



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(12): 1318-1322
Received: 09-09-2025
Accepted: 15-10-2025

D Rajashekhar
Research Scholar, Department of
Soil Science, PJTAU,
Rajendranagar, Hyderabad,
Telangana, India

S Harish Kumar Sharma
University Head, Department of
Soil Science, PJTAU, Telangana,
India

K Bhanu Rekha
Department of Agronomy,
PJTAU, Rajendranagar,
Hyderabad, Telangana, India

Corresponding Author:
D Rajashekhar
Research Scholar, Department of
Soil Science, PJTAU,
Rajendranagar, Hyderabad,
Telangana, India

Effect of sources and levels of zinc on nutrient content and uptake by rice (*Oryza sativa* L.)

D Rajashekhar, S Harish Kumar Sharma and K Bhanu Rekha

DOI: <https://www.doi.org/10.33545/2618060X.2025.v8.i12r.4642>

Abstract

The present study evaluated the influence of different zinc sources and application levels on nutrient uptake in rice. Zinc was supplied as ZnSO₄, Zn-fulvate, Zn-humate and Zn-chelate in combination with the recommended dose of fertilizers (RDF). Among the treatments, RDF supplemented with ZnSO₄ at 2.5 ppm resulted in the highest uptake of nitrogen, phosphorus, potassium and zinc (45.89, 5.37, 43.94 mg pot⁻¹ and 479.38 µg pot⁻¹, respectively), followed by Zn-fulvate at the same level (41.70, 4.62, 38.67 mg pot⁻¹ and 380.32 µg pot⁻¹). In contrast, the lowest nutrient uptake was observed under RDF alone. Zinc application at 2.5 ppm significantly enhanced N, P, K and Zn uptake compared to the control, whereas increasing the level to 5.0 ppm resulted in only marginal improvement. The effectiveness of zinc sources in improving rice nutrition followed the order: ZnSO₄ > Zn-fulvate > Zn-humate > Zn-chelate. These results highlight the superiority of soluble zinc sources, particularly ZnSO₄ and Zn-fulvate, in enhancing nutrient uptake in rice grown on zinc-deficient soils.

Keywords: Zinc sources, humic substances, nutrient uptake, rice, zinc deficiency, ZnSO₄

Introduction

Humic substances constitute the dominant fraction of soil organic matter and play a central role in regulating soil fertility, nutrient dynamics and crop productivity. They originate from the biochemical and physicochemical transformation of plant and animal residues and are ubiquitously present in soils, sediments and natural waters. Based on solubility behavior, humic substances are conventionally classified into three major fractions: fulvic acid (FA), humic acid (HA) and humin^[1]. Among these, humic and fulvic acids are the most chemically active components due to their high reactivity and strong affinity for nutrient elements.

Humic and fulvic acids are complex, heterogeneous, colloidal macromolecules characterized by the presence of functional groups such as carboxyl, phenolic, hydroxyl, carbonyl and amino moieties. These functional groups impart a high capacity for chelation and complex formation with polyvalent metal ions, including micronutrients like zinc, iron, copper and manganese^[2, 3]. The stability and solubility of these metal-organic complexes depend on the nature of both the ligand and the metal ion, influencing nutrient mobility and availability in soil systems.

Zinc is an essential micronutrient required for several physiological and biochemical processes in plants, including enzyme activation, protein synthesis and regulation of growth hormones. However, zinc deficiency is widespread in Indian soils, particularly in intensively cultivated areas, due to continuous nutrient mining, limited organic matter addition and imbalanced fertilizer use^[4, 5]. High soil pH, calcium carbonate content, strong adsorption by clay minerals and interactions with competing ions further reduce zinc availability in soils.

Application of zinc in complexed or chelated forms has been reported to enhance zinc solubility and protect the nutrient from fixation reactions in soil. Organic complexes of zinc, especially those formed with humic and fulvic acids, maintain higher zinc activity in the soil solution and facilitate nutrient transport to the root surface through diffusion and mass flow mechanisms^[6, 7]. Fulvic acid-metal complexes, in particular, are more soluble and mobile than humic acid complexes, thereby improving nutrient uptake efficiency under diverse soil conditions.

Rice (*Oryza sativa* L.), a major staple crop grown under submerged conditions, is highly sensitive to zinc deficiency, which often leads to reduced growth and yield. While zinc sulphate

is commonly used as an inorganic zinc source, its efficiency may be limited under certain soil conditions due to rapid fixation. In contrast, organically complexed zinc forms may offer improved nutrient availability and uptake. Therefore, the present investigation was undertaken to evaluate the comparative effectiveness of different zinc sources, including ZnSO₄, Zn-humate, Zn-fulvate and Zn-chelate, applied at varying levels, on zinc nutrition, macronutrient uptake and soil nutrient availability in rice grown under zinc-deficient conditions.

Materials and Methods

Approximately 1 kg of well-decomposed FYM and vermicompost was collected for analysis. Humic substances were isolated using Tyurin's extraction procedure^[1]. The humic acid (HA) fraction was dissolved in 0.1 N NaOH and repeatedly centrifuged to remove clay impurities, followed by successive precipitation steps for partial purification^[3]. The purified HA was reprecipitated using 1 N H₂SO₄, treated with a dilute HF-HCl mixture, and dialyzed against double-distilled water until free of chloride ions^[8]. The final HA fraction was evaporated at low temperature, dried, weighed, and stored for further analysis. The fulvic acid (FA) fraction, obtained from the acid-soluble portion, was purified through activated charcoal adsorption, washed with 1 N H₂SO₄, and eluted using 1 N NH₄OH. The eluted FA was dried at 40 °C and preserved for subsequent characterization.

For all computations, molecular weights of 1000 for humic acid and 700 for fulvic acid were assumed, based on elemental and functional group analyses reported earlier^[9, 10, 11]. Zinc-humate and zinc-fulvate complexes were synthesized using the stoichiometric coefficient (x), derived from stability constants at pH 7.0 and 30 °C, which was approximately 1.5 for both acids. Corresponding quantities of ZnSO₄ to provide 2.5 and 5.0 ppm Zn were mixed with the calculated amounts of HA or FA, diluted with distilled water, and adjusted to pH 7.0.

Pot culture experiment

A pot experiment was carried out using a zinc-deficient *Alfisol* with a soil pH of 7.7 to study the dry matter yield, nutrient content, and uptake by rice. The soil contained medium organic carbon, low available nitrogen (188 kg ha⁻¹), high available phosphorus (57.8 kg P₂O₅ ha⁻¹) and potassium (286.5 kg K₂O ha⁻¹), and low DTPA-extractable zinc (0.56 µg g⁻¹). Five kilograms of soil were placed in each earthen pot. Rice (cv. MTU 1010) served as the test crop, with 30-day-old seedlings transplanted at five hills per pot, two seedlings per hill. The pots were maintained under submerged conditions from flowering to harvest. A uniform fertilizer schedule equivalent to 120 kg N, 60 kg P₂O₅ and 40 kg K₂O ha⁻¹ was followed, with nitrogen applied as urea in two splits and phosphorus and potassium applied basally. Humic acid, fulvic acid, zinc-humate, zinc-fulvate and zinc chelate were supplied according to treatment structure. Eleven treatments comprising organic and inorganic zinc sources at two levels were imposed, including control, humic and fulvic acids alone, and Zn applied as ZnSO₄, chelate, fulvate or humate at 2.5 and 5.0 mg Zn kg⁻¹ soil.

Plant samples collected at harvest were shade-dried for 3-4 days and oven-dried at 65 °C. Finely ground samples were digested using a di-acid mixture (HNO₃:HClO₄) for the determination of P, K, and Fe, while nitrogen was analyzed following H₂SO₄ digestion. Nitrogen concentration was estimated using the modified micro-Kjeldahl method^[12]. Phosphorus was quantified by the vanado-molybdate yellow color method using Barton's reagent with absorbance measured at 420 nm^[13]. Potassium was

determined using a flame photometer^[13]. Nutrient uptake was computed using standard formulae.

$$\text{Uptake (kg/ha)} = (\text{Nutrient\%} \times \text{Dry Matter Yield (g/pot)}) / 100$$

Results and Discussion

Dry matter yield

Dry matter accumulation in rice was significantly influenced by the source and level of zinc application (Table 1). All zinc-treated pots recorded higher biomass than the control. The highest dry matter production was obtained with RDF + ZnSO₄ at 2.5 ppm (18.31 g pot⁻¹), followed by RDF + Zn-fulvate at the same level (17.11 g pot⁻¹), whereas RDF alone resulted in the lowest biomass (7.02 g pot⁻¹). Application of zinc at 2.5 ppm was more effective than 5.0 ppm, indicating that moderate zinc supply is optimal for rice growth under zinc-deficient conditions.

Among zinc sources, ZnSO₄ was most effective in enhancing dry matter yield, followed by Zn-fulvate, Zn-humate and Zn-chelate. The superior response to ZnSO₄ may be attributed to its higher solubility and rapid availability of zinc in soil, which promotes physiological processes related to photosynthesis and biomass production^[14, 5]. The comparatively better performance of Zn-fulvate over Zn-humate can be linked to the greater solubility and mobility of fulvic acid-metal complexes, facilitating improved zinc uptake^[15].

Application of humic and fulvic acids alone also increased dry matter production over the control, likely due to their stimulatory effects on nutrient uptake, chlorophyll synthesis and metabolic activity in plants^[16, 17]. Application of humic acid at varying doses through foliar and soil methods enhances plant growth and final productivity of rice by improving yield attributes. These effects are attributed to enhanced synthesis and activity of indole-3-acetic acid (IAA), which promotes plant growth^[18, 19]. These findings corroborate earlier reports highlighting the positive role of humic substances in enhancing crop growth under nutrient-limited conditions.

Effect of zinc sources and levels on N, P and K content and uptake by rice

The application of different zinc sources and levels exerted a significant influence on nitrogen, phosphorus and potassium concentration and their uptake by rice. Among the treatments, the combined application of RDF with ZnSO₄ at 2.5 ppm consistently recorded the highest N, P and K contents, followed by Zn-fulvate at the same level, whereas RDF alone resulted in the lowest nutrient concentrations (Table 1).

The enhanced nutrient uptake under ZnSO₄ @ 2.5 ppm was clearly evident, with maximum uptake of nitrogen, phosphorus and potassium, indicating improved nutrient absorption efficiency (Table 2). Zinc supplied at 2.5 ppm was more effective than 5 ppm, suggesting that excessive zinc may not proportionally enhance nutrient uptake. The relative efficiency of zinc sources in improving nutrient content and uptake followed the order: ZnSO₄ > Zn-fulvate > Zn-humate > Zn-chelate.

The superior response to ZnSO₄ may be attributed to its greater solubility and rapid dissociation in soil, which enhances zinc availability to plants and promotes metabolic processes involved in nutrient assimilation. Similar findings have been reported^[20, 21], who observed increased nutrient uptake with readily soluble zinc sources. Application of zinc along with NPK improves nutrient availability in the soil solution, enhances root uptake, and promotes nutrient translocation within plants. A favorable

rhizospheric environment created by this combination increases nutrient concentration in the plant system^[22, 23].

Among humic substances, zinc-fulvate showed better performance than zinc-humate, possibly due to the higher solubility and mobility of fulvic acid-metal complexes, whereas humic acid tends to form relatively less soluble complexes. Humic substances are also known to directly stimulate plant growth by influencing ion transport and physiological activity^[24].^[25] reported that the beneficial effects of humic acid on nutrient uptake are mainly associated with improvements in soil physical, chemical and biological environments. Enhanced nutrient availability and crop performance due to combined application of humic substances with micronutrients have also been reported^[26].

Impact on soil properties

Available nitrogen

soil analysis revealed that available nitrogen was significantly affected by zinc and humic substance application (Table 3). The highest available nitrogen was recorded under RDF + ZnSO₄ @ 2.5 ppm, followed by Zn-fulvate at the same level, while RDF alone resulted in the lowest nitrogen availability. The increase in soil nitrogen may be attributed to enhanced microbial activities, mineralization of organic nitrogen and supplementation of the soil nitrogen pool through humic substances^[18, 27]. Additionally, inhibition of urease activity by humic acid, leading to reduced nitrogen losses through volatilization, may have contributed to higher nitrogen retention in soil^[22]. Humic acid will reduce N losses in soil by around 23-25% from leaching, NH₃ volatilization, and N₂O emission^[28].

Available phosphorus

Available phosphorus content in soil was significantly higher under ZnSO₄ @ 2.5 ppm and Zn-fulvate treatments compared to RDF alone. The interaction of phosphate ions with humic and fulvic acids through phenolic and hydroxyl functional groups may have altered phosphorus dynamics in soil. Humic substances are known to increase the solubility of insoluble phosphorus compounds through chelation and exchange mechanisms^[29]. Increased phosphorus availability may also result from mineralization of organic phosphorus fractions and humic acid-induced phosphorus mobilization^[24, 30]. Similar enhancements in soil phosphorus availability were reported^[31]. Furthermore, the increased availability of phosphorus and micronutrients may be associated with dissolution of calcium, magnesium, iron and manganese carbonates, facilitated by humic substances, which improve nutrient solubility and uptake^[32, 33].

Available potassium

Available potassium content in post-harvest soils followed a trend similar to nitrogen and phosphorus. The highest potassium availability was observed under RDF + ZnSO₄ @ 2.5 ppm, followed by Zn-fulvate treatments, whereas RDF alone recorded the lowest potassium content. The increase in potassium availability may be due to improved cation exchange capacity and nutrient retention promoted by humic substances, resulting in better potassium release into the soil solution^[34].

Table 1: Effect of sources and levels of zinc on dry matter (g pot⁻¹) and nutrient contents (%) of rice

Treatments	Dry matter production	Nitrogen	Phosphorus	Potassium
T ₁ -Control	7.01	1.15	0.15	1.47
T ₂ -Humic acid	11.2	1.30	0.16	1.55
T ₃ -Fulvic acid	12.2	1.46	0.19	1.77
T ₄ -ZnSO ₄ (2.5 ppm)	18.3	2.51	0.29	2.40
T ₅ -Zn-humate (2.5 ppm)	12.7	2.21	0.24	1.97
T ₆ -Zn-fulvate (2.5 ppm)	17.1	2.44	0.27	2.26
T ₇ -Zn-chelate (2.5 ppm)	11.5	1.44	0.17	1.69
T ₈ -ZnSO ₄ (5 ppm)	15.1	2.27	0.25	2.11
T ₉ -Zn-humate (5 ppm)	11.1	1.65	0.19	1.81
T ₁₀ -Zn-fulvate (5 ppm)	12.2	1.95	0.22	1.89
T ₁₁ -Zn-chelate (5 ppm)	8.5	1.31	0.17	1.60
S. E m ±	0.25	0.05	0.006	0.05
C.D. (0.05)	0.74	0.149	0.017	0.146

Table 2: Effect of sources and levels of zinc on nutrient uptake (mg pot⁻¹) by rice

Treatments	Nitrogen	Phosphorus	Potassium
T ₁ -Control	8.10	1.02	10.28
T ₂ -Humic acid	14.58	1.68	17.35
T ₃ -Fulvic acid	17.77	2.26	21.46
T ₄ -ZnSO ₄ (2.5 ppm)	45.89	5.37	43.94
T ₅ -Zn-humate (2.5 ppm)	26.91	2.96	24.06
T ₆ -Zn-fulvate (2.5 ppm)	41.70	4.62	38.67
T ₇ -Zn-chelate (2.5 ppm)	16.61	1.96	19.53
T ₈ -ZnSO ₄ (5 ppm)	34.34	3.78	31.87
T ₉ -Zn-humate (5 ppm)	18.03	2.14	20.16
T ₁₀ -Zn-fulvate (5 ppm)	24.85	2.81	24.05
T ₁₁ -Zn-chelate (5 ppm)	11.13	1.42	13.65
S. E m ±	0.674	0.066	0.596
C.D. (0.05)	1.991	0.195	1.76

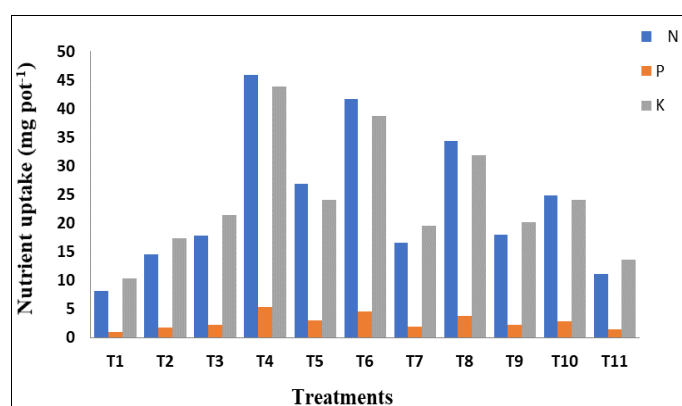


Fig 1: Effect of different sources and levels of zinc on NPK uptake (mg pot⁻¹) by rice

Table 3: Effect of sources and levels of zinc on soil available nutrient (kg ha⁻¹) status after harvest.

Treatments	Nitrogen (kg ha ⁻¹)	Phosphorus (kg ha ⁻¹)	Potassium (kg ha ⁻¹)
T ₁ -Control	163	19.7	242.7
T ₂ -Humic acid	216	21.6	301.4
T ₃ -Fulvic acid	224	22.9	311.6
T ₄ -ZnSO ₄ (2.5 ppm)	299	37.1	391.7
T ₅ -Zn-humate (2.5 ppm)	269	27.9	350.1
T ₆ -Zn-fulvate (2.5 ppm)	291	36.7	386.4
T ₇ -Zn-chelate (2.5 ppm)	252	25.5	321.5
T ₈ -ZnSO ₄ (5 ppm)	278	33.7	373.4
T ₉ -Zn-humate (5 ppm)	266	26.8	344.6
T ₁₀ -Zn-fulvate (5 ppm)	273	29.6	361.1
T ₁₁ -Zn-chelate (5 ppm)	249	24.6	316.1
Initial	188	57.8	286.5
S. E m ±	4.964	0.597	2.42
C.D. (0.05)	14.651	1.762	7.143

Conclusion

1. Application of zinc along with RDF significantly improved N, P and K content and uptake by rice compared to RDF alone.
2. Zinc applied at 2.5 ppm was more effective than 5 ppm in enhancing nutrient uptake and soil nutrient availability.
3. Among zinc sources, ZnSO₄ proved most effective, followed by Zn-fulvate, Zn-humate and Zn-chelate.
4. Fulvic acid-based zinc complexes showed better performance than humic acid complexes due to higher solubility and mobility.
5. Combined application of zinc and humic substances improved post-harvest soil fertility by increasing available nitrogen, phosphorus and potassium.
6. Overall, RDF + ZnSO₄ @ 2.5 ppm can be recommended as the most efficient treatment for improving rice nutrition and soil fertility under zinc-deficient Alfisols.

References

1. Kononova MM. Soil organic matter: Its nature, its role in soil formation and soil fertility. Oxford: Pergamon Press; 1966.
2. Datta SP, Rattan RK, Chhonkar PK. Surface chemistry of micronutrients in soils. Journal of the Indian Society of Soil Science. 2001;49(1):1-10.
3. Stevenson FJ. Humus chemistry: Genesis, composition, reactions. 2nd ed. New York: John Wiley & Sons; 1994.
4. Alloway BJ. Zinc in soils and crop nutrition. 2nd ed. Brussels: International Zinc Association and International Fertilizer Industry Association; 2008.
5. Singh R, Prasad S, Tiwari KN. Zinc deficiency in Indian soils and its management for sustainable crop production. Indian Journal of Fertilisers. 2022;18(4):366-381.
6. Tan KH. Humic matter in soil and the environment: Principles and controversies. 2nd ed. Boca Raton (FL): CRC Press; 2014.
7. Chen Y, De Nobili M, Aviad T. Stimulatory effects of humic substances on plant growth. In: Soil organic matter in sustainable agriculture. Boca Raton (FL): CRC Press; 2021. p. 103-129.
8. Schnitzer M, Gupta UC. Determination of acidity in soil organic matter. Soil Science Society of America Proceedings. 1965;29:274-277.
9. Nagamadhuri KV. Status and changes in organic matter under natural vegetation and continuous cultivation in soils of ANGRAU, Rajendranagar, Hyderabad. M.Sc.(Ag.) Thesis. Hyderabad: ANGRAU; 1996.
10. Reddy KS. Status and nature of organic matter and its interaction with metal ion in certain Alfisols and Vertisols of Acharya NG Ranga Agricultural University, Rajendranagar campus, Hyderabad. Hyderabad: Acharya NG Ranga Agricultural University; 1997.
11. Sailaja M. Interactions between metal ions and humic fractions extracted from an Alfisol and Vertisol in relation to their plant availability. Hyderabad: ANGRAU; 1999.
12. Jackson ML. Soil chemical analysis. New Delhi: Prentice Hall of India Pvt. Ltd.; 1973.
13. Piper CS. Soil and plant analysis. Bombay: Hans Publishers; 1966.
14. Saikh R, Murmu K, Sarkar A, Mondal R, Jana K. Effect of foliar zinc application on growth and yield of rice (*Oryza sativa*) in the Indo-Gangetic Plains of India. Nusantara Bioscience. 2022;14(2).
15. Chen Y, De Nobili M, Aviad T. Stimulatory effects of humic substances on plant growth. In: Soil organic matter in sustainable agriculture. Boca Raton (FL): CRC Press; 2014. p. 103-129.
16. Canellas LP, Olivares FL. Physiological responses to humic substances as plant growth promoter. Chemical and Biological Technologies in Agriculture. 2014;1:3.
17. Rose MT, Patti AF, Little KR, Brown AL, Jackson WR, Cavagnaro TR. A meta-analysis and review of plant-growth response to humic substances. Advances in Agronomy. 2014;124:37-89.
18. Kumar YS, Nayak SB, Reddy CVC, Kumar KA, Vishnuvardhan KM, Kiranmayi J, et al. Effect of potassium humate fertilizers on soil nutrients and productivity of rice crop in Vertisols of southern India. Humic Acid. 2018;19.
19. Mohammadipour E, Golchin A, Mohammadi J, Negahdar N, Zarchini M. Improvement of fresh weight and aerial part yield of marigold (*Calendula officinalis* L.) by humic acid. Annals of Biological Research. 2012;3(11):5178-5180.
20. Gondar D, Lopez FS, Antelo JM, Arce F. Cadmium, lead, and copper binding to humic acid and fulvic acid extracted from an ombrotrophic peat bog. Geoderma. 2006;131:196-203.
21. Srilatha M. Characterization of humic substances and their interactions with metal ions in relation to their availability to rice. Hyderabad: Acharya NG Ranga Agricultural University; 2001.
22. Kumar D, Singh AP. Efficacy of potassium humate and chemical fertilizers on yield and nutrient availability patterns in soil at different growth stages of rice. Communications in Soil Science and Plant Analysis. 2017;48(3):245-261.
23. Kumar R, Kumar M, Yadav S, Kumar R. Effect of sources and methods of zinc application on productivity, nutrient uptake and zinc use efficiency of Basmati rice (*Oryza sativa* L.). International Journal of Current Microbiology and Applied Sciences. 2020;9(1):2231-2242.
24. Vaughan D, Linehan DJ. The growth of wheat plants in humic acid solutions under axenic conditions. Plant and Soil. 1976;44:445-499.
25. Sharif M. Effect of lignitic coal derived humic acid on growth and yield of wheat and maize in alkaline soil. Peshawar: Khyber Pakhtunkhwa Agricultural University; 2002.
26. Manzoor A, Khattak RA, Dost M. Humic acid and micronutrient effects on wheat yield and nutrient uptake in salt-affected soils. International Journal of Agriculture and

- Biology. 2014;16(5):991-995.
27. Baskar K. Growth, yield and N uptake of turmeric (*Curcuma longa* L.) in Alfisols as affected by lignite humic acid. Madras Agricultural Journal. 2006;93(7-13):282-287.
 28. Kong B, Wu Q, Li Y, Zhu T, Ming Y, Li C, *et al.* The application of humic acid urea improves nitrogen use efficiency and crop yield by reducing nitrogen loss compared with urea. Agriculture. 2022;12:1-16.
 29. Tan KH. Humic matter in soils and environment: Principles and controversies. New York: Marcel Dekker Inc.; 2003. p. 385.
 30. Zhu J, Li M, Whelan M. Phosphorus activator contributes to legacy phosphorus availability in agricultural soils: A review. Science of the Total Environment. 2018;612:522-537.
 31. Bharath T, Madhavi K. Nutrient uptake of sorghum crop influenced by top dressing and foliar application of organic nutrient sources. Indian Journal of Applied Research. 2015;5(4):19-22.
 32. Bohn HL, McNeal BL, O'Connor GA. Soil chemistry. 3rd ed. New York: John Wiley & Sons Inc.; 2001.
 33. Cheryl M, Grossl P, Bugbee B. Beneficial effects of humic acid on micronutrient availability to wheat. Soil Science Society of America Journal. 2001;65:1744-1750.
 34. Siregar VMR, Putra SM, Aziz MA, Fadila H, Arisandy P, Wahyuni S, *et al.* Application of humic acid supplemented with micronutrients increases rice production. Jurnal Agronomi Indonesia. 2023;51(3):366-377.