.81	0.18	31.02	53.74	64.50	1.20	
CD (P=0.05)	11.75	0.54	95.59	165.60	198.73	3.69	

Table 3. Effect on economic due to different treatments

Treatment	Gross Return (Rs/ha)	Cost of treatment (Rs/ha)	Net returns (Rs/ha)	B:C ratio	Yield gap (kg/ha)	Value of differential yield (Rs/ha)	Differential cost (Rs/ha)	IBCR
T ₁ - Full package (Seed treatment, seed inoculation, RDF, weed management, insecticide, Ridge furrow)	70518.47	33109	37409.47	1.13	-	-	-	-
T ₂ - Full package – seed treatment	68001.40	31598	36403.40	1.15	41.95	2517.07	1511.00	1.67
T ₃ - Full package – seed inoculation	63837.80	32889	30948.80	0.94	111.34	6680.67	220.00	30.37
T ₄ - Full package – RDF	21225.87	25371	-4145.13	-0.16	821.54	49292.60	7738.00	6.37
T ₅ - Full package – weed management	6180.53	28709	-22528.47	-0.78	1072.30	64337.93	4400.00	14.62
T ₆ - Full package – insecticide application	46759.60	31378	15381.60	0.49	395.98	23758.87	1731.00	13.73
T ₇ - Full package – Ridge furrow	67948.33	30909	37039.33	1.20	42.84	2570.13	2200.00	1.17

Table 4. Partial factor productivity (PFP) and agronomic efficiency (AE) of applied nutrients

Treatment	PFP (kg/ha)			AE (kg/ha)		
	N	P	K	N	P	K
T ₁ - Full package (Seed treatment, seed inoculation, RDF, weed management, insecticide, Ridge furrow)	47.01	11.75	23.51	32.86	8.22	16.43
T ₂ - Full package – seed treatment	45.33	11.33	22.67	31.18	7.80	15.59
T ₃ - Full package – seed inoculation	42.56	10.64	21.28	28.41	7.10	14.20
T ₄ - Full package – RDF	-	-	-	-	-	-
T ₅ - Full package – weed management	4.12	1.03	2.06	-10.03	-2.51	-5.02
T ₆ - Full package – insecticide application	31.17	7.79	15.59	17.02	4.26	8.51
T ₇ - Full package – Ridge furrow	45.30	11.32	22.65	31.15	7.79	15.57

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