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Synergistic Effect of Organic Manures and Bio-Fertilizers on The Morpho-Physiological and Yield Attributes of Soybean (Glycine Max L.) In Semi-Arid Rajasthan

Rasudden[1], P.K. Dhakad[2]*, N. K. Bhinda[2], Deepak Sharma[3], Rakesh Kumar[2], Jyotsna Dayma[2] and Bharti[2]

[1]School of Agricultural Sciences, Nirwan University, Jaipur
[2]Assistant Professor, School of Agricultural Sciences, Nirwan University, Jaipur
*Corresponding Author: puspendra.dhakad@nirwanuniversity.ac.in

Abstract

In Rajasthan, soybean is a pivotal crop, contributing approximately 50% of the region's oilseed production and serving as a vital protein source (36–56%). To optimize its cultivation, field trials were conducted during the 2024 Kharif season at the Nirwan University Agronomy Research Farm in Jaipur. This study evaluated the impact of organic manures and bio-fertilizers on the growth and yield of the PK 472 soybean variety. The research utilized a Randomized Block Design featuring eight treatment combinations across three replications. These ranged from an absolute control (T1) and 100% Recommended Dose of Fertilizers to integrated approaches combining RDF with Farm Yard Manure (FYM) or Vermicompost, augmented by Rhizobium and Phosphorus Solubilizing Bacteria (PSB). The results identified ***T8*** *(100% RDF + 5 t Vermicompost ha^{-1}+ Rhizobium + PSB) as the most effective treatment. It achieved superior growth metrics, including a plant height of 75.25 cm and 57.65 effective nodules. Furthermore, T8 recorded the highest yield attributes, such as a seed yield of 2,471 kg ha^{-1} and a harvest index of 37.03%. Conversely, the control group (T1) consistently yielded the poorest results, highlighting the significance of integrated nutrient management.*

Key words: *Organic manure, PSB, Rhizobium, Soybean, Vermicompost and Yield.*

Introduction

Soybean (Glycine max L.), historically designated as the "Manchurian bean," constitutes a cornerstone of global oilseed production, accounting for approximately 50% of the world's oilseed output and 30% of the total vegetable oil supply. Within the Indian subcontinent, it serves as a vital leguminous crop characterized by a significant nutritional profile containing 36–56% protein and 18% oil. According to 2024-25 production dynamics, India cultivated 12.87 million hectares with a total yield of 13.78 million tonnes (1071 kg ha^{-1}), while Rajasthan, the nation's third-largest producer, recorded 1.18 million tonnes from 1.08 million hectares at a superior productivity rate of 1089 ha^{-1}. Although the crop facilitates sustainable agriculture as symbiotically fixation nitrogen with Bradyrhizobium japonicum, intensive cultivation frequently precipitates soil degradation due to heavy nutrient extraction. While inorganic fertilizers provide rapid nutrient availability, they often lack the capacity to maintain long-term soil health; conversely, organic manures enhance soil structure and microbial activity but struggle to meet the peak nutritional demands of high-yielding varieties. Consequently, this study adopts an Integrated

Nutrient Management (INM) framework to evaluate the synergistic effects of organic manures, bio-fertilizers, and chemical inputs in mitigating biotic and abiotic stressors to optimize the growth and productivity of the PK 472 soybean variety.

Materials and Methods

Experimental Site and Environmental Conditions

The field experiments were executed during the Kharif 2024 at the Agronomy Research Farm of the University. The site experienced significant seasonal variations, with temperatures ranging from 30.70 °C to 45.40 °C, relative humidity between 18.94% and 84.96%, and precipitation levels spanning 0.05 mm to 17.12 mm. The experimental plot followed a structured three-year crop rotation: pearl millet–gram (2021-22), mung bean–mustard (2022-23), and maize–wheat (2023-24). Initial soil analysis revealed a sandy texture with a slightly alkaline pH. Chemical properties included 0.37% organic carbon and available nutrient levels of 137.8 kg ha−1 N, 16.3 kg ha−1 P, 241.2 kg ha^{-1} K, and 0.59 ppm S.

Experimental Design and Treatments

The experiment utilized a RBD with combinations of eight treatment which having three replications for each treatments and their combinations. The treatments integrated chemical fertilizers (100% RDF), organic manures (Farm Yard Manure [FYM] and Vermicompost), and bio-inoculants (Rhizobium and Phosphate Solubilizing Bacteria [PSB]). The specific treatment modules were: T1- Absolute Control, T2- 100 per cent RDF, T3- 100 per cent RDF + 10 t FYM ha^{-1}, T4- 100 per cent RDF + 10 t FYM ha^{-1} + Rhizobium, T5- 100 per cent RDF + 10 t FYM ha^{-1} + Rhizobium + PSB, T6- 100 per cent RDF + 5 t Vermicompost ha^{-1}, T7- 100 per cent RDF + 5 t Vermicompost ha^{-1} + Rhizobium and T8- 100 per cent RDF + 5 t Vermicompost ha^{-1} + Rhizobium + PSB.

Crop Management and Observations

The soybean variety PK 472—a determinate, disease-resistant variety (YMV and Rhizonia)—was sown on July 21, 2024. During sowing of PK 472 variety of soybean seeds were applied with the rate of 80 kg ha−1 with a geometry of 30 cm × 10 cm. Growth attributes were observed for plant population, height, dry matter accumulation (at 30, 60 DAS, and harvest), and nodulation (45 DAS), were systematically recorded. Yield attributes, such as pod count, seeds per pod, test weight (100-seed weight), and total biological yield, were measured at maturity to calculate the Harvest Index (HI).

Statistical Analysis

The collected data underwent statistical analysis employing the analysis of variance technique (ANOVA) following the methodology prescribed by Fisher (1950) for RBD. To calculate the significance of treatment effects, the F-test was applied, and Critical Difference (CD) values were calculated at 5% and 1% probability levels. Furthermore, the value of Standard Error of Mean (S.Em±) and Coefficient of Variation (CV) were computed to ensure data reliability.

Results and Discussion

1. Growth Parameters

1.1 Plant Population (no. m^{-2})

Statistical data analysis shown in table 1 suggested that the plant population of soybean variety PK 472 at both 30 days after sowing (DAS) and harvesting stage was not significantly influenced by the incorporation of organic manures and bio-fertilizers. At 30 DAS, the density ranged from 35.33 plants m−2 (T8) to 32.09 plants m^{-2} (T1). A similar non-significant trend persisted at maturity, where T8 maintained the highest stand (31.33 plants m−2) compared to the minimum recorded in T1 (27.09 plants m^{-2}). Although statistically marginal, these findings suggest that

integrated nutrient management helps sustain a more robust plant stand throughout the life cycle of crop compared to chemical fertilizers alone or the control.

Table 1: Effect of organic manures and bio fertilizers on Growth Parameters of soybean at different stages

Treatment	Plant population (plants m^{-2})		Plant height (cm)			Dry Matter Accumulation (g m^{-2})			Number of effective nodules	Dry weight of effective nodules (mg)
	30 DAS	AT Harvest	30 DAS	60 DAS	AT Harvest	30 DAS	60 DAS	AT Harvest	45 DAS	45 DAS
T1	32.09	27.09	28.20	49.67	53.24	2.90	22.45	26.45	25.61	89.56
T2	32.98	28.32	33.50	55.40	60.15	4.28	35.35	41.48	38.47	135.00
T3	33.26	28.36	35.00	58.33	64.80	4.95	38.44	45.82	42.12	150.00
T4	34.50	29.16	36.30	60.63	66.70	5.33	41.47	48.55	46.44	160.00
T5	35.05	30.38	37.00	63.34	68.97	5.52	43.46	50.95	49.21	165.00
T6	35.00	30.57	36.00	59.77	70.50	5.23	39.52	47.25	45.94	155.00
T7	35.05	30.72	36.80	64.33	72.30	5.58	44.32	52.33	52.95	175.00
T8	35.33	31.33	38.30	68.33	75.25	5.91	46.25	55.53	57.65	190.00
S.Em. ±	1.90	1.63	1.70	2.90	3.11	0.24	1.88	2.22	2.18	7.38
CD (5%)	NS	NS	5.16	8.80	9.43	0.72	5.69	6.75	6.61	22.40

Table 2: Effect of organic manures and bio fertilizers on Yield Attributes of soybean at different stages

Treatment	Yield Attributes			Yield (kg ha^{-1})			
	Number of pods $plant^{-1}$	Number of seeds pod^{-1}	Test weight (g)	Seed yield	Haulm yield	Biological yield	Harvest Index (%)
T1	48.33	2.32	88.24	1245	2195	3440	36.19
T2	57.78	2.58	92.70	1904	3328	5232	36.39
T3	62.22	2.73	97.20	2157	3739	5896	36.59
T4	66.54	2.88	100.90	2278	3927	6205	36.71
T5	69.00	2.98	103.70	2352	4039	6391	36.81
T6	65.87	2.83	99.80	2224	3853	6077	36.60
T7	72.21	3.08	106.40	2382	4075	6457	36.95
T8	77.48	3.23	109.80	2471	4208	6679	37.03
S.Em.±	3.15	0.14	4.86	106	205	310	0.28
CD (5%)	9.56	0.42	14.75	321	623	939	NS

1.2 Plant Height (cm)

Nutrient management practices significantly impacted on the growth attributing parameter as height of plan at all growth stages. At 30 DAS, the maximum height was observed in T8 (38.30 cm), while the minimum height of plant

was recorded in T1 (28.20 cm). By 60 DAS, T8 (68.33 cm) demonstrated significant superiority over the control (49.67 cm) and was statistically at par with T7 (64.33 cm) and T5 (63.34 cm). At the harvest stage, T8 reached a maximum height of 75.25 cm, significantly outperforming other treatments except T7 (72.30 cm). The observed improvement in vegetative growth may be attributed to the synergistic interaction between enhanced nutrient availability and increased microbial activity in the soil. These findings align with previous research by Konthoujam et al. (2013) and Patil et al. (2016).

1.3 Dry Matter Accumulation (g m^{-2})

Dry matter accumulation showed significant variation across all treatments and growth stages. At 30 DAS, T8 recorded the highest accumulation (5.91 g m^{-2}). This trend intensified at 60 DAS, where T8 (46.25 g m^{-2}) exhibited statistically superior results relative to the control. (22.45 g m^{-2}) and comparable to T7 (44.32 g m^{-2}). At harvest, the highest dry matter was again achieved by T8 (55.53 g m^{-2}), followed by T7 and T5. The increased biomass in integrated treatments highlights the efficacy of combining organic and inorganic sources, as corroborated by Shaikh et al. (2019).

1.4 Number of Effective Nodules and Dry Weight (mg $plant^{-1}$)

At 45 DAS, the integrated use of organic manures and bio-fertilizers significantly increased both the number of effective nodules and their dry weight. Treatment T8 recorded the highest number of effective nodules (57.65 plant^{-1}), which was significantly greater than the absolute control (25.61 plant^{-1}) and remained statistically at par with T7 (52.95 plant^{-1}).

The dry weight of nodules followed a similar pattern; T8 recorded the highest weight (190.00 mg $plant^{-1}$), recording significantly better performance compared to all treatments except T7 (175.00 mg $plant^{-1}$). This improvement is attributed to the fact that vermicompost and FYM enhance soil aeration and organic carbon, while Rhizobium and PSB inoculations directly stimulate nodulation and phosphorus solubilization. These findings are in agreement with those reported by Ghodke et al. (2018), who highlighted the positive effects of integrated nutrient management on root health in soybean.

2. Yield Attributes

Data analysis presented in Table 2 indicates that the integration of organic manures and bio-fertilizers significantly enhanced the yield-contributing characters of soybean.

2.1 Number of Pods per Plant

The maximum number of pods per plant (77.48) was achieved with the incorporation of T8 (100 Per cent RDF + 5 t vermicompost ha^{-1} + Rhizobium + PSB). This was closely followed by T7 (72.21) and T5 (69.0). The lowest pod count was consistently noted under the absolute control treatment (T1), highlighting the critical role of balanced nutrition in reproductive development.

2.2 Number of Seeds per Pod

The number of seeds in a pod ranged from 2.32 (T1) to 3.23 (T8). The results for T8 were significantly superior to most treatments but remained statistically at par with T7 (3.08) and T5 (2.98). Integrated modules like T4 and T6 also showed a marked improvement over the use of chemical fertilizers alone (T2).

2.3 Test Weight (1000-Seed Weight)

The 1000-seed weight, a vital indicator of seed boldness, varied significantly from 88.42 g (T1) to 109.80 g (T8). The treatment T8 produced the highest test weight, followed by T7 (106.40 g) and T5 (103.70 g). These results are consistent with the observations of Rana and Badiyala (2014) and Rana et al. (2016), who reported that the integrated use of organic and

inorganic nutrient sources promotes improved grain filling.

3. Yield Dynamics ($kg\ ha^{-1}$)

Statistical evaluation (ANOVA) confirmed that seed, haulm, and biological yields were significantly affected by nutrient management, though the Harvest Index (HI) remained statistically non-significant.

3.1 Seed Yield

The highest seed yield (2471 kg ha^{-1}) was recorded under T8, representing a substantial increase over both the control (1245 kg ha^{-1}) and RDF alone (1904 kg ha^{-1}). T8 was statistically comparable to T7 (2382 kg ha^{-1}) and T5 (2352 kg ha^{-1}), emphasizing the efficacy of vermicompost and bio-inoculants in boosting productivity.

3.2 Haulm and Biological Yield

Haulm yield followed a similar trajectory, with T8 yielding the maximum biomass (4208 kg ha^{-1}), significantly outperforming T2 (3328 kg ha^{-1}). Consequently, the total biological yield was maximum in T8 (6679 kg ha^{-1}) and minimum in T1 (3440 kg ha^{-1}). The enhanced biomass production is attributed to improved soil physical properties and sustained nutrient release from organic sources (Verma et al., 2017).

3.3 Harvest Index (HI)

The HI values ranged from 36.19% (T1) to 37.03% (T8). The lack of significant variation suggests that the increase in economic yield was proportionate to the increase in vegetative biomass. This indicates that while INM increases overall productivity, the partitioning of photosynthates remains relatively stable, a trend supported by Singh et al. (2020).

The synergistic application of RDF, vermicompost, and bio-fertilizers (Rhizobium and PSB) provides a balanced nutrient supply and improves soil health. This leads to enhanced nodulation, better N-fixation, and efficient translocation of photosynthates to reproductive parts, ultimately resulting in superior soybean yields compared to conventional chemical fertilization.

Summary and Conclusion

The present investigation evaluated the influence of integrated nutrient management—combining organic manures and bio-fertilizers—on the growth dynamics and parameters of yield for soybean (Glycine max L.). The study revealed that growth parameters, including plant height and dry matter accumulation, were significantly enhanced by integrated treatments. At the harvest stage, the maximum plant height (75.25 cm) and dry matter accumulation (55.53 g m^{-2}) were recorded under T8 (100% RDF + 5 t Vermicompost ha^{-1} + Rhizobium + PSB), which proved significantly superior to the control in which organic manure and bio-fertilizers were not incorporated and chemical fertilization alone. Furthermore, T8 facilitated the highest nodulation efficiency, yielding 57.65 effective nodules per plant with a dry weight of 190.00 mg, thereby indicating improved nitrogen-fixing potential.

Regarding yield components, the treatment T8 consistently outperformed other modules, achieving the highest number of pods per plant (77.48), seeds per pod (3.23), and test weight (109.80 g). These attributes translated into a peak seed yield of 2471 kg ha^{-1} and a haulm yield of 4208 kg ha^{-1}, while the harvest index reached 37.03%. In contrast, the lowest values of findings across all recorded parameters were observed in the absolute control (T1) which devoid of any incorporation of organic manure and bio fertilizer consortium.

Conclusion

Based on the experimental findings from the 2024 Kharif season, it was ascertained that the integrated application of 100 pre ernt RDF + 5 t Vermicompost ha^{-1} supplemented with

Rhizobium and PSB (T8) is the most efficient and influential strategy for optimizing soybean productivity. This treatment not only maximized growth and yield attributes but also significantly enhanced nutrient uptake (N, P, and K). While integrated treatments involving FYM (T5) and Vermicompost without one bio-inoculant (T7) showed comparable results, T8 emerged as the superior management practice for achieving sustainable and high productivity in the soybean-growing regions of Rajasthan.

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