



Coal Humic Acid and SP-36 Effects on Phosphorus Availability and Uptake by Pakcoy in Ultisol

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Abstract

Ultisol is a type of soil that has limited availability of phosphorus. The low availability of phosphorus is due to its strong fixation by aluminum and iron. This study aims to test the effects of coal humic acid and SP-36 fertilizer on increasing phosphorus availability and its uptake by pakcoy plants. The study was conducted as a greenhouse pot experiment using a factorial completely randomized design with treatments for humic acid and SP-36 fertilizer doses. The coal humic acid dose treatments included H0 (0 g/plant), H1 (2 g/plant), and the SP-36 fertilizer dose treatments included P0 (0 kg/ha), P1 (100 kg/ha), and P2 (200 kg/ha). The treatment combinations are arranged in three replicates, and each treatment consists of three pots. The soil parameters analyzed included pH H₂O, available P, exchangeable Al, available Fe, and phosphorus uptake by pakcoy plants. The results showed that the application of coal humic acid significantly increased P availability and decreased Fe availability in the soil. The application of SP-36 fertilizer significantly increased pakcoy plants' phosphorus uptake. There is a significant interaction between the effects of coal humic acid and SP-36 fertilizer on a reduction of Al-exchangeable in Ultisol soil. In conclusion, the combined use of coal humic acid and SP-36 fertilizer offers a practical strategy for improving phosphorus management in marginal Ultisol soils.

Keywords: Coal humic acid, phosphorus, pakcoy, SP-36 fertilizer, Ultisol

INTRODUCTION

Ultisols are highly weathered soils with deep profiles and argillic horizons, widely distributed across tropical and subtropical regions, including Indonesia, where they occur extensively on agricultural land (Arifin et al., 2021; Pratamaningsih et al., 2024). However, their low fertility is linked to strong acidity, low base saturation and cation exchange capacity, phosphorus deficiency, and potential aluminum (Al) and iron (Fe) toxicity (Purwanto et al., 2020; Septiyana et al., 2021). Although total soil phosphorus may be relatively high, its availability to plants is often low because it is strongly fixed by Al and Fe (Agustini et al., 2024; Jibrin et al., 2026). Therefore, appropriate fertility-management strategies, particularly those that enhance phosphorus availability, are essential for improving the productivity and sustainable use of Ultisols.

Humic acid is a soil-improvement ingredient that can enhance soil properties. It can improve soil fertility by enhancing the soil's physical, chemical, and biological properties. In addition, humic acid can stimulate plant growth, nutrient uptake, and other physiological processes.

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According to [Lisdiyanti et al. \(2018\)](#), humic acid is the end product of the decomposition of organic matter and is highly active because it contains carboxyl (-COOH) and phenolic (-OH) groups that are known to play a role in the provision of phosphorus elements through a chelation reaction that displaces excess metal cations, thereby reducing the activity of Al and Fe metals that usually bind P. Although [Lisdiyanti et al. \(2018\)](#) studied the effects of humate combined with SP-36, the sources of the humate used in the treatment were not specified; it was only described as a commercial humate. The effects of coal-derived humic acid, different SP-36 doses, and their interactions on plant phosphorus uptake in Ultisol remain unclear. Therefore, this study specifically evaluated these factors to assess their potential to increase phosphorus availability and uptake by pakcoy.

In addition to high humic acid content, low-rank coal contains essential elements that play important roles in plant growth. [Zhou et al. \(2019\)](#) state that humic acid results from the biological and chemical degradation of organic matter over millions of years. In general, humic acid can help recondition soil as a planting medium. Humic acid is a subfraction of humus that is brown to black in color and contributes to the physical and chemical quality of the soil ([Drosos et al., 2026](#)). This research used humic acid extracted from low-rank coal to investigate how combining coal-derived humic acid with SP-36 fertilizer affects P availability and its adsorption by pakcoy plants in Ultisol soil. This study hypothesizes that coal-derived humic acid and SP-36 fertilizer independently increase soil P availability and phosphorus uptake by pakcoy, while their combined application results in significant interactions that further increase the plant's P availability and P uptake in Ultisol.

LITERATURE REVIEW

Humic acid has potential as a soil-improvement agent in Ultisols because it can modify soil chemical conditions and enhance plant nutrient acquisition. Humic substances are complex organic molecules that facilitate soil-root interactions, improve nutrient-use efficiency, and stimulate lateral root formation and root growth ([Nardi et al., 2017](#)). Similarly, [Ampong et al. \(2022\)](#) reported that humic acids can improve soil properties, support plant growth, and enhance agronomic performance by influencing nutrient availability and plant physiological processes. [Yuan et al. \(2023\)](#) further showed that humic substances can increase P availability in soil-plant systems, while [Yang et al. \(2021\)](#) emphasized their role in regulating minerals, ions, water, and soil microorganisms. These functions are especially relevant to Ultisols, where P availability is constrained by strong interactions with Fe and Al minerals.

The effects of humic substances on P availability may involve several complementary mechanisms. Humic molecules can form complexes with Fe and Al, reducing the reactivity of these metals and limiting the formation of insoluble Fe-P and Al-P compounds. They may also compete with phosphate for adsorption sites on Fe and Al oxides, promoting P desorption and increasing its mobility in soil ([Gerke, 2021](#); [Yang et al., 2021](#)). In addition, humic-Fe-P and humic-Al-P associations may serve as relatively mobile P pools that contribute to plant P acquisition. However, the magnitude and direction of these effects depend on the chemical characteristics of the humic material, soil pH, mineralogy, application rate, and incubation period ([Yuan et al., 2023](#)). Therefore, humic acid should not be regarded simply as a direct P source but rather as a chemical mediator that modifies metal-phosphate interactions.

Low-rank or young coal is a potentially valuable source of humic substances because it contains a substantial proportion of humified organic matter. [Akimbekov et al. \(2021\)](#) proposed low-rank coal as a soil amendment and fertility-management material because its humic fraction may improve soil chemical and biological properties. However, findings on coal-derived materials are not fully consistent. [Panday et al. \(2021\)](#) reported that coal char increased soil organic carbon and some nutrient concentrations, including Fe, K, and Mg, but did not consistently increase crop

yield in the short term. In contrast, [Li et al. \(2026\)](#) showed that coal-based charcoal combined with organic fertilizer improved soil physical and chemical properties and promoted plant growth in degraded soil. This contrast may be explained by differences in material type, production process, chemical composition, application rate, soil conditions, crop species, and experimental duration. In particular, coal char and coal-derived humic acid should not be considered chemically equivalent: coal char is a thermally transformed, carbon-rich material, whereas coal humic acid is an extracted, chemically reactive fraction. Thus, the effects reported for coal char cannot be directly extrapolated to coal-derived humic acid.

Although previous studies have established the potential of humic substances and coal-derived materials to improve soil fertility, the specific effects of coal-derived humic acid on P dynamics in Ultisol remain poorly understood. In particular, evidence is limited on interactions between coal-derived humic acid and SP-36 fertilizer rates, as well as their combined effects on Fe- and Al-mediated P fixation and plant P uptake. Therefore, the present study evaluates the main and interactive effects of coal-derived humic acid and SP-36 fertilizer on soil P availability, exchangeable Al, available Fe, and P uptake by pakcoy grown in Ultisol. This approach links proposed chemical mechanisms to measurable soil and plant responses and provides evidence to improve P management in marginal Ultisol soils.

RESEARCH METHOD

This research was conducted as a greenhouse experiment. The experiment was arranged in a factorial Complete Randomized Design (CRD) with variations in the doses of coal humic acid and SP-36 fertilizer applied to Ultisol soil. The humic acid dose consisted of two levels, and the SP-36 fertilizer dose consisted of three levels. The treatment combinations were arranged in three replicates. To account for variation in crop performance within replicates, each replicate was applied to three polybags, and the data were averaged across the three polybags. The total was 54 polybags. The coal humic acid dose treatments included H0 = 0 g/plant and H1 = 2 g/plant. The SP-36 fertilizer dose treatments included P0 = 0 kg/ha, P1 = 100 kg/ha, and P2 = 200 kg/ha. Statistical analyses were performed using Analysis of Variance (ANOVA) and Duncan Multiple Range Test (DMRT), with the sources of variation and degrees of freedom in the ANOVA table consisting of:

Table 1. Sources of Variation and Degrees of Freedom for the ANOVA

Source of variation	df
Treatments	5
Coal humic acid (H)	(1)
SP-36 (P)	(2)
H*P	(2)
Error	12
Total	17

Coal Humic Acid Extraction

The extraction was conducted following the procedure proposed by [Partoyo et al. \(2026\)](#), including: (1) Low-rank coal is ground until the grain diameter is around 0.25 mm. (2) The fine-sized sample is then added with 2M NaOH to pH 10-11, then stirred and left for 12 hours. (3) Performed filtration to separate solid residues. (4) The filtrate is mixed with HCl 2N to pH 1 to precipitate the humic acid, then let it sit for 12 hours. (5) Humic acid deposits are separated from supernatant liquids by filtration. (6) Neutralize humic acid deposits with a 0.5 N KOH solution to pH 6-7.

Soil sampling, preparation, and application of SP-36 and coal humic acid

The soil sample used in the study was collected from a bare, grass-covered area in Krumpit, Banyumas, Central Java. Based on the soil map and validated by the soil profile description at the sampling site, it was classified as Ultisol. A preliminary laboratory analysis was conducted on the Ultisol samples before treatment. This analysis aimed to determine soil pH (electrometry), available P (Bray-I), exchangeable Al (KCl 1 N extraction), and available Fe (ammonium acetate pH 4.8 extraction).

Air-dried Ultisol soil samples were ground and sieved through a 2 mm sieve, then weighed to 1 kg and placed in a 20 x 20 cm polybag. Before placing each soil sample in a polybag, it was mixed with SP-36 fertilizer at the treatment dose. Humic acid was measured according to the treatment dose and diluted with aquadest to meet watering needs, reaching field capacity in the polybag containing the Ultisol soil. The soil, mixed with SP-36 fertilizer and humic acid, was then incubated for one week. After incubation, pakcoy seedlings were transplanted into polybags. The crop was maintained and watered as needed to ensure field-capacity moisture content in the soil. The crop was harvested at 30 days old.

Soil and Crop Analysis After Harvest

Laboratory analysis was carried out 30 days after transplantation for soil samples from the planting media and pakcoy crop yields. The analyzed soil parameters include soil pH, available P, exchangeable Al, and available Fe. The observed crop yield parameter was phosphorus absorption of the pakcoy plant.

FINDINGS AND DISCUSSION

The Ultisol soil used in this research was marginal, at least according to laboratory analysis of the collected soil sample. The soil was acidic (pH H₂O 4.82), with high available Fe (5.99 ppm) and very low available phosphorus (1.28 ppm). Ultisol is an ultimate soil with advanced soil genesis. The ultimate development of Ultisol soil led to the leaching of alkaline cations, so acidic cations such as H⁺ and Al³⁺ dominated the soil exchange complex. The high iron (Fe) content in the soil is closely related to the soil's acidic pH. At low pH, the solubility of iron compounds increases, so more Fe ions dissolve and become available in the soil solution. This condition causes the measured Fe content to be high. The low available P content in the soil is due to strong P-Fe bonds. As a result, most of the phosphorus is bound by Fe so that it cannot be absorbed or utilized by plants.

The application of SP-36 fertilizer and coal humic acid did not affect the pH of H₂O in the Ultisol. Although the soil pH in all treatments was higher (ranging from 5.22 to 5.51) than the control (5.07) (Table 2), all remained in the acid class. This indicates that humic acids at the treatment dose, prepared as neutral, cannot significantly neutralize acidic soil (Table 3). The OH⁻ ions carried by the humic acids were insufficient to raise the soil pH to neutral.

Table 2. Ultisol chemical properties after treatment with coal humic acid and SP-36 fertilizer

No	Treatment	pH H ₂ O	Al-exchangeable (me%)	Fe-available (ppm)	P-available (ppm)
1	H0P0	5.07	0.743	5.693	1.213
2	H0P1	5.32	0.686	5.527	1.343
3	H0P2	5.31	0.579	5.201	1.252
4	H1P0	5.41	0.556	5.546	1.325
5	H1P1	5.34	0.445	5.457	1.575
6	H1P2	5.27	0.650	5.335	1.437

Description:

H0P0: Without the application of coal humic acid and SP-36 fertilizer

H0P1: Coal humic acid 0 g/plant and 100 kg/ha SP-36 fertilizer

H0P2: Coal humic acid 0g/plant, and 200 kg/ha SP-36 fertilizer

H1P0: Coal humic acid 2 g/plant and 0 kg/ha SP-36 fertilizer

H1P1: Coal humic acid 2 g/plant and 100 kg/ha SP-36 fertilizer

H2P2: Coal humic acid 2 g/plant, and 200 kg/ha SP-36 fertilizer

Table 3. Effect of coal humic acid and SP-36 fertilizer on pH H₂O of the Ultisol soil

Factor H	Factor P			Mean
	P0	P1	P2	
H0	5.07	5.31	5.31	5.23p
H1	5.41	5.34	5.27	5.34p
Mean	5.24a	5.32a	5.29a	(-)

Remarks: Column/row numbers with the same letter do not differ significantly (DMRT 5%). The sign (-) indicates no interaction between treatments.

The application of SP-36 fertilizer and coal humic acid reduced exchangeable Al in Ultisol (Figure 1). The effect of humic acid in lowering exchangeable Al was influenced by the SP-36 fertilizer dose. These two factors interact to determine the level of exchangeable Al in Ultisol soil (Table 4). Exchangeable Al in the control (H0P0) was 0.734 me%, compared with the lowest level in the treatment with coal humic acid at 2 g/plant and 100 kg/ha SP-36 fertilizer, which was 0.447 me%.

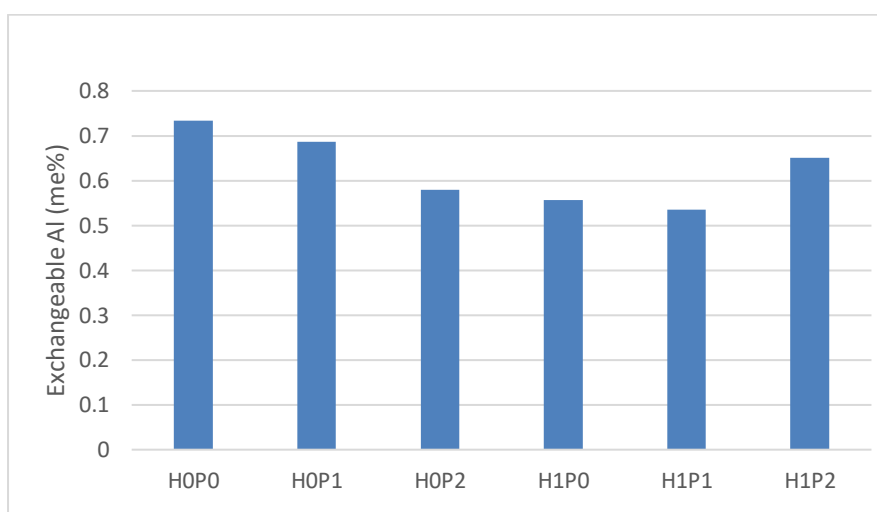


Figure 1. Exchangeable Al in Ultisol soil treated with coal humic acid and SP-36 fertilizer

Table 4. Effect of coal humic acid and SP-36 fertilizer on exchangeable-Al (me%) in Ultisol soil

Factor H	Factor P			Mean
	P0	P1	P2	
H0	0.734d	0.686bcd	0.579bc	0.666
H1	0.556ab	0.447a	0.650bcd	0.550
Mean	0.645	0.565	0.614	(+)

Remarks: Numbers with the same letter do not differ significantly (DMRT 5%). The sign (+) indicates interaction between treatments.

Regarding Fe availability in the soil, coal humic acid treatment significantly reduced the level of available Fe (Figure 2). This decrease was independent of the SP-36 fertilizer dose. Without SP-36 fertilizer treatment or with SP-36 fertilizer application, available Fe still decreased (Table 5).

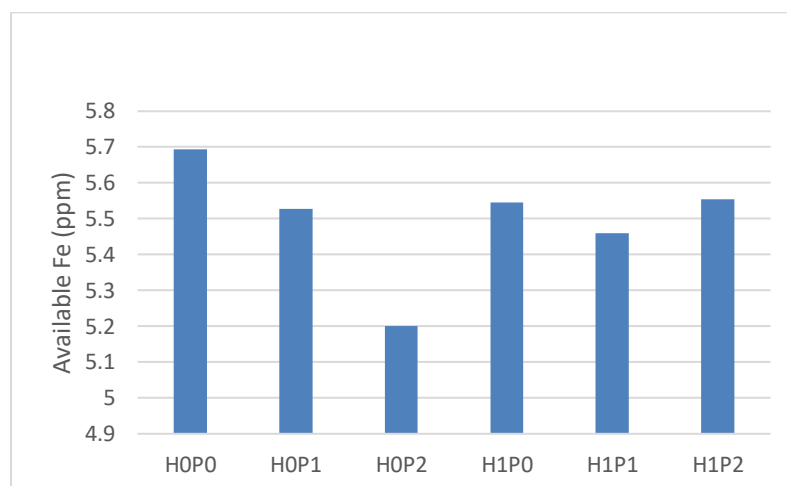


Figure 2. Available Fe in Ultisol soil treated with coal humic acid and SP-36 fertilizer

Table 5. Effect of coal humic acid and SP-36 fertilizer on available Fe (ppm) in Ultisol soil

Factor H	Factor P			Mean
	P0	P1	P2	
H0	5,510	5,359	5,088	5,331p
H1	5,142	5,045	5,046	5,077q
Mean	5,326a	5,220a	5,067a	(-)

Remarks: Column/row numbers with the same letter do not differ significantly (DMRT 5%). The sign (-) indicates no interaction between treatments.

Furthermore, the study showed that treatment with coal humic acid increased P availability. This increase occurred both in the absence of SP-36 fertilizer and when SP-36 fertilizer was applied (Table 6). This positive effect may arise because humic acid can reduce exchangeable Al (Figure 1) and available Fe (Figure 2).

Table 6. Effect of coal humic acid and SP-36 fertilizer on available P (ppm) in Ultisol soil

Factor H	Factor P			Mean
	P0	P1	P2	
H0	1.213	1.343	1.252	1.269p
H1	1.325	1.575	1.437	1.445q
Mean	1.269a	1.459a	1.344a	(-)

Remarks: Column/row numbers with the same letter do not differ significantly (DMRT 5%). The sign (-) indicates no interaction between treatments.

The results in Table 7 show that phosphorus uptake by pakcoy plants is significantly affected by the SP-36 fertilizer treatment, whereas the application of coal humic acid, either alone or in combination, has no noticeable effect. The highest P nutrient uptake was observed in the HOP2 treatment, while the lowest value was found in the HOP0 treatment (Figure 3).

Table 7. Effect of coal humic acid and SP-36 fertilizer on P uptake (mg) by pakcoy plants

Factor H	Factor P			Mean
	P0	P1	P2	
H0	0.169	0.427	0.821	0.472p
H1	0.196	0.455	0.611	0.420p
Mean	0.183a	0.441b	0.716c	(-)

Remarks: Column/row numbers with the same letter do not differ significantly (DMRT 5%). The sign (-) indicates no interaction between treatments.

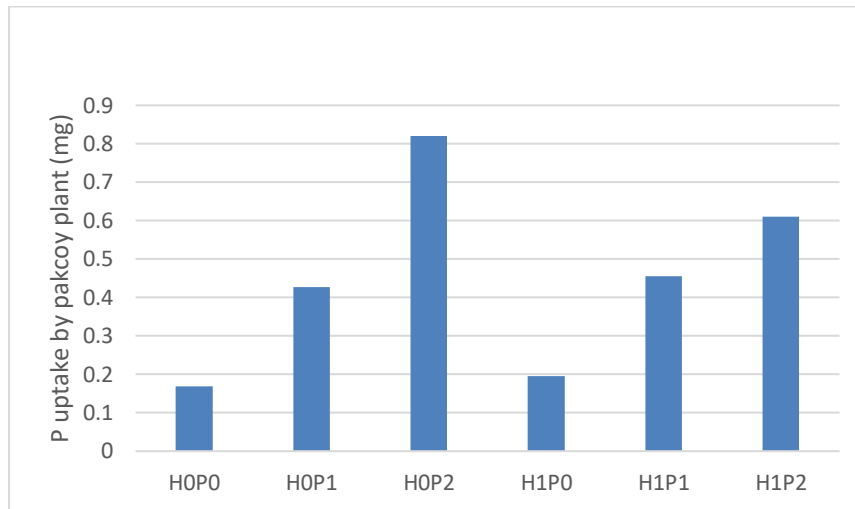


Figure 3. Phosphorus uptake by pakcoy plants from Ultisol soil treated with coal humic acid and SP-36 fertilizer.

CONCLUSIONS

The application of coal humic acid significantly increases phosphorus availability in the soil. Coal humic acid can reduce Fe availability. There was an interaction between coal humic acid and SP-36 fertilizer in reducing Al-exchangeable in Ultisol soil. The application of SP-36 fertilizer significantly increases available P in the soil and P uptake by pakcoy plants.

LIMITATIONS & FURTHER RESEARCH

Although humic acid derived from coal and SP-36 fertilizers improves Ultisol chemistry—by increasing P availability and reducing Al and Fe—its direct impact on pakcoy growth warrants further study. Improvements in soil chemistry alone may not elicit a rapid plant response. Therefore, field studies with longer observation periods, broader dose ranges, and combinations with lime, organic matter, or micronutrients are recommended to verify whether improved soil dynamics consistently lead to higher crop yields.

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