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Manvendra Singh Solanki
Research Scholar, Department of Horticulture, R.B.S. College, Bichpuri, Agra, Uttar Pradesh, India

Gyanendra Kumar Singh
Professor, Department of Horticulture, R.B.S. College, Bichpuri, Agra, Uttar Pradesh, India

Corresponding Author:
Manvendra Singh Solanki
Research Scholar, Department of Horticulture, R.B.S. College, Bichpuri, Agra, Uttar Pradesh, India

Integrated nutrient management enhances growth and yield of okra cv. 'kashi kranti

Manvendra Singh Solanki and Gyanendra Kumar Singh

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Abstract

Integrated nutrient management (INM) offers a pathway to sustain okra (*Abelmoschus esculentus* L. Moench) productivity while improving soil health under semi-arid Vertisol conditions. A two-season field experiment (*kharif* 2022 and 2023) was carried at R.B.S. College, Bichpuri, Agra, India (27°2′ N, 77°9′ E) to evaluate organic-inorganic nutrient combinations on growth and yield of okra cv. 'Kashi Kranti'. The trial employed a randomized block design with 15 treatments and four replications. Treatments were structured around the recommended dose of fertilizer (RDF; N:P:K = 100:60:50 kg ha^{-1}) with partial substitution by farmyard manure (FYM), vermicompost (VC), and poultry manure (PM). Growth observations (plant height, number of fully expanded leaves, plant spread) were recorded at 30, 60, 90 days after sowing (DAS) and at picking stage; yield attributes (fresh pod weight, pods per plot) and yield per plot were assessed at harvest. Across both years, treatment effects were significant from 60 DAS and onward ($p \leq 0.05$). The integrated ternary blend T_{15} (50% RDF + FYM 3.4 t ha^{-1} + VC 1.02 t ha^{-1} + PM 0.51 t ha^{-1}) consistently outperformed the mineral-only control (T_1, 100% RDF), increasing plant height at picking by 16.4%-15.8%, leaf number by ≈22%, plant spread by ≈17%, fresh pod weight by 20.4%-20.7%, and pods per plot by ≈33%, culminating in ~60% higher plot-level yield in both seasons. Treatments T_{12}, T_{13} and T_{14} were statistically at par with T_{15} for several traits, indicating that partial substitution of mineral fertilizers with organics can closely approach maximal performance. The results demonstrate that replacing 50% of RDF with a balanced FYM-VC-PM blend optimizes nutrient supply, enhances canopy development, and stabilizes yield, offering a practical INM recommendation for sustainable okra production on Sanday loam.

Keywords: RDF; N:P:K, FYM, Vermicompost, Poultry manure, Okra

Introduction

Okra (*Abelmoschus esculentus* L. Moench) is a widely cultivated warm-season vegetable in South Asia and across the tropics and subtropics, valued for its tender pods, dietary fiber, vitamins and minerals, as well as its role in smallholder income and employment during the *kharif* season (Uwiringiyimana *et al*., 2024) [20]. Despite its economic and nutritional importance, okra productivity on many farms remains constrained by declining soil organic matter, nutrient mining and imbalanced fertilization, problems that are accentuated under semi-arid climates and heavy clay (Vertisol) soils where moisture dynamics and poor soil structure can limit nutrient availability (Anal *et al*., 2018) [3]. Reliance on mineral fertilizers alone can meet immediate macronutrient demand but often fails to address longer-term soil health, while exclusive use of organic manures may not synchronize nutrient release with crop demand, especially early in the season. Integrated nutrient management (INM) is the judicious combination of inorganic fertilizers with organic sources such as farmyard manure (FYM), vermicompost (VC) and poultry manure (PM) offers a pathway to reconcile short-term crop needs with long-term soil sustainability (Srivastava and Ngullie, 2009; Koshariya and Jadhav, 2021) [19, 9]. Mineral fertilizers provide readily available nitrogen, phosphors and potassium during early establishment, whereas FYM, VC and PM improve soil physical condition, cation-exchange capacity and microbial activity and supply a broader spectrum of nutrients through gradual mineralization (Singh *et al*., 2024) [18]. In Vertisols, these attributes can enhance root growth, water retention and nutrient use efficiency, potentially translating into improved vegetative vigor (height, leaf area, canopy spread) and yield attributes (pod set, pod weight and total yield). 'Kashi Kranti', a high-yielding, yellow vein mosaic virus (YVMV)-resistant cultivar released for Indian conditions, is particularly relevant for evaluating INM strategies aimed at both productivity and resilience (Kumar *et al*., 2019) [10]. However, quantitative evidence on the optimal proportion and combination of organic and inorganic sources for okra under the North Western Plains Zone (NWPZ) and semi-arid Vertisol conditions remains limited. This study was therefore undertaken to (i) quantify the effects of different combinations of FYM, VC and PM with the recommended dose of fertilizer on growth and yield of okra cv. 'Kashi Kranti'; (ii) identify integrated regimes that can match or surpass 100% RDF for key growth parameters and yield and (iii) generate location-specific recommendations for sustainable nutrient management of okra in semi-arid Sanday loam.

2. Materials and Methods

2.1 Experimental Design and Treatments

A field experiment on okra (*Abelmoschus esculentus* (L.) Moench) cv. 'Kashi Kranti' was laid out in a randomized block design (RBD) with 15 treatments and four replications, totaling 60 plots. Sowing was done by dibbling seeds on both sides of the ridges in an alternate fashion at a spacing of 60 cm × 45 cm (row × plant). Each gross plot measured 3.60 m × 3.00 m (10.80 m²) and the net plot 2.70 m × 1.80 m (4.86 m²). The total experimental area was 925.43 m². Nutrient management treatments were structured around the recommended dose of fertilizer (RDF; N:P:K = 100:60:50 kg ha^{-1}) with partial substitution by organic sources farmyard manure (FYM), vermicompost (VC) and poultry manure (PM)- as follows: T_1- control (100% RDF); T_2- 75% RDF + 25% via FYM @ 5 t ha^{-1}; T_3- 50% RDF + 50% via FYM @ 10 t ha^{-1}; T_4- 75% RDF + 25% via VC @ 1.7 t ha^{-1}; T_5- 50% RDF + 50% via VC @ 3.4 t ha^{-1}; T_6- 75% RDF + 25% via PM @ 0.75 t ha^{-1}; T_7- 50% RDF + 50% via PM @ 1.5 t ha^{-1}; T_8- 75% RDF + 25% via FYM-VC (FYM @ 2.5 t ha^{-1} + VC @ 0.85 t ha^{-1}); T_9- 50% RDF + 50% via FYM-VC (FYM @ 5 t ha^{-1} + VC @ 1.7 t ha^{-1}); T_{10}- 75% RDF + 25% via FYM-PM (FYM @ 2.5 t ha^{-1} + PM @ 0.425 t ha^{-1}); T_{11}- 50% RDF + 50% via FYM-PM (FYM @ 5 t ha^{-1} + PM @ 0.85 t ha^{-1}); T_{12}- 75% RDF + 25% via VC-PM (VC @ 0.85 t ha^{-1} + PM @ 0.425 t ha^{-1}); T_{13}- 50% RDF + 50% via VC-PM (VC @ 1.7 t ha^{-1} + PM @ 0.85 t ha^{-1}); T_{14}- 75% RDF + 25% via FYM-VC-PM (FYM @ 1.7 t ha^{-1} + VC @ 0.51 t ha^{-1} + PM @ 0.255 t ha^{-1}); and T_{15}- 50% RDF + 50% via FYM-VC-PM (FYM @ 3.4 t ha^{-1} + VC @ 1.02 t ha^{-1} + PM @ 0.51 t ha^{-1}).

2.3 Crop Husbandry

The field was thoroughly prepared by ploughing and harrowing to achieve a fine tilth, followed by manual layout of the plots. Organic manures (FYM, VC and PM) were applied and incorporated before sowing as per the treatment rates. At sowing, the full recommended doses of P_2O_5 and K_2O were placed in rows using single superphosphate (SSP) and muriate of potash (MOP), respectively. Nitrogen was applied as urea in two equal splits: 50% at sowing and 50% at 30 days after sowing (DAS). A light irrigation by the flood method was given immediately after sowing to ensure uniform germination. The variety 'Kashi Kranti' is high-yielding and resistant to yellow vein mosaic virus (YVMV).

2.4 Observations recorded

Growth parameters viz., plant height, number of fully expanded green leaves and plant spread were recorded at 30, 60, 90 DAS and at picking stage, while yield attributes and yield were recorded at the picking stage. Plant height was measured from the base to the apical growing tip and expressed in centimeters (cm). Plant spread was measured along the east-west and north-south axes; the mean of the two readings was taken as plant spread (cm). At each picking, all marketable pods from the tagged plants were harvested and weighed individually on an electronic balance (Sartorius, Japan) to obtain pod weight (g). The total number of pods per net plot was counted and at final harvest the marketable produce within plot boundaries was weighed on a calibrated balance; average yield per plot was expressed in kilograms (kg).

2.5 Statistical Analysis: Data were subjected to analysis of variance (ANOVA) appropriate for an RBD as outlined by Gomez and Gomez (1984). Treatment effects were tested using an F-test at the 5% level of significance.

3. Results and Discussion

The effect of different treatments on the plant height of okra at the picking stage, plant height ranged from 99.27 cm (T_1) to 115.53 cm (T_{15}) in 2022 and from 99.92 cm (T_1) to 115.67 cm (T_{15}) in 2023. Whereas, treatment T_{15} exhibited the highest plant height (115.53 cm in 2022 and 115.67 cm in 2023), followed by T_{14} (114.13 cm in 2022 and 114.29 cm in 2023), T_{13} (113.65 cm in 2022 and 113.87 cm in 2023) and T_{12} (112.24 cm in 2022 and 112.35 cm in 2023) which were statistically at par with T_{15}. While, treatment T_1 recorded the shortest plant height (99.27 cm in 2022 and 99.92 cm in 2023). The percentage improvement in plant height of T_{15} compared to T_1 was 16.38% in 2022 and 15.76% in 2023. The superior performance of T_{15} can be attributed to a balanced nutrient supply from both organic and inorganic sources, promoting sustained vegetative growth.

Table 1: Effect of organic and inorganic sources of nutrient on plant height of okra cv. Kashi Kranti.

Treatments	Plant height (cm) At picking stage		Number of fully opened green leaves At picking stage		Plant spread (cm) At picking stage		Yield per plot (kg)	
	2022	2023	2022	2023	2022	2023	2022	2023
T_1	99.27	99.92	26.15	26.19	35.67	35.75	7.80	7.86
T_2	101.35	101.55	26.87	26.90	37.77	37.85	8.26	8.36
T_3	102.44	102.51	27.27	27.29	38.13	38.17	8.46	8.55
T_4	104.65	104.78	29.60	29.64	38.75	38.83	9.07	9.17
T_5	108.27	108.59	30.07	30.10	39.37	39.43	9.73	9.85
T_6	103.40	103.61	29.07	29.11	39.07	39.15	8.77	8.86
T_7	106.34	106.66	29.76	29.79	38.47	38.53	9.38	9.52
T_8	109.76	109.98	30.47	30.50	39.87	39.95	10.38	10.46
T_9	111.39	111.45	30.90	30.94	40.53	40.59	10.90	11.04
T_{10}	109.10	109.70	30.36	30.39	39.64	39.71	10.17	10.28
T_{11}	110.35	110.56	30.68	30.40	40.23	40.33	10.59	10.71
T_{12}	112.24	112.35	31.13	31.15	40.67	40.76	11.30	11.44
T_{13}	113.65	113.87	31.29	31.32	40.95	41.03	11.75	11.83
T_{14}	114.13	114.29	31.46	31.50	41.23	41.31	12.01	12.11
T_{15}	115.53	115.67	31.89	31.92	41.87	41.95	12.50	12.62
SEm±	1.42	1.33	0.29	0.31	0.39	0.36	0.35	0.28
C.D. at 5%	4.06	3.81	0.84	0.89	1.10	1.02	1.01	0.79

The lack of early separation among treatments likely reflects reliance on seed reserves and basal mineral N, together with the time required for organic amendments to mineralize, whereas later-stage gains under INM indicate superior temporal synchronization of nutrient supply-readily available N-P-K from the mineral fraction supporting early canopy establishment, followed by gradual release from FYM, vermicompost and poultry manure sustaining cell division and elongation during peak vegetative growth (Oyege and Balaji Bhaskar, 2023) [13]. Concomitant improvements in soil physical condition, cation-exchange capacity and moisture retention in Vertisols, along with bioactive compounds from vermicompost and the relatively labile N in poultry manure, plausibly underpinned the observed height advantage (Singh *et al*., 2024) [18].

The treatment T_{15} exhibited a percentage improvement in the number of leaves over T_1 by 21.94% in 2022 and 21.88% in 2023. The advantage of T_{15} over T_1 at picking indicates that integrated nutrient management (INM) enhanced canopy development by synchronizing immediate mineral nutrient availability (from the 50% RDF fraction) with the gradual mineralization of FYM, vermicompost and poultry manure. Mechanistically, sustained nitrogen supply supports leaf initiation and expansion, phosphorus improves root growth and energy metabolism and potassium aids turgor maintenance and stomatal function; concurrently, organics improve Vertisol structure, moisture retention, cation-exchange capacity and micronutrient supply, while vermicompost may contribute bioactive compounds that stimulate photosynthetic apparatus development (Singh, 2020; Dayal *et al*., 2023) [17, 4]. Collectively, these processes elevated leaf production across the season under INM, thereby increasing photosynthetic capacity and potential assimilate supply to reproductive sinks (Wu and Ma, 2015) [21].

The effect of various treatments on the plant spread of okra at the picking stage, exhibited the highest plant spread (41.87 cm in 2022 and 41.95 cm in 2023) with treatment T_{15} and it was followed by T_{14} (41.23 cm in 2022 and 41.31 cm in 2023), T_{13} (40.95 cm in 2022 and 41.03 cm in 2023) and T_{12} (40.67 cm in 2022 and 40.76 cm in 2023), which were statistically at par with T_{15}. While, the smallest plant spread was observed in T_1 (35.67 cm in 2022 and 35.75 cm in 2023).

The plant spread of treatment T_{15} showed a percentage improvement over T_1 of 17.40% in 2022 and 17.35% in 2023. Plant spread differences became significant at later growth stages, with T_{15} showing the maximum spread, indicative of a well-developed canopy. Mechanistically, the superior spread under INM reflects tighter temporal matching of nutrient release with crop demand—readily available N-P-K from the mineral fraction supporting early axis development, followed by gradual mineralization of FYM, vermicompost and poultry manure sustaining cell enlargement and branching alongside improvements in Vertisol structure, moisture retention and cation-exchange capacity that reduce transient stress and promote lateral shoot growth (Mondal, 2023) [12]. Vermicompost-derived humic substances and the relatively labile N in poultry manure likely stimulated root proliferation and leaf expansion, increasing leaf area and light interception and thus reinforcing canopy spread (Oyege and Balaji Bhaskar, 2023) [13]. The statistical parity of T_{12}-T_{14} with T_{15} indicates that even modest reductions in RDF, when complemented with organics, can approximate the canopy benefits of the full ternary blend, underscoring INM as a robust strategy to enhance architectural vigor and potential assimilate capture under semi-arid conditions. Similar findings related to plant height, number of leaves and plant spread were reported in close conformity with the Al-Mansour *et al*. (2018) [1] in basil and Al-Naggar *et al*. (2021) [2] in *Chenopodium*.

The mineral fraction (50% RDF) ensures immediate N-P-K availability for early growth, whereas FYM (slow-release and CEC enhancement), vermicompost (humified C and bioactive compounds) and poultry manure (labile N) synchronize mid- to late-season nutrient supply with pod development, improving photosynthate production and allocation, turgor-driven cell expansion (K), energy metabolism (P) and overall sink strength (Kamaleshwaran and Elayaraja, 2021) [8]. Concomitant improvements in Vertisol structure, water-holding capacity and microbial activity further reduce transient stress, supporting sustained pod growth. The statistical parity of T_{12}-T_{14} with T_{15} suggests that partial mineral fertilizer substitution with organics can approach the maximal pod mass attained under the full ternary blend, offering a practical pathway to enhance pod quality and yield while reducing exclusive reliance on inorganic inputs. High maximum fruit weight was observed due to integrated nutrients application reported by Kumar *et al.* (2013) [11] in okra.

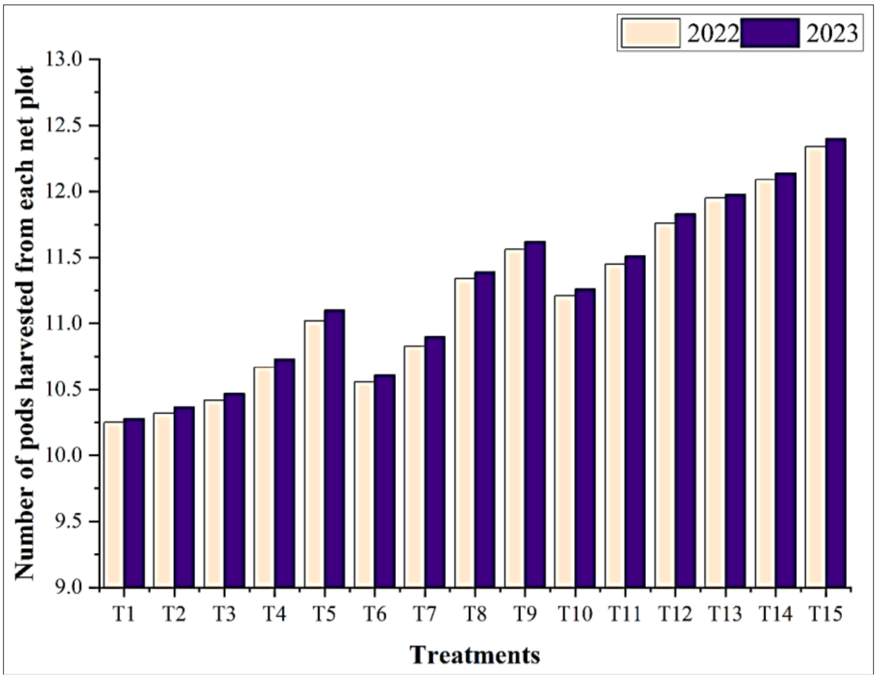

Fig 1: Effect of organic and inorganic sources of nutrient on fresh weight of marketable pod of okra cv. Kashi Kranti.

The effect of different organic and inorganic nutrient sources on number of pods harvested from each net plot in okra cv. Kashi Kranti are presented in Fig. 2 and differences were found statistically significant among the treatments. The collective application of treatment T_{15} shows significantly maximum number of pods harvested from each net plot (1013.25 and 1017.75) which was found at par with treatment T_{14} (993.75 and 997.50), T_{13} (983.25 and 987.75) and T_{12} (960.75 and 966.75) during 2022 and 2023, respectively. However, minimum number of pods harvested from each net plot was recorded with treatment T_1 (761.25 and 765.00) during 2022 and 2023, respectively. An increase of 33.1% in 2022 and 33.1% in 2023 was recorded in T_{15}, significantly enhancing the number of pods harvested compared to T_1. The significant increase in the number of pods harvested in treatment T_{15} can be attributed to the combined application of organic and inorganic nutrient sources, which likely improved soil fertility, enhanced nutrient uptake and provided a continuous supply of nutrients during the critical growth and reproductive stages. The mineral fraction in T_{15} ensures immediate N-P-K availability for early growth, while FYM, vermicompost and poultry manure provide complementary, season-long nutrient release and improve Vertisol structure, moisture retention, cation-exchange capacity and microbial activity; together these effects likely enhanced canopy development (greater height, spread and leaf number), flower retention and pod-setting capacity, thereby elevating pods per plot (Sen *et al*., 2022) [15]. The statistical equivalence of T_{12}-T_{14} with T_{15} further suggests that partial substitution of RDF with organics can closely approximate the maximal response, offering a pragmatic path to higher pod numbers with reduced reliance on inorganic fertilizers.

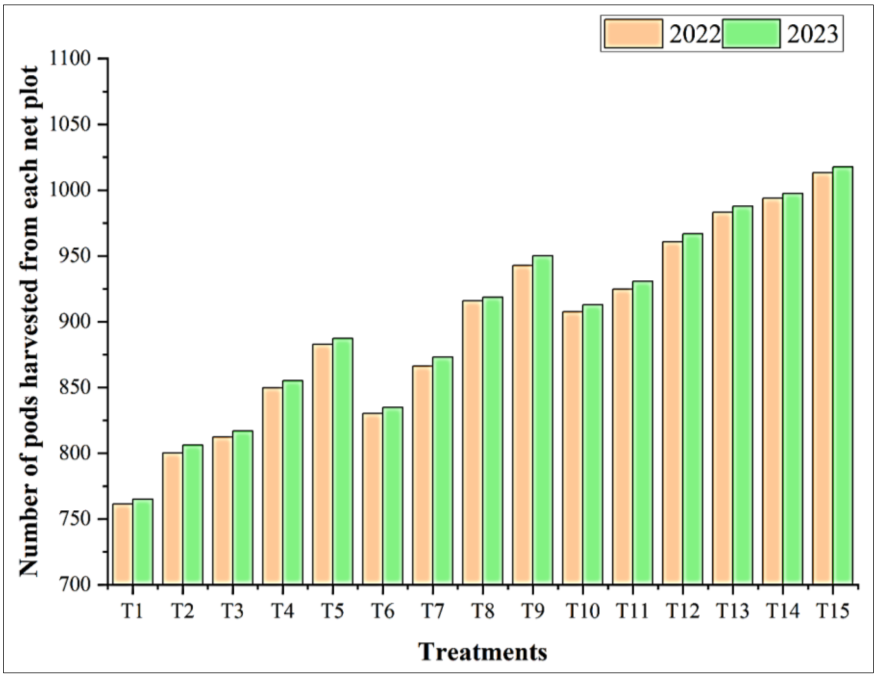

Fig 2: Effect of organic and inorganic sources of nutrient on number of pods harvested from each net plot of okra cv. Kashi Kranti.

In Table 4 summarizes result related to effect of various organic and inorganic nutrient sources on yield per plot of Okra cv. Kashi Kranti across two years. However, the differences were found statistically significant among the treatments. Among the various treatments applied during the experimentation showed that the collective application of treatment T_{15} shows significantly maximum yield per plot (12.50 and 12.62 kg) which was found at par with treatment T_{14} (12.01 and 12.11 kg) and T_{13} (11.75 and 11.83 kg) during 2022 and 2023, respectively. However, minimum yield per plot was observed with treatment T_1 (7.80 and 7.86 kg) during 2022 and 2023, respectively.

The mineral fraction of RDF ensures immediate N-P-K availability for early growth, while FYM, vermicompost and poultry manure provide complementary, season-long nutrient release and micronutrients, enhance cation-exchange capacity and improve soil structure and moisture retention in Vertisols conditions that stabilize leaf area development, reduce transient stress and support sustained assimilate supply to developing pods (Sanwal *et al*., 2023) [14]. Potassium's role in turgor maintenance and stomatal regulation, phosphorus in energy metabolism and root proliferation and the relatively labile nitrogen from poultry manure, together with humified carbon and bioactive compounds from vermicompost, likely increased sink strength and reduced flower/pod abscission, translating into higher plot-level yield (Isitekhale and Osemwota, 2014) [7]. The statistical parity of T_{14} and T_{13} with T_{15} suggests diminishing returns beyond a threshold of balanced organic complementation, indicating that partial substitution of RDF with organics can closely approach maximal yield while potentially lowering mineral fertilizer inputs. The stability of treatment rankings across years underscores the robustness of INM for okra in semi-arid Vertisols and points to integrated regimes particularly ternary blends as agronomically effective and environmentally prudent options for sustaining high productivity. These results related to yield are in close conformity with the findings of Shampazuraini *et al*. (2023) [16] and Fogawat *et al*. (2024) [5] in okra.

Conclusion

Across two *kharif* seasons, integrated nutrient management (INM) consistently enhanced vegetative growth and yield of okra cv. 'Kashi Kranti' relative to the mineral-only control. The best-performing treatment, T_{15} (50% RDF + FYM 3.4 t ha^{-1} + vermicompost 1.02 t ha^{-1} + poultry manure 0.51 t ha^{-1}), exhibit taller plants, more fully expanded leaves, greater plant spread, heavier pods, and markedly more pods per plot, culminating in plot-level yield gains in both years. Treatments T_{12}, T_{13} and T_{14} were statistically at par with T_{15} for several traits, indicating that partial substitution of mineral fertilizers with organics can closely approach the maximum response, likely due to better temporal synchronization of nutrient supply and improvements to Vertisol structure, moisture retention, cation-exchange capacity, and biological activity. Practically, these results support replacing half of the recommended mineral NPK (50:30:25 kg ha^{-1}) with a balanced blend of FYM, vermicompost, and poultry manure to achieve superior and more stable productivity while reducing exclusive reliance on chemical fertilizers.

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