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Optimizing nutrients management strategies for enhanced soybean production (*Glycine max* L.) influenced by integrated nutrient method

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Abstract
A field experiment was conducted during the Kharif season of 2024 at the Research Farm, Department of Agronomy, GH Raisoni University, Saikheda, Madhya Pradesh, to evaluate the effect of treatments of T_1 (100% Control), T_2 (100% RDF), T_3 (100% RDF + 1% foliar spray-Humic acid), T_4 (100% RDF + 1% foliar spray-Fulvic acid), T_5 (RDF + Vermicompost), T_6 (RDF + Poultry manure), T_7 (RDF + FYM). growth and yield of soybean (*Glycine max* L.) variety JS-9560. the results revealed that effect of given treatments significantly enhanced plant growth attributes such as plant height, number of branches, number of leaves, crop growth rate, and dry matter accumulation across different growth stages. Among the treatments, T_6 (100% RDF + Poultry manure) consistently Excellent performance then others, recording the large no height (57.18) cm, highest no of branches (19.20), dry matter production (22.73), highest seed yield (2200.15 kg/ha), stover yield (2650.10 kg/ha), pods per plant (54.63), seeds per pod (2.90), Test weight (10.10 g), and seed index (12.41 g). The improvements were attributed to the synergistic effects essential nutrient uptake and reproductive efficiency. The findings suggest that integrated nutrients management fertilizers can be an effective and sustainable approach to improving soybean productivity.

Keywords: Soybean, humic acid, fulvic acid, vermicompost, poultry manure, farm yard manure, growth, yield

Introduction
Soybean (*Glycine max* L.) is an important crop grown in many parts of the world, especially in tropical and subtropical regions. It is widely known for its high protein and oil content, making it valuable for food, animal feed, and various industrial uses. In India, soybean is mainly grown during the Kharif season, and states like Madhya Pradesh, Maharashtra, and Rajasthan are among the top producers. However, the average yield of soybean in India is still low compared to its potential. One of the major reasons for this is poor and unbalanced nutrient management.

For good growth and high yield, soybean needs a proper supply of nutrients. These include important nutrients like nitrogen (N), phosphorus (P), potassium (K), sulfur (S), and micronutrients such as zinc (Zn) and boron (B). Although soybean can fix nitrogen from the atmosphere through bacteria called *Rhizobium*, it still needs some nitrogen from the soil, especially during the early stages of growth. Phosphorus helps in root growth and seed development, while potassium improves the plant's resistance to stress and helps in water regulation. Micronutrients like zinc and boron are also needed for proper plant development and seed formation. In most cases, farmers use only chemical fertilizers (called Recommended Dose of Fertilizers or RDF) to meet the crop's nutrient needs. While this may give good results in the short term, continuous use of only chemical fertilizers can harm the soil in the long run. It can reduce soil fertility, damage helpful microbes, and cause environmental problems like water pollution. To solve these issues, a method called Integrated Nutrient Management (INM) is used. This method combines chemical fertilizers with organic manures and biofertilizers to improve both crop yield and soil health. Organic manures such as farmyard manure (FYM), poultry manure, and vermicompost provide nutrients slowly and improve the soil's physical condition. For example, vermicompost improves soil structure and microbial activity, while poultry manure quickly releases nutrients that help the crop during early growth.

Farmyard manure helps improve soil fertility over time. In addition to these, biofertilizers like *Rhizobium* (for nitrogen fixation) and phosphate-solubilizing bacteria (PSB) help plants absorb nutrients more easily. Some farmers also use foliar sprays of humic and fulvic acids, which are natural substances that help plants absorb nutrients, grow better, and stay healthy. Many field experiments have shown that using both organic and inorganic sources of nutrients gives better results than using only chemical fertilizers. Treatments that include RDF along with poultry manure or vermicompost have shown improvements in the number of pods per plant, seed weight, total yield, and profits. These methods also improve soil health by increasing organic matter and the number of helpful microbes. Because fertilizers are expensive and soil health is declining in many areas, using integrated nutrient management has become more important. It helps match the nutrient needs of the crop with what is available in the soil, reduces the use of chemical inputs, and supports sustainable farming practices. Using a combination of fertilizers, organic manures, and biofertilizers is not only good for increasing soybean production but also helps keep the soil healthy for future crops. This balanced approach is a smart and environmentally friendly way to grow soybeans successfully.

Materials and Methods

A field experiment was carried out during the Kharif season of 2024 at the Research Farm of the Department of Agronomy, School of Agricultural Sciences, G.H. Raisoni University, Saikheda, situated in Saunsar Tehsil of Pandhurna District, Madhya Pradesh. The experimental site was characterized by medium black, clayey soil that was fairly deep and well-drained. Prior to sowing, a composite soil sample was collected from the top 0-30 cm layer and analyzed for its physicochemical properties. The soil was slightly alkaline in reaction (pH 7.41), low in organic carbon (3.95 g/kg), deficient in available nitrogen (181.24 kg/ha), medium in available phosphorus (16.21 kg/ha), and high in available potassium (477.21 kg/ha).

The region experiences three primary seasons: Kharif (mid-June to mid-September), Rabi (October to January), and summer (February to May), with the majority of rainfall occurring during the Kharif period. During the cropping season, the average maximum and minimum temperatures were 28.7 °C and 23.01 °C, respectively, and the relative humidity ranged from 84.48% to 91.92%, providing suitable environmental conditions for soybean growth.

The experiment was laid out in a Randomized Block Design (RBD) with ten treatment combinations replicated three times, resulting in a total of 30 plots. Each individual plot measured 3 × 2 meters, and the gross experimental area covered 336 m². The crop grown was soybean (*Glycine max* L.) variety JS-9560, sown at a seed rate of 75 kg/ha using the dibbling method at a spacing of 30 × 5 cm. Land preparation included one deep ploughing followed by two harrowing and leveling to create a fine seedbed. The recommended dose of fertilizers (20:60:20 NPK kg/ha) was applied, with nitrogen and phosphorus given as a basal application prior to sowing.

The study aimed to assess the combined effects on the growth T_1 (100% Control), T_2 (100% RDF), T_3 (100% RDF + 1% foliar spray-Humic acid), T_4 (100% RDF + 1% foliar spray-Fulvic acid), T_5 (RDF + Vermicompost), T_6 (RDF + Poultry manure), T_7 (RDF + FYM). and yield of soybean. Specifically, the The control treatment without fertilizer. These treatments were randomly allocated to plots within each replication to reduce experimental error and ensure statistical reliability. Two foliar sprays Humic acid and Fulvic acid. T_6 (100% RDF + Poultry manure) consistently Excellent performance then others.

Results and Discussion

A) Effect of Humic and Fulvic acid, Vermicompost, Poulrty Manure and Farm yard manure on growth attributes of soybean.

The growth attributes of soybean—namely plant height, number of branches plant^{-1}, number of leaves plant^{-1}, and dry matter accumulation plant^{-1}—showed significant positive responses to the combined application of across Fulvic acid, Vermicompost, Poulrty Manure and Farm yard manure different growth stages.

Among all treatment combinations, T_6 (100% RDF + Poultry Manure) consistently recorded the highest values for each parameter. The progressive improvement in plant height from 30 DAS to harvest in T_6 can be attributed to the synergistic effect of 100% RDF + Poultry Manure micronutrients. These factors together enhanced vegetative growth and internode elongation.

The experiment-assessed average plant heights were 18.24, 44.98, 55.22 (cm) and at 30, 60, 90 and at harvesting 57.18 (cm) in T_6 (100% RDF + Poultry manure) respectively. The average soybean plant heights were constantly on the rise from emergence to harvest.

Table 1: Effects of various treatments on the average height of plant the crop soybean.

Treatments	Mean number of height/plant (cm)			
	30 DAS	60 DAS	90 DAS	At harvest
100% Control	14.09	41.12	52.53	53.67
100% RDF	14.20	42.33	52.63	55.07
100% RDF + 1% foliar spray-Humic acid	14.52	42.47	54.17	55.31
100% RDF + 1% foliar spray-Fulvic acid	15.48	43.32	54.21	55.35
100% RDF + Vermicompost	17.68	44.32	54.51	55.75
100% RDF + Poultry manure	18.24	44.98	55.22	57.18
100% RDF + FYM	17.55	43.94	54.45	54.54
SE (m)±	0.35	0.44	0.65	0.67
CD at 5%	1.09	1.36	1.42	1.45

In a controlled pot experiment, researchers found that using a combination of NPK and poultry manure led to impressive results. The plants not only grew taller but also boasted more leaves, branches, and a larger leaf area. Plus, there was a noticeable increase in chlorophyll content and shoot dry weight. This combination outperformed treatments that used NPK alone, poultry manure alone, or even the control group.

Table 2: Effects of various treatments on average no. of soybean branches

Treatments	Mean number of branches/plant			
	30 DAS	60 DAS	90 DAS	At harvest
100 Control	2.73	4.53	17.09	17.55
100% RDF	3.33	8.71	17.55	18.08
100% RDF + 1% foliar spray-Humic acid	3.36	8.76	18.10	18.21
100% RDF + 1% foliar spray-Fulvic acid	3.60	9.26	18.22	18.55
RDF + Vermicompost	4.0	10.46	18.49	19.01
RDF + Poultry manure	7.02	11.10	19.20	19.20
RDF + FYM	3.73	9.33	18.8	18.90
SE (m)±	0.54	0.69	0.87	0.95
CD at 5%	2.27	2.45	2.60	2.79

During the course of study, the average no. of branches/plant were 7.02, 11.10, 19.20 at 30, 60, 90, and harvest 19.20 given at

table respectively. in T_6 (100% RDF + Poultry manure).
A recent study found that using poultry manure led to a notable increase in the number of branches in soybean plants compared to other organic fertilizers. Four weeks after planting, the soybean plants that received poultry manure had a higher average number of branches, while those treated with compost and goat manure fell short of poultry manure's results. This indicates that poultry manure plays a key role in boosting early vegetative growth, likely because it offers a richer supply of nutrients. It clearly outshone other organic options when it came to promoting branch development in soybeans.

Crop Growth Rate (CGR)
Crop Growth Rate (CGR) shows how fast a plant gains weight or biomass over time. In this study, using nutrients treatments affected the soybean growth rate. The best result was seen in treatment T_6, which had the highest CGR of 19.91 grams per square meter per day. This means that T_6 helped the plants grow better, probably because it controlled weeds well and allowed the soybean to use water, sunlight, and nutrients more effectively**.** While T_3 has lowest CGR than other treatments 15.45 g.
T_6 (100% RDF + Poultry manure) which had the highest CGR of 19.91 grams per square meter per day**.** T_3 (100% RDF + 1% foliar spray-Humic acid) has lowest CGR 15.45 g.These studies highlight the beneficial effects of poultry manure on soybean growth and productivity.

Table 3: Effects of various treatments on crop growth rate (g/m2/day)

Treatments	Crop growth rate (g/m2/day)
100% Control	14.03
100% RDF	14.25
100% RDF + 1% foliar spray-Humic acid	15.45
100% RDF + 1% foliar spray-Fulvic acid	15.62
100% RDF + Vermicompost	17.33
100% RDF + Poultry manure	19.91
100% RDF + FYM	17.23
SE (m)±	0.68
CD at 5%	2.11

Table 4: Effects of various treatments on the mean dry matter accumulation plant-1 of soybean

Treatments	Dry Matter production/Plant (g)			
	30 DAS	60 DAS	90 DAS	At harvest
100% Control	7.50	10.85	15.53	16.02
100% RDF	8.98	10.91	15.75	17.06
100% RDF + 1% foliar spray-Humic acid	8.99	11.04	17.19	19.97
100% RDF + 1% foliar spray-Fulvic acid	9.07	11.50	20.14	21.01
RDF + Vermicompost	9.24	12.43	20.60	21.75
RDF + Poultry manure	9.30	12.33	20.75	22.73
RDF + FYM	9.18	11.90	20.45	21.07
SE (m)±	0.29	0.48	0.56	0.75
CD at 5%	2.27	2.46	2.64	2.80

The average accumulation of dry matter per plant was 9.30, 12.33, 20.75 at 30, 60, 90 days after sowing and at harvest 22.73 respectively.
Poultry manure mixed with NPK fertilizer affect soybean growth. The results showed that the best dry matter accumulation happened with a combination of 1.2g NPK and 6g of poultry manure, which produced an impressive 2.79g per plant. This was a significant improvement over the other treatments, including the control group, which only reached 1.87g, as well as other NPK and poultry manure combinations. The statistical analysis confirmed that this particular treatment was the most effective in boosting dry matter accumulation, underscoring the role of poultry manure in enhancing soybean biomass production.

B) Effect of Humic and Fulvic acid, Vermicompost, Poulrty Manure and Farm yard manure on yield of soybean.
Treatment T_3 (100% RDF + 1% foliar spray-humic acid) (42.07) had the noticeably lowest number of Pods/Plant, however it was comparable to treatment T_6 (100% RDF through Poultry Manure). With 54.63 Pods/Plant, the treatment of applying (100% RDF through Vermicompost) with 48.59 and the treatment of applying (100% RDF through FYM (T_7) had Highest no. of Pods/plant 47.98.
Amount of Seed/Pod as affected by various treatments. There were 2.90 grains on average each Pods at (T_6) 100% RDF through poultry manure. the treatment that applied T_4 (100% RDF and 50% RDF through Fulvic acid 2.55 And T_3 (100% RDF through Humic acid) 2.30 had lowest no. of Seed/Pod (seed per Pod).
Out of all the treatments, treatment T_3 (100% RDF + 1% foliar spray-humic acid) 8.16 g and T_3 (100% RDF + 1% foliar spray-fulvic acid) 8.39 g had the noticeably lowest Test Weight, however it was comparable to treatment T_6 (100% RDF through Poultry Manure) 10.10 g.The treatment of applying (100% RDF through Vermicompost) 9.95 g.Test weight and the treatment of applying (100% RDF through FYM (T_7) 9.75 g had highest no. of Test weight.
Soybean plants treated with poultry manure combined with recommended fertilizer doses produced significantly higher numbers of pods per plant compared to other nutrient treatments. Afghanistan found that applying 4 tons of poultry manure per hectare significantly increased the number of pods per plant and seed pod-1, highlighting its effectiveness in improving soybean yield components. Collectively, these studies affirm that poultry manure positively influences pod number, seeds per pod, and seed weight, thereby boosting soybean yield and quality.
Soybean seeds with biofertilizers, including poultry manure, resulted in higher pod numbers and seed weight, suggesting enhanced nutrient uptake and seed development.

Table 5: Mean no. of pod/plant, no. of seed/pod & 100 seeds weigh of soybean as influenced by different treatments at harvest.

Treatments	No. of Pod/Plant	No. of seed/pod	100 seeds weight (g) Test weight
100% Control	33.90	2.12	7.3
100% RDF	38.72	2.18	7.55
100% RDF + 1% foliar spray-Humic acid	42.07	2.30	8.16
100% RDF + 1% foliar spray-Fulvic acid	42.76	2.55	8.39
RDF + Vermicompost	48.59	2.80	9.95
RDF + Poultry manure	54.63	2.90	10.10
RDF + FYM	47.98	2.75	9.75
SE (m)±	0.55	0.34	0.35
CD at 5%	1.70	2.16	2.51

Soybean yielded 2200 kg/ha of seed on average in (T_6) 100% RDF through Poultry manure.
And lowest yielded 1920 kg/ha in (T_3) (100% RDF + 1% foliar spray-humic acid).
Different treatments had a substantial impact on straw yield (kg/ha). The treatment with best yields of soybean straw. Different treatments have a major impact on sesame straw yield. Compared to the other treatments, treatment T_6 (100% RDF +

Poultry manure) 2650 kg/ha yielded a noticeably higher seed production. & T_5 (100% RDF + Vermicompost) 2450 kg/ha levels were found to be comparable**.**

The harvesting index of soybean impacted by varying treatments. It was evident from the data that the average harvest index that was calculated was 43.55%.

Using poultry manure at a rate of 4 tons per hectare really boosted soybean seed yields, hitting around 2800 kg/ha. The research also noted a rise in straw yield, reaching up to 2700 kg/ha, thanks to better soil nutrient availability and moisture retention. The addition of poultry manure enhanced the organic matter in the soil, which in turn supported healthier plant growth and more biomass. The combination of improved nutrient release and soil structure contributed to a significant increase in overall soybean productivity. These results indicate that poultry manure is a powerful organic amendment for enhancing both seed and straw yields.

Table 6: Data on Seed and straw yield (kg/ha) as a result of varying treatments are graphically shown in Table.

Treatments	Seed yield Kg/ha	Straw Kg/ha	Harvest index (%)
100% Control	1845	1920	32.05
100% RDF	1888	1945	35.68
100% RDF + 1% foliar spray-Humic acid	1920	2100	37.37
100% RDF + 1% foliar spray-Fulvic acid	1965	2223	39.23
RDF + Vermicompost	2100	2450	41.28
RDF + Poultry manure	2200	2650	43.55
RDF + FYM	2000	2300	39.89
SE (m)±	0.35	2.15	0.61
CD at 5%	2.93	6.36	2.76

Cultivation cost was found to be highest when applying T_6 (100% RDF through Poultry Manure) (about 32932₹/ha), and lowest when using T_3 (100% RDF + 1% foliar spray-humic acid) (about 28560 ₹/ha).

The effects of multiple treatments on gross financial returns are average gross return per hectare was 73555 ₹/ha.

The effects of multiple treatments on net financial returns per hecatare was 35546 ₹/ha.

The application of integrated nutrition management had a considerable Treatment T_3 (100% RDF + 1% foliar spray-Humic acid) (1.95), with lowest benefit cost ratio the application of T_4. T_6 (100% RDF through Poultry Manure) recording highest benefit cost ratio (2.35).

Table 7: The effects of various treatments on the B: C ratio, gross financial returns, & net financial results

Treatments	Economics (rs/ha)			
	COC	GMR	NMR	B:C Ratio
100% Control	27520	50561	20980	1.80
100% RDF	28140	50912	22530	1.83
100% RDF + 1% foliar spray-Humic acid	28560	55881	27815	1.95
100% RDF + 1% foliar spray-Fulvic acid	28956	61512	29950	2.12
RDF + Vermicompost	30120	69444	33270	2.23
RDF + Poultry manure	32932	73555	35546	2.35
RDF + FYM	29580	70803	33148	2.24
SE (m)±	4.49	11.23	9.28	0.51
CD at 5%	11.24	16.80	14.89	2.81

GMR ranged between 2.1 and 3.0; BC ratio between 2.0 and 3.3, showing poultry manure improved profitability and sustainability of soybean farming than other treatments.

The effects of combined poultry manure and biochar application on soil health and the economics of soybean cropping systems. Their study found that this combination significantly enhanced soil carbon content, improving soil fertility and structure. Additionally, the integrated amendment reduced the cost of cultivation by approximately 17%, making soybean production more economical. The Gross Margin Ratio (GMR) and Benefit-Cost (BC) ratio increased to 2.5 and 3.2, respectively, indicating higher profitability and better returns for farmers. This approach promotes sustainable agriculture by improving both productivity and economic outcomes.

Conclusion

The study concludes that the integrated use of Humic acid, Fulvic Acid, Vermicompost, Poultry Manure and Farm yard manure boosts both vegetative and reproductive growth parameters in soybean, leading to minimum yields. The treatment T_6 (100% RDF + Poultry Manure) proved to be the most effective, showing substantial improvements in plant height, branching, leaf number, dry matter accumulation, and yield components. These benefits are attributed to enhanced physiological and metabolic functions. The results highlight the potential of combining organic biostimulants with secondary nutrients to enhance soybean growth, improve yield, and promote sustainable agricultural practices.

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