



Effect of Humic Acid-based Bio-stimulant on Soil Fertility Status in *Vertisol* under Rice Cultivation of Chhattisgarh, India

Sweta Parganiha ^{a++*}, K. Tedia ^{a#}, L. K. Srivastava ^{a†},
Neet Upasna Lakra ^{a++}, Raj Singh Sengar ^{a‡}
and Shaurya Parganiha ^{b++}

^a Soil Science and Agricultural Chemistry, Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh), India.

^b Vegetable Science, Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh), India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: <https://doi.org/10.9734/ijpss/2026/v38i116394>

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://pr.sdiarticle5.com/review-history/169109>

Original Research Article

Received: 22/08/2026

Accepted: 28/10/2026

Published: 30/10/2026

Abstract

A field experiment was carried out during the kharif seasons of 2023 and 2024 at the Research Farm of Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur, Chhattisgarh, India, to evaluate the influence of a humic acid-based biostimulant on the fertility status of a Vertisol in Chhattisgarh. The experiment was established using a randomised block design (RBD) with twelve treatments, each replicated three times. The treatments comprised T1 – recommended dose of fertilisers (RDF; 120:60:40); T2 – RDF + root dipping in humic acid powder solution (1 g/L); T3 – RDF + humic acid powder at 250 g/acre (soil application, SA); T4 – RDF + humic acid powder at 500 g/acre (SA); T5 – RDF + humic acid powder at 1000 g/acre (SA); T6 – 80% RDF + root dipping in humic acid powder solution (1 g/L); T7 – 80% RDF + humic acid powder at 250 g/acre (SA); T8 – 80% RDF + humic acid powder at 500 g/acre (SA); T9 – 80% RDF + humic acid powder at 1000 g/acre (SA); T10 – 80% RDF + humic acid powder at 1 g/L (foliar spray, FS); T11 – 80% RDF + humic acid powder at 2 g/L (FS); and T12 – 80% RDF + humic acid powder at 4 g/L (FS).

⁺⁺ Ph.D. Research Scholar; [#] Professor; [†] Professor and Head; [‡] M.Sc. Research Scholar;

*Corresponding author: E-mail: swetaparganiha45@gmail.com;

The findings indicated that the different combinations of humic acid-based biostimulant applications, administered through soil and foliar methods alongside 80% or 100% RDF, had no statistically significant effect on soil pH, electrical conductivity (EC; dS/m), organic carbon (OC; %), available nitrogen and potassium (kg ha⁻¹), or the concentrations of micronutrients, including zinc, manganese, copper and iron (mg kg⁻¹). In contrast, soil-available phosphorus (kg ha⁻¹) differed significantly among treatments, with the highest concentration observed under RDF + humic acid powder at 500 g/acre (T4), followed by RDF + humic acid powder at 1000 g/acre (T5).

Keywords: *Rice; humic acid; root dipping; soil application; foliar spray; Soil fertility.*

1. Introduction

Rice (*Oryza sativa* L.) is a major staple food crop in India, and enhancing its productivity is essential to meet the growing food demand. However, intensive cropping, imbalanced fertiliser application, and inadequate addition of organic manures have contributed to declining soil fertility, deterioration of soil health, rising input costs, and environmental concerns (Sharma *et al.*, 2019). In the 2014–2014/15 fertiliser-use assessment, rice accounted for 29% of fertiliser nutrient use in India (International Fertilizer Association & International Plant Nutrition Institute, 2017). Rice demand in India was projected to reach approximately 156 million tonnes by 2030 (Indian Council of Agricultural Research, 2011), highlighting the need for sustainable nutrient management practices.

Among organic inputs, humic acid-based biostimulants have emerged as promising tools for enhancing plant growth, root development, nutrient uptake, and crop productivity. Biostimulants have been reported to increase crop yields by up to 17.9% across different crop groups and may help reduce fertiliser-related environmental impacts (Li *et al.*, 2022). Humic substances improve soil physical, chemical, and biological properties by enhancing soil structure, water-holding capacity, nutrient retention, and beneficial microbial activity. They may also improve nutrient availability, nutrient-use efficiency, and soil fertility, thereby supporting sustainable crop production. The integrated application of biostimulants with recommended fertilisers may help maintain soil health while improving rice productivity.

Bansal *et al.* (2024) investigated the residual effects of humic acid, phosphate-solubilising bacteria and phosphorus nutrition on soil chemical properties following rice cultivation, reporting no statistically significant treatment effects on the residual soil properties examined.

In a separate foxtail millet experiment, Kumar *et al.* (2025) assessed the effects of soil and foliar humic acid applications with different fertiliser rates on soil microbial populations; these findings concern soil biological responses in a crop other than rice.

In acidic paddy soil, Hartina *et al.* (2025) evaluated humic acid with and without gypsum and identified treatment-dependent responses in soil chemical properties and phosphorus use efficiency.

Ali *et al.* (2025) examined the combined use of humic acid and phosphate-solubilising bacteria in direct-seeded rice and reported effects on rhizosphere activity and phosphorus acquisition under different phosphorus fertilisation levels.

Mindari *et al.* (2025) also investigated humic acid and biosilica applications in sandy soil used for rice cultivation, observing changes in soil nutrient availability and plant nutrient uptake.

Research gap: Previous studies addressed different soil types, cropping systems or amendment combinations, leaving uncertainty about the relative effects of root dipping, soil application and foliar spraying of humic acid powder on residual soil fertility in the Vertisols of Chhattisgarh under rice cultivation.

1.1 Objective

The objective of the present investigation was to evaluate the effects of the tested combinations of humic acid powder application methods and 80% or 100% of the recommended fertiliser dose on post-harvest soil chemical properties and available macro- and micronutrients in a Vertisol under rice cultivation in Chhattisgarh.

2. Materials and Methods

The field experiment was carried out at the research farm of Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur, Chhattisgarh, India, during the Kharif seasons of 2023 and 2024 to evaluate the influence of a humic acid-based biostimulant on soil fertility in Vertisols under rice cultivation in Chhattisgarh. The experimental soil was clayey in texture and classified as a Vertisol, locally referred to as Kanhar soil. The chemical characteristics of the soil at the experimental site are summarised in Table 1. The rice variety Rajeshwari, developed and released by IGKV, was selected as the test crop for the study. Before establishing the experiment, the field was prepared through two successive ploughings using a cultivator, followed by division into individual plots measuring 4 × 5 m. All experimental plots were systematically labelled and arranged in accordance with the prescribed experimental design.

The experiment was laid out in a randomised block design (RBD) consisting of 12 treatments, with each treatment replicated three times. To minimise experimental bias, the treatments were randomly allocated to the experimental plots within each block. The treatment combinations included T1 – recommended dose of fertilisers (RDF; 120:60:40); T2 – RDF + root dipping with humic acid

powder (1 g/L); T3 – RDF + soil application of humic acid powder at 250 g/acre; T4 – RDF + soil application of humic acid powder at 500 g/acre; T5 – RDF + soil application of humic acid powder at 1,000 g/acre; T6 – 80% RDF + root dipping with humic acid powder (1 g/L); T7 – 80% RDF + soil application of humic acid powder at 250 g/acre; T8 – 80% RDF + soil application of humic acid powder at 500 g/acre; T9 – 80% RDF + soil application of humic acid powder at 1,000 g/acre; T10 – 80% RDF + foliar application of humic acid powder (1 g/L); T11 – 80% RDF + foliar application of humic acid powder (2 g/L); and T12 – 80% RDF + foliar application of humic acid powder (4 g/L). The treatments involved the application of either 80% or 100% of the recommended doses of nitrogen (N), phosphorus (P) and potassium (K). Urea, single superphosphate (SSP) and muriate of potash (MOP) served as the sources of mineral nutrients, while humic acid powder was applied as a biostimulant according to the respective treatment combinations. At transplanting, one-third of the recommended nitrogen dose was supplied through urea, together with the entire recommended quantities of phosphorus and potassium fertilisers.

The remaining two equal splits (1/3rd of Urea) of nitrogen were given at tillering and panicle initiation stage of rice. According to the treatment requirements, rice seedlings were subjected to root dipping in humic acid powder solution for two hours before transplanting in the respective treatments (T₂ and T₆). Humic acid powder was applied twice (at the tillering and panicle initiation stages, respectively) as a foliar application, as per the treatments. The soil samples collected from the furrow slice (0-15 cm) before the commencement of the experiment and after harvest in each of the two years were analysed to ascertain the soil chemical properties.

Soil pH was measured in a soil–water suspension prepared at a ratio of 1:2.5, following the procedure outlined by Piper (1966). After measuring the pH, the soil suspension was allowed to stand overnight, and the electrical conductivity (EC) of the supernatant was subsequently measured using a Solu-bridge, as described by Black (1965). Soil organic carbon content was analysed using the rapid titration technique developed by Walkley and Black (1934). Available nitrogen was quantified using the alkaline potassium permanganate method proposed by Subbiah and Asija (1956), while available phosphorus was estimated following the procedure established by Olsen *et al.* (1954). Available potassium was extracted using neutral normal ammonium acetate solution, and its concentration was determined using a flame photometer in accordance with the method described by Hanway and Heidel (1952). Available micronutrients (Fe, Zn, Mn, Cu) were extracted using DTPA (Lindsay & Norvell, 1978).

All field and laboratory observations were recorded and tabulated. The final results were statistically analysed using a randomised block design (Gomez & Gomez, 1976). The standard error of the mean (SEM) and critical differences were determined at a probability of 5% to assess significant treatment effects.

Table 1. Initial physico-chemical properties of experimental soil

Parameter	Values
Physical properties international pipette method (Black1965)	
Mechanical Composition	Texture- Clayey
Sand%	23.5
Silt %	28.4
Clay %	48.1
Chemical Properties	
pH	7.50
EC (dS m ⁻¹)	0.19
Organic Carbon (%)	0.49
Available N (kg ha ⁻¹)	215
Available P (kg ha ⁻¹)	17.5
Available K (kg ha ⁻¹)	495
Available Fe (mg/kg)	17.80
Available Zn (mg/kg)	1.18
Available Mn(mg/kg)	9.56
Available Cu (mg/kg)	0.58

3. Results and Discussion

3.1 Effect of Humic Acid on Soil Chemical Properties

3.1.1 pH

The results pertaining to the changes in soil reaction at harvest of rice are presented in Table 2. The effects of combinations of soil and foliar applications of humic acid in conjunction with 80% and 100% RDF on soil pH were not significant in either year. Soil pH ranged from 7.51-7.57 and 7.52-7.58, respectively in either year. The pooled data also showed that the highest pH (7.58) was observed in RDF+ RD with HP(1g/L) whereas the lowest (7.51) was recorded in 80% RDF+HP @ 500g/acre. The buffering effect of humic acid causes resistance to changes in soil pH, resulting in a non-significant effect of humic acid application on pH.

The non-significant changes in pH under different treatment combinations might be attributed to the higher buffering capacity of *Vertisol*. These findings are well supported by the results reported by Bansal *et al.* (2024).

3.1.2 Electrical Conductivity

Electrical conductivity (EC) provides information on the dominance of soluble salts in the soil and is one of the criteria to distinguish between saline and non-saline soils. The data on EC of soil after the harvest of the crop are presented in Table 2. Different combinations of humic acid biostimulant applied through soil and foliar methods in conjunction with 80% and 100% RDF had no significant effect on EC in either year. The values of EC ranged between 0.20-0.26 dS m⁻¹ during 2023 and 0.22-0.28 dS m⁻¹ during 2024 across all combinations of biostimulants along with RDF. The highest EC (0.26 dS m⁻¹) was observed in RDF + RD with HP(1g/L) and RDF (120:60:40) in 2023, and a similar trend was also observed during 2024.

Despite minor numerical differences, the EC values across treatments were statistically indistinguishable. The results of non-significant differences in soil EC under different treatments might be due to the high buffering capacity of *Vertisol*. Related soil-chemical responses to nutrient management have been studied in a Vertisol by Pendro *et al.* (2018) and in rice under humic acid application by Bansal *et al.* (2024).

3.1.3 Organic Carbon

The results regarding soil organic carbon (SOC) as influenced by the treatments are shown in Table 2, and SOC was not significantly affected by the incorporation of different combinations of biostimulant applied through soil and foliar methods alongside 80% and 100% RDF in either year. The SOC content in soil ranged between 0.48- 0.54% during 2023 and 0.49-0.56% during 2024. Among all treatments the highest SOC was recorded in RDF+ HP @ 500g/acre during 2023 and 2024, respectively, whereas the lowest was obtained in 80% RDF+ HP @1g/L in either year of experiment.

Based on the pooled analysis, the highest OC (0.54 %) was observed in RDF + HP @ 500 and 1000 g/acre whereas the lowest (0.48 %) was recorded in 80% RDF+HP @1 g/L. Bansal *et al.* (2024) also reported non-significant treatment effects on residual soil properties after humic acid application in rice. Pramanick *et al.* (2014) and Nayak *et al.* (2020) investigated seaweed biostimulants in sesame and rice, respectively; these studies did not directly establish non-significant changes in soil organic carbon.

Table 2. Effect of biostimulant on soil chemical properties after harvest of rice

Treatments		pH			EC (dSm ⁻¹)			OC (%)		
		2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁	RDF (120:60:40)	7.56	7.57	7.57	0.25	0.27	0.26	0.50	0.52	0.51
T ₂	RDF +RD with HP (1g/L)	7.57	7.58	7.58	0.25	0.28	0.26	0.51	0.53	0.52
T ₃	RDF + HP @ 250g/acre (SA)	7.56	7.56	7.56	0.24	0.27	0.26	0.53	0.54	0.53
T ₄	RDF + HP @ 500g/acre (SA)	7.55	7.56	7.56	0.23	0.26	0.24	0.54	0.56	0.54
T ₅	RDF+ HP @1000g/acre (SA)	7.56	7.57	7.57	0.24	0.27	0.25	0.53	0.55	0.54
T ₆	80% RDF+ RD with HP(1g/L)	7.54	7.55	7.55	0.23	0.25	0.24	0.49	0.50	0.49
T ₇	80% RDF+HP @ 250g/acre (SA)	7.53	7.54	7.53	0.22	0.24	0.23	0.50	0.51	0.50
T ₈	80% RDF+HP @ 500g/acre (SA)	7.51	7.52	7.51	0.21	0.23	0.22	0.52	0.54	0.53
T ₉	80% RDF+HP @ 1000g/acre (SA)	7.52	7.53	7.52	0.21	0.22	0.21	0.51	0.53	0.52
T ₁₀	80% RDF+HP @ 1g/L (FS)	7.54	7.55	7.55	0.23	0.25	0.24	0.48	0.49	0.48
T ₁₁	80% RDF+HP @ 2g/L (FS)	7.53	7.54	7.53	0.22	0.24	0.23	0.49	0.50	0.49
T ₁₂	80% RDF+HP @ 4g/L (FS)	7.52	7.53	7.52	0.21	0.23	0.22	0.50	0.51	0.50
SEm (±)		0.04	0.04	0.02	0.02	0.04	0.02	0.03	0.03	0.02
CD (P=0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS

RD= Root dipping, HP= Humic acid powder, SA= Soil application, FS = Foliar spray

3.2 Effect of Humic on Nutrient Availability

3.2.1 Available Nitrogen

Nitrogen is an important nutrient in this experiment and the results on soil available nitrogen are presented in Table 3. Different combinations of biostimulants applied through soil and foliar methods along with 80 and 100% RDF had no significant effect on availability of nitrogen in either year. The availability of nitrogen in soil varied between 215.7 – 219.4 kg ha⁻¹ and 216.1 – 220.3 kg ha⁻¹ among the treatments, including 80% RDF + HP @1 g/l and RDF in either year.

Based on the pooled analysis, the highest available nitrogen (219.9) was observed in 100% RDF whereas the lowest (216.1 kg ha⁻¹) was recorded in 80% RDF+HP @500g/acre. The treatments showed a marginal increase in residual available N in the soil from the initial level (215 Kg ha⁻¹). This might be due to the addition of nitrogen through the fertilizer and less uptake of nitrogen from the soil, leading to a substantial amount of leftover N nutrient in the soil. Related non-significant residual soil responses were reported by Bansal *et al.* (2024). Non-significant changes in soil available nitrogen have also been discussed by Layek *et al.* (2018) and Bansal *et al.* (2024).

3.2.2 Available Phosphorus

The incorporation of different combinations of biostimulants applied through soil and foliar along with 80 and 100% RDF significantly affected the availability of phosphorus in the soil. Based on the pooled data, the highest available phosphorus content

was recorded with RDF + HP @ 500 g/acre (20.1 kg ha⁻¹), which was statistically at par with RDF + HP @ 1000 g/acre (20.0 kg ha⁻¹) and RDF + HP @ 250 g/acre (19.7 kg ha⁻¹).

With 80% RDF and HP, available phosphorus increased numerically at higher HP doses. The lowest value among soil-applied HP treatments was recorded with 80% RDF + HP @ 250 g/acre (18.2 kg ha⁻¹), whereas 80% RDF + HP @ 500 g/acre (19.3 kg ha⁻¹) and 80% RDF + HP @ 1000 g/acre (19.4 kg ha⁻¹) were statistically similar and significantly superior to that of lower dose of humic acid powder.

When root dipping with RDF (19.0 kg ha⁻¹) was compared with RDF alone (18.6 kg ha⁻¹), the root-dipping treatment resulted in slightly higher available phosphorus, although both remained statistically comparable. Similarly, under reduced fertilizer levels, 80% RDF + root dipping (17.8 kg ha⁻¹) recorded higher phosphorus than 80% RDF + foliar spray @ 1 g/L (17.6 kg ha⁻¹), although both were significantly lower than their respective RDF counterparts.

Among the foliar sprays, 80% RDF + HP @ 4 g/L (18.4 kg ha⁻¹) was statistically at par with 80% RDF + HP @ 2 g/L (18.1 kg ha⁻¹), and both were significantly higher than 80% RDF + HP @ 1 g/L (17.6 kg ha⁻¹). In general, the soil-applied HP treatments recorded higher available phosphorus values compared to the corresponding foliar treatments.

Soil available phosphorus was reported to improve significantly with the application of organic, inorganic and organic + inorganic sources of nutrients compared with the control and the increase in available phosphorus status may be attributed to the application of FYM, which not only serves as a direct source of phosphorus but also helps solubilize native soil phosphorus through the release of various organic acids. These acids exert a chelating effect, thereby reducing phosphorus fixation in the soil. Pramanik *et al.* (2020) investigated nutrient uptake and residual soil fertility under seaweed-biostimulant treatments with 75% and 100% of the recommended fertiliser dose in rice. Related rice studies have examined the nutrient uptake response to seaweed extract (Banjare *et al.*, 2022) and residual soil effects of humic acid with phosphorus nutrition (Bansal *et al.*, 2024).

3.2.3 Available Potassium

Data on soil available potassium are presented in Table 3. The application of different combinations of biostimulants did not significantly affect potassium availability in the soil. During 2023, the available potassium in soil ranged from 488.0 to 492.8 kg ha⁻¹, while it varied between 489.7 and 494.9 kg ha⁻¹ during 2024 across treatments.

Based on the pooled data, the highest available potassium (493.9 kg ha⁻¹) was observed under 100% RDF whereas the lowest (488.9 kg ha⁻¹) was recorded in 80%RDF+HP @500g/acre. However, the combined application of humic acid and inorganic fertilisers exhibited a statistically non-significant effect on soil available potassium. This might be due to the ion exchange dynamics influenced by humic acid. It is suggested that the application of composted humic acid facilitates the exchange of HA-bound NH₄⁺ and K⁺ with Na⁺ and Ca²⁺ ions in the soil, thereby reducing soil salinity. This reduction in sodium levels likely occurs as K⁺ ions replace Na⁺ on adsorption sites of soil colloids, leading to an increased proportion of potassium in the soil. The observed enhancement in soil-available potassium may be attributed to a reduction in potassium fixation and the mobilisation of previously fixed potassium through the action of humic acid. Humic substances can penetrate the intermicellar spaces of clay minerals and access specific sorption sites for potassium (K⁺) ions. By competing with K⁺ ions for these sorption sites, humic substances may reduce potassium retention, thereby improving its availability in the soil (Manjeera *et al.*, 2021; Kumar *et al.*, 2023). No variation in the soil available potassium was also reported by Layek *et al.* (2018) and Banjare *et al.* (2022).

Table 3. Effect of biostimulant on available major nutrients after harvest of rice

Treatments	Macronutrients (kg ha ⁻¹)								
	Available nitrogen			Available phosphorus			Available potassium		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T ₁ - RDF (120:60:40)	219.4	220.3	219.9	18.2 ^{abcd}	19.0 ^{abcd}	18.6 ^{bcde}	492.8	494.9	493.9
T ₂ - RDF +RD with HP (1g/L)	219.2	220.0	219.6	18.6 ^{abcd}	19.5 ^{abc}	19.0 ^{abcde}	492.6	494.8	493.7
T ₃ - RDF + HP @ 250g/acre (SA)	218.8	219.6	219.2	19.5 ^{ab}	19.9 ^{ab}	19.7 ^{abc}	492.3	494.7	493.5
T ₄ - RDF + HP @ 500g/acre (SA)	217.8	218.2	218.0	19.9 ^a	20.3 ^a	20.1 ^a	491.9	494.4	493.2
T ₅ - RDF+ HP @1000g/acre (SA)	218.4	219.1	218.8	19.7 ^a	20.2 ^a	20.00 ^{ab}	492.1	494.7	493.4
T ₆ - 80% RDF+ RD with HP(1g/L)	216.6	217.4	217.0	17.5 ^{cd}	18.0 ^{cd}	17.8 ^{de}	489.1	491.4	490.3
T ₇ - 80% RDF+HP @ 250g/acre (SA)	216.3	216.7	216.5	17.8 ^{cd}	18.5 ^{bcd}	18.2 ^e	488.6	490.9	489.8
T ₈ - 80% RDF+HP @ 500g/acre (SA)	215.7	216.1	215.9	18.8 ^{abcd}	19.9 ^{ab}	19.3 ^{abcde}	488.0	489.7	488.9
T ₉ - 80% RDF+HP @ 1000g/acre (SA)	216.0	216.3	216.1	19.1 ^{abc}	19.7 ^{ab}	19.4 ^{abcde}	488.4	489.8	489.1
T ₁₀ - 80% RDF+HP @ 1g/L (FS)	216.8	217.6	217.2	17.4 ^d	17.9 ^d	17.6 ^e	489.3	491.7	490.4
T ₁₁ - 80%- RDF+HP @ 2g/L (FS)	216.5	217.1	216.8	17.7 ^{cd}	18.4 ^{bcd}	18.1 ^{de}	489.1	491.1	490.1
T ₁₂ - 80% - RDF+HP @ 4g/L (FS)	216.2	216.6	216.4	17.9 ^{bcd}	18.8 ^{abcd}	18.4 ^{cde}	488.5	490.5	489.5
SEm (±)	3.6	2.7	2.7	0.6	0.5	0.5	6.8	5.9	6.1
C.D. (P=0.05)	NS	NS	NS	1.7	1.6	1.4	NS	NS	NS
Initial	215			17.5			495		

3.2.4 Available Zinc

The data on the availability of zinc in the soil are presented in Table 4. The incorporation of different combinations of biostimulants in soil as well as foliar treatments did not significantly affect zinc availability in the soil. In 2023, soil available zinc ranged from

1.20 to 1.27 mg kg⁻¹, whereas it varied between 1.15 and 1.23 mg kg⁻¹ during 2024 across treatments. The pooled data showed that the highest (1.25 mg kg⁻¹) available zinc status was recorded in 100 % RDF, whereas the lowest (1.18 mg kg⁻¹) was recorded in 80 % RDF + HP @ 500 g/acre. The same trend was observed during both the years in these treatments.

Humic acid has a good tendency to form chelates with metal ions and the formation of humate-metal ion complexes make them more readily available to plants. These findings were consistent with Manjeera *et al.* (2021), who examined the availability of zinc following humic acid application.

3.2.5 Available Iron

The results pertaining to soil available iron as influenced by different treatment combinations are presented in Table 4. The analysis revealed that soil available iron was not significantly affected by the application of biostimulants along with soil or foliar application in conjunction with 80 or 100% (RDF) in either year. Soil available iron ranged between 17.88- 18.78 mg kg⁻¹ during 2023 and 17.08-17.98 mg kg⁻¹ during 2024 across treatments. In the pooled data, the highest (18.38 mg kg⁻¹) available iron was recorded in 100% RDF, whereas the lowest (17.48 mg kg⁻¹) was obtained in 80% RDF+HP@ 500g/acre. The same trend was observed during both the years in these treatments.

Manjeera *et al.* (2021) observed that HA application did not significantly influence soil available iron at any growth stage of rice.

3.2.6 Available Manganese

The data on the availability of manganese in soil under different treatment combinations are presented in Table 5. The incorporation of different combinations of biostimulants through soil and foliar methods along with varying levels of RDF, did not significantly influence manganese availability in soil in either year. Despite the lack of significant variation among treatments, the post-harvest values were consistently higher than the initial soil manganese levels. During 2023, the available manganese ranged from 9.55 to 10.01 mg kg⁻¹, while in 2024, it varied between 9.47 and 9.93 mg kg⁻¹ in different treatments.

The highest pooled (9.97 mg kg⁻¹) available manganese content was recorded under 100% RDF, whereas the lowest (9.51 mg kg⁻¹) was obtained in 80% RDF+HP @ 500g/acre. The same trend was observed in both years.

Humic acid has the capacity to form chelates with metal ions and the formation of humate-metal ion complexes make them more readily available to plants. The formation of humate-Mn complexes might have contributed to increased manganese availability in humic acid applied plots. The same trend was observed in both the seasons. Manjeera *et al.* (2021) revealed that there was no significant treatment-related variation on available manganese content in soil at any of the three stages of crop growth.

3.2.7 Available Copper

The results pertaining to soil available copper as influenced by different treatment combinations are presented in Table 5. The analysis revealed that soil available copper was not significantly affected by the application of biostimulants (via soil or foliar application in conjunction with 80 or 100% recommended dose of fertilizers (RDF) in either year. Soil available copper ranged between 0.59- 0.65 mg kg⁻¹ during 2023 and 0.55-0.61 mg kg⁻¹ during 2024 in different treatments.

In the pooled data, the highest (0.63 mg kg⁻¹) available copper was recorded in 100% RDF whereas the lowest (0.57 mg kg⁻¹) was obtained in 80% RDF+HP @ 500 g/acre.

Table 4. Effect of bio stimulant on available micronutrients content after harvest of rice

Treatments	Micronutrients (mg kg ⁻¹)					
	Zn			Fe		
	2023	2024	Pooled	2023	2024	Pooled
T ₁ - RDF (120:60:40)	1.27	1.23	1.25	18.78	17.98	18.38
T ₂ - RDF +RD with HP (1g/L)	1.26	1.22	1.24	18.72	17.92	18.32
T ₃ - RDF + HP @ 250g/acre (SA)	1.25	1.21	1.23	18.61	17.81	18.21
T ₄ - RDF + HP @ 500g/acre (SA)	1.23	1.19	1.21	18.45	17.65	18.05
T ₅ - RDF+ HP @1000g/acre (SA)	1.25	1.21	1.23	18.54	17.74	18.14
T ₆ - 80% RDF+ RD with HP(1g/L)	1.22	1.18	1.20	18.38	17.58	17.98
T ₇ - 80% RDF+HP @ 250g/acre (SA)	1.21	1.17	1.19	18.12	17.32	17.72
T ₈ - 80% RDF+HP @ 500g/acre (SA)	1.20	1.15	1.18	17.88	17.08	17.48
T ₉ - 80% RDF+HP @ 1000g/acre (SA)	1.20	1.16	1.18	17.94	17.14	17.54
T ₁₀ - 80% RDF+HP @ 1g/L (FS)	1.22	1.18	1.20	18.42	17.62	18.02
T ₁₁ - 80%- RDF+HP @ 2g/L (FS)	1.21	1.17	1.19	18.26	17.46	17.86
T ₁₂ - 80% - RDF+HP @ 4g/L (FS)	1.20	1.16	1.18	17.99	17.19	17.59
SEm (±)	0.06	0.09	0.07	0.88	0.97	0.82
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS
Initial	1.18			17.8		

RD= Root dipping, HP= Humic acid powder, SA= Soil application, FS = Foliar spray

The findings of the present study are consistent with those reported by Manjeera *et al.* (2021). Similarly, Rutkowska *et al.* (2014) observed that prolonged application of farmyard manure increased the concentrations of zinc (Zn), boron (B) and iron (Fe) in the soil solution. Humic acid possesses the ability to attract positively charged ions and form chelated complexes with micronutrients, thereby functioning as a reservoir of essential plant nutrients. Owing to its polyvalent nature, humic acid can bind micronutrient cations and facilitate their subsequent release for plant uptake (Schnitzer & Khan, 1972; Sposito, 1989). Furthermore, humic acid may enhance nutrient availability by promoting mineral decomposition through two possible mechanisms. Firstly, humic acid may interact with soil minerals and facilitate their dissolution, resulting in the release of nutrients from mineral-bound forms into adsorbed forms. Secondly, it may promote the formation of stable organo-mineral complexes with micronutrient ions, such as HA-Fe²⁺, HA-Mn²⁺, HA-Zn²⁺ and HA-Cu²⁺, potentially increasing their accessibility and availability for plant uptake (Brady & Weil, 1996).

Table 5. Available manganese and copper status after harvest of the rice crop

Treatments	Micronutrients (mg kg ⁻¹)					
	Mn			Cu		
	2023	2024	Pooled	2023	2024	Pooled
T ₁ - RDF (120:60:40)	10.01	9.93	9.97	0.65	0.61	0.63
T ₂ - RDF +RD with HP (1g/L)	9.92	9.84	9.88	0.63	0.61	0.62
T ₃ - RDF + HP @ 250g/acre (SA)	9.88	9.80	9.84	0.63	0.59	0.61
T ₄ - RDF + HP @ 500g/acre (SA)	9.77	9.69	9.73	0.62	0.58	0.60
T ₅ - RDF+ HP @1000g/acre (SA)	9.82	9.74	9.78	0.63	0.59	0.61
T ₆ - 80% RDF+ RD with HP(1g/L)	9.69	9.61	9.65	0.61	0.57	0.59
T ₇ - 80% RDF+HP @ 250g/acre (SA)	9.62	9.54	9.58	0.60	0.56	0.58
T ₈ - 80% RDF+HP @ 500g/acre (SA)	9.55	9.47	9.51	0.59	0.55	0.57
T ₉ - 80% RDF+HP @ 1000g/acre (SA)	9.58	9.50	9.54	0.59	0.55	0.57
T ₁₀ - 80% RDF+HP @ 1g/L (FS)	9.72	9.64	9.68	0.62	0.58	0.60
T ₁₁ - 80%- RDF+HP @ 2g/L (FS)	9.66	9.58	9.62	0.61	0.57	0.59
T ₁₂ - 80% - RDF+HP @ 4g/L (FS)	9.60	9.52	9.56	0.60	0.56	0.58
SEm (±)	0.4	0.5	0.4	0.08	0.06	0.06
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS
Initial	9.56			0.58		

RD= Root dipping, HP= Humic acid powder, SA= Soil application, FS = Foliar spray

4. Conclusion

The results of this investigation showed that the application of humic acid-based biostimulants along with recommended fertiliser doses had no statistically significant effect on soil pH, electrical conductivity, organic carbon, available nitrogen, potassium, and micronutrients (Zn, Fe, Mn and Cu) in the Vertisol of Chhattisgarh. However, available phosphorus was significantly influenced by the treatments. The application of recommended dose of fertilisers (RDF) along with humic acid powder at 500 g acre⁻¹ (T₄) recorded the highest available phosphorus content, which was statistically at par with RDF + humic acid powder at 1000 g acre⁻¹ (T₅) and 250 g acre⁻¹ (T₃). Overall, the application of humic acid powder at 500 g acre⁻¹ along with the recommended dose of fertilisers was the most promising treatment for improving residual soil phosphorus availability, although its effects on other soil chemical properties were not statistically significant under the experimental conditions.

5. Limitations

This investigation was confined to a single Vertisol experimental site at Raipur over the 2023 and 2024 kharif seasons. Although the study included three replications, the results may not represent soils with different mineralogical properties, fertility status or management histories. The assessment focused on post-harvest soil chemical properties and available nutrients. Consequently, the findings do not establish long-term changes in soil fertility or the performance of the tested treatments across other rice-growing environments. The non-significant responses for most indicators should be interpreted within the study's experimental conditions.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that no competing interests exist.

References

- Ali, S. K. A., Dhyani, V. C., Kumari, A., & Prajapati, S. K. (2025). Synergistic effect of humic acid and phosphate solubilizing bacteria on rhizospheric functions and phosphorous acquisition in direct-seeded rice (*Oryza sativa*). *The Indian Journal of Agricultural Sciences*, 95(11), 1400–1405. <https://doi.org/10.56093/ijas.v95i11.167027>

- Banjare, L., Banwasi, R., Jataw, G. K., & Shrivastav, L. K. (2022). Effect of seaweed extract on yield and nutrient uptake of rice in a Vertisol. *The Pharma Innovation Journal*, 11(3), 2193–2198. <https://www.thepharmajournal.com/archives/2022/vol11issue3/PartAC/11-3-366-733.pdf>
- Bansal, K. K., Sharma, A. K., Sharma, A., Bharti, V., Sharma, V., Sharma, M. K., & Dey, T. (2024). Residual effect of humic acid, PSB and phosphorus nutrition on soil chemical properties after harvest of rice crop under the subtropical condition of Jammu. *International Journal of Plant & Soil Science*, 36(3), 59–68. <https://doi.org/10.9734/ijpss/2024/v36i34398>
- Black, C. A. (Ed.). (1965). *Methods of soil analysis*. American Society of Agronomy. <https://www.worldcat.org/search?q=Methods+of+soil+analysis+Black+1965>
- Brady, N. C., & Weil, R. R. (1996). *The nature and properties of soils* (11th ed.). Prentice Hall. <https://agris.fao.org/search/en/providers/122535/records/65ddfc3c0f3e94b9e5c8de>
- Gomez, K. A., & Gomez, A. A. (1976). *Statistical procedures for agricultural research with emphasis on rice*. International Rice Research Institute. https://books.google.com/books?id=DZo_AAAAYAAJ
- Hanway, J. J., & Heidel, H. (1952). Soil analysis methods as used in Iowa State College Soil Testing Laboratory. *Iowa Agriculture*, 57, 1–31.
- Hartina, Monkham, T., Vityakon, P., & Sukitprapanon, T.-S. (2025). Coapplication of humic acid and gypsum affects soil chemical properties, rice yield, and phosphorus use efficiency in acidic paddy soils. *Scientific Reports*, 15, Article 4350. <https://doi.org/10.1038/s41598-025-89132-8>
- Indian Council of Agricultural Research. (2011). *ICAR vision 2030*. Indian Council of Agricultural Research. <https://icar.gov.in/sites/default/files/inline-files/ICAR-Vision-2030.pdf>
- International Fertilizer Association, & International Plant Nutrition Institute. (2017). *Assessment of fertilizer use by crop at the global level: 2014–2014/15*. International Fertilizer Association. <https://www.fertilizer.org/resource/assessment-of-fertilizer-use-by-crop-at-the-global-level-2014-2014-15/>
- Kumar, Y. S. S., Nayak, S. B., Reddy, C. V. C. M., Kumar, K. A., Vishnuvardhan, K. M., Kiranmayi, J., & Rao, E. N. (2023). Effect of potassium humate fertilizers on soil nutrients and productivity of rice crop in Vertisols of Southern India. *Ecology, Environment and Conservation*, 29(1), 71–76. <https://doi.org/10.53550/EEC.2023.v29i01.009>
- Kumar, Y. S. S., Rao, C. S., Prasad, P. R. K., Sridhar, T. V., Basha, S. J., & Jayalalitha, K. (2025). Studies on the effect of fertilizers and humic acid on soil microbial populations of foxtail millet crop. *Asian Journal of Current Research*, 10(3), 60–66. <https://doi.org/10.56557/ajocr/2025/v10i39472>
- Layek, J., Das, A., Idapuganti, R. G., Sarkar, D., Ghosh, A., Zodape, S. T., Lal, R., Yadav, G. S., Panwar, A. S., Ngachan, S., & Meena, R. S. (2018). Seaweed extract as organic biostimulant improves productivity and quality of rice in eastern Himalayas. *Journal of Applied Phycology*, 30(1), 547–558. <https://doi.org/10.1007/s10811-017-1225-0>
- Li, J., Van Gerreway, T., & Geelen, D. (2022). A meta-analysis of biostimulant yield effectiveness in field trials. *Frontiers in Plant Science*, 13, Article 836702. <https://doi.org/10.3389/fpls.2022.836702>
- Lindsay, W. L., & Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal*, 42(3), 421–428. <https://doi.org/10.2136/sssaj1978.03615995004200030009x>
- Manjeera, K. S., Subbaiah, P. V., Prasad, P. R. K., & Rekha, M. S. (2021). Available nutrient status of soil as influenced by combined application of humic acid and inorganic nitrogen. *International Journal of Plant & Soil Science*, 33(22), 209–217. <https://doi.org/10.9734/ijpss/2021/v33i2230697>
- Mindari, W., Chakim, M. G., Widjajani, B. W., Sasongko, P. E., Aditya, H. F., Pazi, A. M. M., & Gandaseca, S. (2025). The optimization of biosilica and humic acid to increase soil nutrient availability and nutrient uptake in rice plant in sandy soil. *Caraka Tani: Journal of Sustainable Agriculture*, 40(1), 18–33. <https://doi.org/10.20961/carakatani.v40i1.89018>
- Nayak, P., Biswas, S., & Dutta, D. (2020). Effect of seaweed extracts on growth, yield and economics of kharif rice (*Oryza sativa* L.). *Journal of Pharmacognosy and Phytochemistry*, 9(3), 247–253. <https://doi.org/10.22271/phyto.2020.v9.i3d.11269>
- Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate (USDA Circular No. 939). U.S. Department of Agriculture. <https://agris.fao.org/search/en/providers/122535/records/65dded244c5aef494fd7641c>
- Pendro, R. P., Porte, S. S., Tiwari, A., & Varma, A. (2018). Effect of organic and inorganic fertilizer on physico-chemical properties, macro nutrient and soybean productivity in a Vertisol. *Journal of Pharmacognosy and Phytochemistry*, 7(Special Issue 1), 9–12. <https://www.phytojournal.com/special-issue/2018.v7.i1S.3061/effect-of-organic-and-inorganic-fertilizer-on-physico-chemical-properties-macro-nutrient-and-soybean-productivity-in-a-vertisol>
- Piper, C. S. (1966). *Soil and plant analysis: A laboratory manual of methods for the examination of soils and the determination of the inorganic constituents of plants*. Hans Publishers. <https://www.worldcat.org/title/221189064>
- Pramanick, B., Brahmachari, K., & Ghosh, A. (2014). Efficacy of Kappaphycus and Gracilaria sap on growth and yield improvement of sesame in new alluvial soil. *Journal of Crop and Weed*, 10(1), 77–81. https://cwss.in/Journal/Complete_journal/Vol.10%20No.1_14.pdf
- Pramanik, M., Dutta, D., & Samui, I. (2020). Effect of seaweeds on growth and yield of boro rice (*Oryza sativa* L.). *Current Journal of Applied Science and Technology*, 39(33), 28–34. <https://doi.org/10.9734/cjast/2020/v39i3331015>
- Rutkowska, B., Szulc, W., Sosulski, T., & Stepień, W. (2014). Soil micronutrient availability to crops affected by long-term inorganic and organic fertilizer applications. *Plant, Soil and Environment*, 60(5), 198–203. <https://doi.org/10.17221/914/2013-PSE>
- Schnitzer, M., & Khan, S. U. (1972). *Humic substances in the environment*. Marcel Dekker. <https://agris.fao.org/search/en/providers/122535/records/65ddfb43b766d82b18fb9643>
- Sharma, S., Padbhushan, R., & Kumar, U. (2019). Integrated nutrient management in rice–wheat cropping system: An evidence on sustainability in the Indian subcontinent through meta-analysis. *Agronomy*, 9(2), Article 71. <https://doi.org/10.3390/agronomy9020071>
- Sposito, G. (1989). *The chemistry of soils*. Oxford University Press. <https://books.google.com/books?id=UwG952T7230C>

- Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science*, 25, 259–260. <https://eurekamag.com/research/013/939/013939242.php>
- Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, 37(1), 29–38. <https://doi.org/10.1097/00010694-193401000-00003>

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2026): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here: <https://pr.sdiarticle5.com/review-history/169109>