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Sustainable Production of Soybean (*Glycine max* L.) Crop Through Chemical Fertilizers and Organic Manures Along with the Improvement in Soil Health

R. R. Lohar*† and C. P. Hase**
*Department of Environmental Science, B. G. College, Sangvi, Pune-411007, Maharashtra, India
**Department of Botany, B. G. College, Sangvi, Pune-411007, Maharashtra, India
†Corresponding author: R. R. Lohar; rajaram.lohar@ritindia.edu

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ABSTRACT

A field experiment was carried out on the black cotton soil in the years 2018 and 2019 in the district of Sangli, Maharashtra, India to evaluate the sustainable agricultural practices for improving the growth and yield of the soybean (*Glycine max* L.) variety *JS-335* along with the soil improvement. Twelve treatments were evaluated in a randomized block design with three replications. The results revealed that combined applications of chemical fertilizer (RDF-30:80:20:40) and organic manures (FYM and VCM) improved the growth attributes and seed yield as compared to control and other treatments along with a significant improvement in the soil health parameters. This agricultural practice emerged as a promising method for sustainable cultivation of soybean (*C.V. JS-335*) which improved the economic yield (kg.ha^{-1}), agronomic efficiency (kg.ha^{-1}), physiological efficiency (kg.ha^{-1}), partial factor productivity (kg.ha^{-1}), apparent recovery efficiency (kg.ha^{-1}) and sustainable yield index (0.80) with maximum return having cost: benefit ratio (1:3.8). The results found statistically significant and correlated having a positive relationship between yield and sustainability parameters.

INTRODUCTION

Soybean (*Glycine max* L.) is often designated as the "Golden bean" which is one of the most economic, nutritious, and oil seed crops, rich in protein and carbohydrate (Patil et al. 2017). The food items like soy milk, sauce, paste, cake, paneer, soy flour, soy-namkeen, and soy flakes are prepared from soybean on a commercial scale which is exceptionally very popular among consumers. It is also added to bread, cereals, and meat products (Huang et al. 2014). Soybean protein is rich in lycin, different minerals, and vitamins like thiamine and riboflavin (Dass et al. 2018). Because of these nutrient qualities in soybean it is known as 'vegetarian meat' and described as a 'miracle crop'. The area under soybean cultivation at the global level is 121.53 million hectares and production is 334.89 million tons. In India, the area under soybean cultivation is 11.72 million hectares with a production of 10.5 million tons (Anonymous 2014-15, ICAR). Leading states in the cultivation of soybean are Madhya Pradesh, Rajasthan, Maharashtra, and Andhra Pradesh. It was reported that the use of FYM and Vermicompost in soybean caused adequate expansion in plant development and seed yield in the two seasons (Ranjitha 2016). Javed & Panwar (2013) revealed that a mixture of organic and inorganic composts causes a significant rise in the yield of soybean. To meet the global demand for soybean, the application of sustainable agricultural practices is a need of time. Considering all these realities, present investigation was undertaken to evaluate sustainable agricultural practices through applications of different fertilizers for improving the soil health, growth parameters and the yield attributes of the crop. The sustainability of agricultural practices was assessed based on sustainable parameters like economic yield, agronomic efficiency, physiological efficiency, partial factor productivity, apparent recovery efficiency, and sustainability yield index.

MATERIALS AND METHODS

The present investigation was carried out on the black cotton soil in the Walwa-tehsil, Sangli district which is located in the western part of Maharashtra having latitude and longitude coordinators as 16.8676 and 74.5703 respectively. The average temperature is 25.4^{o}C and the total annual rainfall is 580 mm. The experiment was designed with RBD including 12 different treatments of organic and chemical fertilizers for soybean variety *JS-335*. The whole experimental field was divided into three equal blocks and each block was again divided into twelve equal-sized plots measuring 2.5 m × 2.5 m to accommodate the treatments and control. A total of 36 plots were prepared and all the treatments were

randomly designed. The seeds as well as FYM, VCM, and RDF were procured from authentic and reliable sources. The twelve treatments were selected with three replications and each consisted of T1:75% RDF, T2:75% RDF + 25% FYM, T3:75% RDF + 25% VCM, T4: 100% RDF, T5: 100% RDF + 25% FYM, T6: 100% RDF + 25% VCM, T7: 125 % RDF, T8: 125% RDF + 25% FYM, T9: 125% + 25% VCM, T10: 100% FYM, T11: 100%VCM, T12: absolute control (No fertilizer). The recommended dose of fertilizer (RDF-30:80:20:40, N:P:K:S), Farmyard Manure, Vermicompost.

The N, P, K, and other nutrients of organic manures were determined by official methods of analysis of AOAC international (AOAC 2005). N was estimated by the micro-Kjeldahl digestion method. Samples were digested with the nitric perchloric sulphuric acid mixture for the determination of P, K, Ca, and Mg. Phosphorus was determined by colorimeter using the vanadomolybdate method, K was determined using a flame photometer, and Ca and Mg were determined by the EDTA titration method.

The Chemical Composition of Organic Manures

Farmyard manure: N-0.52%, P_2O_5-0.22%, K_2O-0.54%, Na-0.08%, S-0.01%, Fe-1900 mg/kg, Zn-52mg/kg, B-2.1mg/kg, Mo-0.72 mg/kg, Cu-2mg/kg, Mn-6mg/kg

Vermicompost: N-0.54%, P_2O_5-0.023%, K_2O-0.28%, Na- 0.12%, Fe- 1.1%, Zn-0.09%, Ca-0.003%, Mg-0.32%, Cu-0.003%, Mn-0.10%

The organic and inorganic fertilizers were applied to each plot according to the planned treatments. The whole amount of organic manures was applied on a dry weight basis basally during final land preparation. The organic manures were applied one month before sowing so that well decomposition of the organic manures would take place for the crop and thoroughly incorporated into the soil. The growth parameters, seed yield, biochemical analysis, and oil content in the seed were analyzed as and when required by using the random collection method of the samples. The experimental plot was ploughed in mid-November after the monsoon rains were over. The field was then harrowed and leveled properly. All stubbles were removed and the layout was done according to the experimental design. The seeds of soybean were treated with Rhizobium culture for the entire nutritional schedule as seed treatment before sowing the seeds except for the absolute control plot. The required chemical fertilizers were purchased from a fertilizer store by calculating the quantity as per the recommended dose of fertilizer applied to each plot. The seeds were sown directly into the plots by maintaining 10 cm plant to plant and 45 cm row to row spacing. The seeds were sown on 15th November for both consecutive seasons. The crop was irrigated after 15 to 20 days of interval. From time to time inter cultivation for weeding and other operations was carried out regularly. The second dose was given before the pod formation. The pods were harvested after the full maturity of the crop.

The observations on plant height were measured at 30, 45, 60, and 75 DAS using randomly selected ten plants from each treatment, and the average height was calculated. A total number of leaves per plant were measured at 30, 45, and 60 DAS using randomly selected ten plants from each treatment.

Yield attributes like number of immature pods per plant, number of mature pods per plant, number of seeds per pod, Seed index (100 seed weight), total seed yield (kg.ha^{-1}), and stover yield (kg.ha^{-1}) were analyzed from each treatment using randomly selected ten plants and the average was recorded in tables.

Analysis of soil: The soil samples (0-15cm) were collected from all the experimental plots at harvest. The samples were air dried and then sieved through a 2 mm sieve and stored in a polythene bag with labels. Soil samples were analyzed for available nitrogen, phosphorus, potassium, and organic carbon content. Available nitrogen was determined by the antacid potassium permanganate method (Subbiah & Asija 1956). Available phosphorus was determined by Olsen's method. The available potassium in soil extracts was analyzed using a flame photometer. The organic carbon was determined by Walkley-Black's (1934) chromic acid wet oxidation method.

Analysis of Sustainability Parameters

Harvest index (%), economic yield (kg.ha^{-1}), agronomic efficiency (kg.ha^{-1}), physiological efficiency (kg.ha^{-1}), partial factor productivity (kg.ha^{-1}), apparent recovery efficiency (kg.ha^{-1}), and Sustainability yield index were calculated by using following formulae.

i) $\text{Harvest index (\%)} = \frac{\text{Economic Yield (Kg/ha)}}{\text{Biological Yield (Kg/ha)}} \times 100$

ii) $\text{Agronomic efficiency (AE)} = \frac{Y-Yo}{F}$

iii) $\text{Physiological Efficiency} = \frac{Y-Yo}{U-Uo}$

iv) $\text{Apparent recovery efficiency (RE)} = \frac{U-Uo}{F}$

v) $\text{Partial Factor Productivity (PFP)} = \frac{Y}{F}$

vi) Sustainable Yield Index = $(Ym-SD)/Ymax$

Where, Y-yield of a harvested portion of the crop with nutrient applied, Y_o-Yield with no nutrient applied, F- Amount

of nutrient applied, *U*- Total nutrient uptake in above-ground crop biomass with nutrient applied, U_0- Nutrient uptake in above-ground crop biomass with no nutrient applied. *Ym*-Mean yield, SD- Standard Deviation, Y_{max}-Maximum yield, W_2-Weight of the empty flask (g), W_1-Weight of empty Flask + Weight of oil (g), *X*=Weight of a sample taken for extraction

Economics of soybean production: The cost of soybean production for all the treatments was calculated depending on input cost and the average market price of soybean per quintal. Overall returns were determined by deducting the cost of production from gross income. The cost-to-benefit ratio was estimated by the proportion of the total cost and gross returns of a particular treatment.

Statistical analysis: The data were statistically analyzed for least significance difference (LSD) at a 5% probability level and coefficient of correlations by analysis of variance (ANOVA) using the data analysis tool pack of MS Excel (2013).

RESULTS AND DISCUSSION

Growth attributes: The growth attributes such as plant height, number of leaves per plant, number of branches per plant, leaf area, dry weight, etc. contribute to the crop yield (Rana & Badiyala 2014). It was observed that all these parameters were positively influenced by the treatment of different doses of organic manures like farmyard manure, vermicompost, and inorganic or chemical fertilizer like RDF. Plant height was increased in Soybean by all the treatments applied. The results recorded in Table 1 indicated that the application of RDF 125%+ Farmyard manure 25% and RDF 125% + Vermicompost 25% had shown a significant increase in plant height as compared to all other treatments and control. The results are statistically significant. The maximum plant height was recorded at 30, 45, 60, and 75 DAS in the combined application of RDF + FYM and RDF +VCM (Table 1). The plant height was increased with the advancement of age in all the stages of the crop growth because the growth process is irreversible (Patil & Udmale 2016). Thakur and Girothia (2010) and Saxena et al. (2013) also reported an increase in growth attributes like plant height, leaf number, leaf area, leaf area index, branch number, etc. ultimately increasing the productivity of soybean.

The number of leaves per plant was significantly increased with the combined applications of 125% RDF + farmyard manure 25% and 125% RDF + Vermicompost 25% (Table 1). It was 17.33 and 18.67, 36.67 and 37.00, 72.33 and 73.67 at 30 DAS and 60 DAS respectively. These treatments caused the highest increase in the

Table 1: Effect of fertilizer treatments on the growth attributes of soybean plants.

Fertilizer Treatment	Plant Height DAS(cm)				No. of leaves per plant DAS			Plant dry weight (g)			Nodule Count per plant		Nodule fresh weight (g)		Nodule dry weight (g)	
	30	45	60	75	30	45	60	30	45	60	30	45	30	45	30	45
T1	20.0	32.7	39.7	42.3	9.0	26.3	41.3	2.5	8.5	16.6	8.8	18.5	0.3	0.4	0.1	0.4
T2	20.6	38.3	53.3	57.4	10.3	18.3	44.3	2.5	11.0	17.4	11.4	38.2	0.3	0.4	0.1	0.4
T3	21.3	40.0	54.7	58.7	11.7	19.0	45.0	2.6	11.8	17.6	11.7	31.7	0.3	0.4	0.1	0.4
T4	22.3	42.3	58.0	61.7	10.1	26.7	45.3	2.6	13.5	18.3	10.4	31.3	0.3	0.4	0.1	0.4
T5	25.3	43.0	60.3	65.3	12.3	34.3	48.7	2.8	14.7	18.8	11.8	26.9	0.3	0.4	0.1	0.5
T6	26.4	43.7	61.3	67.4	13.0	34.7	48.3	2.9	14.8	19.0	12.0	27.3	0.3	0.4	0.1	0.6
T7	23.3	45.3	59.7	62.2	13.3	33.7	50.7	2.8	16.5	21.2	16.3	43.1	0.3	0.4	0.1	0.5
T8	28.3	47.7	67.0	69.8	17.3	36.7	72.3	3.2	17.8	23.4	19.3	35.9	0.3	0.4	0.1	0.5
T9	28.7	48.3	68.7	69.7	18.7	37.0	73.7	3.3	18.0	23.5	20.1	36.0	0.3	0.4	0.1	0.5
T10	18.3	30.3	32.0	38.2	9.7	24.3	40.3	2.5	7.5	17.9	9.8	34.0	0.2	0.4	0.1	0.3
T11	19.3	32.3	33.0	39.3	10.0	25.7	41.0	2.5	7.9	18.0	10.0	34.5	0.2	0.4	0.1	0.3
T12	14.0	22.7	28.0	38.0	7.7	14.3	36.0	2.1	6.6	13.2	8.3	20.7	0.2	0.3	0.1	0.3
LSD (0.05)	8.06	13.95	28.67	26.69	7.04	15.19	26.31	0.62	8.61	5.28	8.68	14.64	.07	0.03	0.030	0.18
SE±	1.09	1.88	3.87	3.60	0.95	2.05	3.55	0.08	1.16	0.71	1.17	2.05	0.00	0.00	0.004	0.02
CV%	15.66	15.50	24.06	20.84	25.66	23.66	23.55	10.39	29.93	12.33	30.27	20.22	11.47	3.7	17.51	19.31

Note: LSD-Least Significant Difference at p=0.05, SE±: Standard Error of the Mean, CV%: Coefficient of Variation

number of leaves per plant as compared to the remaining treatments and control. The leaves are the main photosynthetic organ of every plant, hence increase in the number of leaves increases the photosynthetic area and chlorophyll content. The increase in plant height and number of leaves per plant leads to an increase in yield (Thakur & Girothia 2010, Devi et al. 2011, Kumar et al. 2016).

It was reported that there was an increase in plant dry weight in soybean for different treatments (Table 1) but it was revealed that the combined treatments of RDF + FYM and RDF + VCM emerged as superior treatments causing an increase in dry weight of plant as compared to other treatments used and control. The increase in dry weight of soybean was recorded at 30, 45, and 60 DAS. The increase was by 3.15 g and 3.25 g, 17.83g, 18.00 g, 23.35 g, and 23.45 g at 30, 45, and 60 DAS respectively. All the results are statistically significant and the finding of the present investigation was supported by Jagmeet et al. (2015).

In leguminous plants like soybean number of nodules on the roots of each plant is a very important factor in growth attributes. The root nodules fix atmospheric nitrogen symbiotically and provide it to the host plant. The nitrogen supplied by root nodule bacteria contributes significantly and plays a vital role in plant growth (Chaturvedi et al. 2010). In the present study, all the treatments of chemical and organic fertilizers have significantly induced an increase in the number of nodules per plant (Table 1). Due to the application of 125% RDF + 25% FYM and 125% RDF + VCM 25%. The increase was by 19.33, 20.10, 35.90, and 36.00 respectively. This has directly influenced the various growth attributes like plant height, number of leaves per plant, etc.

The fertilizer treatments of RDF 125% + FYM 25% and RDF 125% + VCM 25% caused a positive increase in the fresh and dry weight of nodules in soybean (Table 1). Nodule fresh weight was 0.32 g, 0.33 g, 0.42 g, and 0.43 g at 30, 45, and 60 DAS. Which was much better than control and other treatments? The nodule dry weight recorded was 0.099, 0.098, 0.48, and 0.48 g at 30, 45, and DAS with both treatments. Similar results were reported by Billore et al. (2009) and Singh et al. (2010). They claimed that the combined application of synthetic and organic fertilizers increase positively soil condition as well as enhanced the activity of nodulation resulting in improved vegetative growth of the treated plant as compared to control. Further, they reported that such type of fertilizer application to plants increases their metabolic activities and causes improvement in various growth parameters. In the present study sulfur present in the RDF is an integral component of the nitrogenase enzyme playing a key role in nitrogen fixation. This may be the probable reason for the increase in the number of nodules per plant, the fresh and dry weight of nodules in soybean treated with RDF + FYM and RDF + VCM (Najar et al. 2011). The additional probable reasons for the improvement of growth attributes and nodule number, dry and fresh weight of nodule may be due to the different types of enzymes and growth-promoting factors secreted by earthworms in vermicompost.

Yield and yield attribute: The results shown on this parameter in Table 2 indicated that a maximum number of pods per plant were recorded in the treatments of combined applications of RDF + FYM and RDF + VCM as compared to all other treatments and control. The highest number of pods per plant observed in soybean was 64.80 and 65.27 respectively in both the treatments. Similar results were observed by Rana et al. (2018) with combined treatments of organic and chemical fertilizers for the increase in the growth of the number of pods per plant. As recorded in Table 2 highest number of filled pods was also recorded in the treatments of combined applications of RDF + FYM and RDF + VCM. The maximum number of filled pods per plant recorded in both treatments was between 55 and 56. Both the parameters studied have greatly contributed to an increase in economic yield over control and remaining treatments (Singh & Rai 2004). The results recorded in Table 2 clearly showed that the highest results on this parameter were recorded in the combined treatments T8 and T9 i.e. RDF + FYM and RDF + VCM. The significant values are 2.83 and 2.90 seeds per pod respectively. The increase in the number of seeds per pod has a direct relation with enhanced seed yield or economic yield. All the above parameters mentioned have a direct relationship with economic yield in soybean (Suryawanshi et al. 2006). Similar to the increase in economic yield stover yield was also very high in both the treatments T8 (3184.47 $kg.ha^{-1}$) and T9 (3210.28 $kg.ha^{-1}$). It is seen that among these two better treatments of combined fertilizers T9 which is RDF + VCM was superior to T8 (RDF + FYM) and slightly better over T8 (Khutate et al. 2005).

Biological yield is a very important aspect of the cultivation of legume crops like soybean. The results recorded on this parameter in Table 2 indicates that the biological yield was also highest in the treatments of T8 and T9 in which combined application of RDF + FYM and RDF + VCM was followed for the soybean crop. The recorded values were 5669.64 $kg.ha^{-1}$ and 5720.61

Table 2: Effect of fertilizer treatments on yield and yield attributes of Soybean.

Season 2018/2019								
Fertilizer treatment	No. of Pods per plant	No. of filled Pods per plant	No. of Seeds per Pod	Stover Yield ($kg.ha^{-1}$)	Biological Yield [$Kg.ha^{-1}$]	Harvest Index [%]	Seed Index [%]	Economic Yield ($kg.ha^{-1}$)
T1	50.7	40.0	2.6	2,057.5	3,478.1	40.8	13.3	1,420.6
T2	52.3	44.3	2.6	2,184.3	3,814.4	42.7	14.1	1,630.1
T3	53.0	44.9	2.6	2,208.0	3,853.1	42.7	14.3	1,645.0
T4	51.9	45.3	2.6	2,674.5	4,384.6	39.0	15.1	1,710.1
T5	55.1	70.8	2.6	2,884.0	4,962.3	41.9	14.7	2,078.3
T6	55.9	70.9	2.7	2,910.2	5,020.3	42.0	18.9	2,110.1
T7	56.9	47.9	2.6	3,085.3	5,275.3	41.5	15.1	2,190.0
T8	64.8	55.3	2.8	**3,184.5**	**5,669.6**	**43.8**	**15.8**	**2,485.2**
T9	65.3	56.0	2.9	**3,210.3**	5,720.6	43.9	16.1	2,510.3
T10	48.3	39.7	2.3	2,028.7	3,536.8	42.6	12.2	1,508.1
T11	48.8	40.3	2.3	2,082.0	3,592.1	42.0	12.7	1,510.1
T12	40.6	33.3	2.3	1,228.4	2,439.0	49.6	11.8	1,210.6
LSD (0.05)	12.76	25.58	0.42	1080.28	1948.98	3.05	4.06	887.36
SE±	1.72	3.45	.057	146.06	263.51	0.41	0.55	119.97
CV%	10.44	22.72	7.35	18.69	19.49	3.25	12.36	21.04

Note: LSD-Least Significant Difference at p=0.05, SE±: Standard Error of the Mean, CV%: Coefficient of Variation

$kg.ha^{-1}$ respectively. When the effect of both treatments on biological yield is compared the treatment T9 (RDF + VCM) had shown better results than T8 (Devi et al. 2011). The results on the harvest index showed the same trend as that of the seed index. The treatments of RDF + FYM and RDF + VCM had shown almost similar values (43.83% and 43.88%). Amongst all the yield attributes harvest index is the most reliable indicator of crop profitability and economic returns in general. The profitability of any crop when it is cultivated is judged through the values of the harvest index.

$$\text{As it is the ratio of } \left(\frac{\text{Economic Yield (Kg/ha)}}{\text{Biological Yield (Kg/ha)}} \right) \times 100$$

These results are in conformity with the findings of Shweta et al. (2014). The results on the seed index revealed that the superior treatments T8 and T9 were almost at par (15.84% and 16.05%). Both treatments were equally influenced by the results of the seed index (Bandopadhyay et al. 2010).

Soil health: Soil health was significantly improved by the application of RDF + FYM and RDF + VCM (Table: 3). The contents of different soil nutrients and organic carbon were increased due to the application of a combination of fertilizers in T8 and T9 as compared to the control and other treatments. The increase in organic carbon was very high in T8 and T9 treatment (5.63 $g.kg^{-1}$ and 5.67 $g.kg^{-1}$) as compared to control (3.90 $g.kg^{-1}$). Organic carbon plays a major role in the improvement of soil fertility and soil health. It has a direct effect on the increase in seed yield and seed quality in soybean. As soybean is a nodule crop fixing nitrogen symbiotically, effectively helps in the improvement of soil health and fertility. Similar results were recorded by several researchers Navale et al. (2003), Kundu et al. (2008), and Muneshwar et al. (2008). They claimed that the application of FYM and vermicompost resulted in higher content of N, P, K, and seed yield as well as oil content in soybean. The chemical or synthetic fertilizer if applied alone causes soil pollution and desertification of soil but the application of vermicompost and FYM as well as Nano-compost help to improve soil fertility, physico-chemical properties of soil, and biological properties such as soil enzymes, soil microflora, etc. are improved having with great effect on yield and yield quality of various crops (Naderi & Danes 2013).

Sustainability parameters: The application of organic fertilizers along with chemical fertilizers is an effective method for the sustainable cultivation of different crops (Table 4). The organic fertilizers showed a significant effect on economic yield, agronomic efficiency, physiological efficiency, partial factor productivity, apparent recovery, and

Table 3: Effects of fertilizer treatments on organic carbon and available nutrients in the soil before sowing and after harvesting in soybean (Pooled over 2 years).

Fertilizer Treatments	Before sowing					After harvest				
	N ($kg.ha^{-1}$)	P_2O_5 ($kg.ha^{-1}$)	K_2O	S	OC ($g.kg^{-1}$)	N ($kg.ha^{-1}$)	P_2O_5	K_2O	S	OC ($g.kg^{-1}$)
T1	182.7	13.4	164.2	16.9	4.1	214.3	17.8	165.3	17.3	4.2
T2	198.4	17.4	179.3	15.9	4.4	221.6	21.3	182.2	16.7	4.5
T3	200.8	17.9	180.8	16.8	4.4	223.4	21.8	183.1	17.0	4.5
T4	215.1	22.6	176.7	23.9	4.8	220.7	27.8	178.1	24.1	4.9
T5	230.4	18.3	181.2	24.8	5.2	232.3	22.1	183.8	25.7	5.4
T6	232.3	18.9	181.8	25.8	5.2	234.2	22.3	184.2	26.0	5.4
T7	255.2	21.2	182.7	26.7	5.4	258.9	23.3	186.5	27.6	5.5
T8	262.1	22.8	190.8	31.1	5.5	266.7	24.4	193.3	31.9	5.6
T9	265.0	23.0	190.9	30.4	5.6	267.4	24.7	194.0	31.8	5.7
T10	204.3	17.2	152.3	16.8	4.0	218.3	19.3	155.2	17.1	4.0
T11	205.4	17.4	152.8	16.8	4.0	219.2	19.7	156.1	17.1	4.1
T12	172.3	10.1	109.0	13.1	3.9	175.1	12.4	109.3	13.2	3.9
LSD(0.05)	62.74	6.72	30.06	13.0	1.41	45.17	6.26	30.24	13.60	1.48
SE±	8.48	0.90	4.06	1.76	0.19	6.10	0.84	4.08	1.83	0.20
CV (%)	12.60	15.79	7.66	26.1	13.24	8.64	12.6	7.60	26.58	13.59

Note: LSD-Least Significant Difference at p=0.05, SE±: Standard Error of the Mean, CV%: Coefficient of Variation

Table 4: Effect of fertilizer treatments on agronomic efficiency, physiological efficiency, partial factor productivity, apparent recovery efficiency, sustainable yield index in soybean.

Fertilizer treatments	Agronomic Efficiency (AE) ($kg.kg^{-1}$)	Physiological Efficiency (PE) ($kg.kg^{-1}$)	Partial Factor Productivity (PFP) ($kg.kg^{-1}$)	Apparent Recovery Efficiency (RE) ($kg.kg^{-1}$)	Sustainable Yield Index (SYI)
T1	7.0	5.5	47.4	1.3	0.4
T2	14.0	8.8	54.3	1.6	0.5
T3	14.5	8.9	54.8	1.6	0.5
T4	16.6	5.7	57.0	2.9	0.5
T5	28.9	9.0	69.3	3.2	0.7
T6	30.0	9.3	70.3	3.2	0.7
T7	32.6	8.2	73.0	4.0	0.7
T8	42.5	10.4	82.8	4.1	0.8
T9	43.3	10.5	83.7	4.1	0.8
T10	9.9	9.3	50.3	0.4	0.4
T11	10.0	9.1	50.3	0.4	0.4
T12	-	-	-	-	0.3
LSD(0.05)	36.31	14.8	29.57	3.17	0.3794
SE±	4.26	2.001	3.99	0.42	0.04
CV (%)	-	-	21.04	-	29.74

Note: LSD-Least Significant Difference at p=0.05, SE±: Standard Error of the Mean, CV%: Coefficient of Variation

sustainable yield index. All these sustainable parameters were highly improved due to the applications of chemical fertilizers along with FYM and vermicompost. The nutrient combination treatments of 125% RDF + FYM and 125% RDF + VCM emerged as the best sustainable treatments for the improvement of yield, yield parameters, growth parameters along with improvement in soil health.

Economics of the soybean cultivation using different fertilizers treatments: The economics of soybean cultivation was greatly influenced by the different treatments of fertilizers used (Table 5). It was seen from the data that a significant increase in seed yield (2510.3 (kg. ha^{-1}) was obtained for soybean variety JS-335 due to the treatment of T9 followed by T8. The maximum net return of Rs. 36,333.72 per hectare was achieved by these treatments. The cost-benefit ratio was 1: 3.8 followed by T8.

Correlation and regression analysis: The correlation coefficient between applied nutrients ($kg.ha^{-1}$) to the soil and accumulation of organic carbon ($g.kg^{-1}$), agronomic efficiency ($kg.ha^{-1}$), and economic yield ($kg.ha^{-1}$) were significantly and positively correlated ($r = 0.97$ & $r = 0.99$) respectively and there is a linear relationship between these variables. It all reflects the immediate effect of applied compost and VCM which has a direct influence on financial returns from the cultivation of soybean.

Multiple regression analysis: The multiple regression model employed to see the relationship between five independent variables (x_1 to x_5) and one dependent variable Y is given below.

Relationship between Yield of crop and Sustainability parameters

Regression equation:

$$Y = b_0 + b_1x_1+b_2x_2+b_3x_3+b_4x_4+b_5x_5+e$$

Where,

Y=Economic yield ($kg.ha^{-1}$)

b_0= Intercept value

x_1= Agronomic efficiency ($kg.ha^{-1}$)

x_2= Physiological efficiency ($kg.ha^{-1}$)

x_3= Partial factor productivity ($kg.ha^{-1}$)

x_4= Apparent recovery ($kg.ha^{-1}$)

x_5= Organic carbon ($g.kg^{-1}$)

The value of multiple R (0.99) and R^2 (0.99) is positive (0.99) indicating that there is a positive correlation between Economic yield and the observed values of Agronomic efficiency, Physiological efficiency, Partial factor productivity, and apparent recovery which also indicates the regression model fits the observed data. A positive coefficient indicates that as the value of the independent variables increases the mean value of economic yield increases. A low p-value (<0.05) and correspondent t-stat of independent variables indicate a highly significant increase in the economic yield. The changes in these independent variables are related to changes in the response variable indicating the results are highly significant.

CONCLUSION

It was reported that cultivation of soybean variety *JS-335*

Table 5: Economics of different fertilizer treatments for the cultivation of soybean variety JS-335 (Pooled for two years).

Fertilizer Treatment	Economic Yield ($kg.ha^{-1}$)	Gross Income ($Rs.ha^{-1}$)	Expenditure ($Rs.ha^{-1}$)	Net Income ($Rs.ha^{-1}$)	C:B ratio
T1	1,420.6	78,130.3	28,104.4	50,025.8	1:02.8
T2	1,630.1	89,655.5	31,458.1	58,197.4	1:02.9
T3	1,645.0	90,477.2	31,746.4	58,730.8	1:02.9
T4	1,710.1	94,053.9	32,432.4	61,621.5	1:02.9
T5	2,078.3	114,303.8	35,719.9	78,583.8	1:03.2
T6	2,110.1	116,054.4	35,168.0	80,886.4	1:03.3
T7	2,190.0	120,452.2	35,427.1	85,025.1	1:03.4
T8	2,485.2	136,684.4	36,941.7	99,742.6	1:03.7
T9	2,510.3	138,068.2	36,333.7	101,734.4	1:03.8
T10	1,508.1	82,945.5	26,756.6	56,188.9	1:03.1
T11	1,510.1	83,054.4	25,954.5	57,099.9	1:03.2
T12	1,210.6	66,581.9	25,412.9	41,169.0	1:02.6

* Average market rate of soybean Rs. 5500/q, **Total expenditure cost includes the expenditure from land preparation to the harvesting of turmeric.

showed promising results with the application of chemical fertilizers such as RDF and organic manures like FYM and vermicompost. There was significant improvement with these treatments in growth and yield attributes. Improvement in the yield attributes is directly related to the market price of soybean. The integrated application of chemical fertilizer + FYM and chemical fertilizer + vermicompost was found to be highly effective to improve soil health and productivity through improved sustainability attributes like agronomic efficiency, partial factor productivity, and sustainable yield index. The cost-benefit ratio of these treatments was comparatively higher indicating that such treatments may be recommended to the farmers for the sustainable cultivation of soybean.

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