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Research Paper

Coal-Based Humic Acid Fertilizer Effects on Soil Properties and Mustard Growth

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Abstract

Humic acid is an essential organic substance that improves soil quality and enhances plant growth. This study investigates the novel application of low-rank coal waste as a source of humic acid for agricultural purposes. Humic acid was extracted from coal and applied as a soil amendment to two contrasting soil types under greenhouse conditions. The application of coal-derived humic acid significantly improved soil pH, electrical conductivity, and organic carbon content, leading to enhanced mustard crop performance. Higher concentrations of humic acid promoted stronger plant growth and increased leaf greenness. The results highlight the potential of converting low-rank coal waste into humic-based fertilizers as an effective strategy for improving soil fertility and supporting sustainable agricultural practices.

Keywords *Humic Acid, Ameliorant, Fertilizer, Low-Rank Coal, Mustard*

INTRODUCTION

Deterioration in soil quality for agricultural production is increasingly occurring and affecting land productivity. Some treatments using soil ameliorants show various results. It still needs to be investigated to develop appropriate technologies that can enhance land productivity by improving soil quality, especially in marginal soils. In the coal mining industry, low-rank coal is widely recognized as a material with low calorific value and limited economic potential. Consequently, it is often neglected by mining companies and remains stockpiled or discarded as waste in mining areas.

Researchers showed that coal can be extracted to produce humic acid (Asif, 2022; Fatima et al., 2021; Sarlaki et al., 2019). Humic acid has been recognized for its beneficial effects on improving the physical and chemical properties of soils (Akimbekov et al., 2021). Several crops have shown a benefit from the application of humic acid (Bhatt & Singh, 2022; Dönder & Toğay, 2021). From this background, further research is needed to utilize unused low-rank coal as an effective fertilizer for enhancing soil quality and supporting crop growth and yield.

Furthermore, the environmental benefits of converting coal-derived humic substances into soil amendments—particularly in improving soil fertility and supporting sustainable land management—have not been fully explored. Therefore, this study aims to develop a practical approach for extracting humic acids from low-rank coal and to evaluate their potential application as a soil conditioner or fertilizer component. The results are expected to contribute to the advancement of sustainable coal utilization and provide a scientific basis for transforming mining by-products into valuable agricultural inputs.

LITERATURE REVIEW

Low-rank coal (LRC), such as lignite and sub-bituminous coal, has garnered significant attention due to its potential to be harnessed beyond the energy sector. For energy and industrial

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use, LRC is not economically feasible, and in the mining process, it is usually sent to landfills. The amount of this low-ranking coal is estimated to be substantial, and its stockpiles are also highly disruptive to the natural environment (Amoah-Antwi et al., 2021). This type of coal can mainly be applied as a soil conditioner. This potential utilizes the chemical properties of LRC, particularly the content of organic matter and humic substances, which can enhance soil fertility and health (Aftab et al., 2024; Akimbekov et al., 2021). The application of NPK fertilizer combined with humic acid extracted from low-rank coal is beneficial for increasing the growth and yield of vegetable crops (Ichwan et al., 2022). LRC-derived humates, when applied to the soil at specific doses and combinations, can increase soil productivity (Amoah-Antwi et al., 2021).

Humic acid plays a crucial role in enhancing the quality of agricultural soil. This component functions to improve the physical, chemical, and biological properties of the soil (Jiang et al., 2025). Chemically, humic acid can increase the cation exchange capacity (CEC), providing macronutrients such as N, P, K, Ca, Mg, and S, as well as micronutrients like Zn, Cu, Mo, Co, B, Mn, and Fe (Yang et al., 2021). In addition, humic acid can form chelate complex compounds with toxic metal ions such as Al and Fe, thereby reducing soil toxicity (Smailov et al., 2020).

Physically, humic acid helps improve soil structure by binding soil particles into stable aggregates (Maffia et al., 2025). This increases water holding and soil aeration. From a biological perspective, humic acid serves as a source of energy for soil microorganisms, which play a crucial role in nutrient cycling and the formation of soil micro- and macro-pores (Nardi et al., 2021). Humic acids play several vital roles, such as increasing soil physical and biochemical activities by improving structure, texture, and water holding capacity (Kandra et al., 2024), and microbial population; increasing soil nutrient availability, especially micronutrients, by chelating and co-transporting micronutrients to plants (Ampong et al., 2022).

RESEARCH METHOD

This study used a factorial experimental design with two factors, arranged on a Randomized Complete Block Design (RCBD) (Felipe, 2020). The first factor was the concentration of humic acid, and the second factor was the type of soil. The experiment was conducted in a greenhouse with a potted setup. Humic acids were extracted from low-rank coal (LRC). The extraction was performed by successive alkaline solubilization and acid flocculation of low-rank coal (Fatima et al., 2021). Soils were mixed with humic acid and incubated for a week before being planted with mustard seedlings. Mustard was selected as a test crop due to its responsiveness to the fertilizer treatment, as well as its short age.

Crop cultivation was supported by 2g per plant of NPK fertilizer (16-16-16) on seven days after transplanting. Mustard was maintained until harvest age. Soil properties were analyzed for pH (potentiometric method), electrical conductivity (conductometer method), and C-organic content (Walkley & Black method). Observations on crop growth were conducted by measuring plant height, counting the number of leaves, and assessing leaf greenness (RHS, 2005). The level of of humic acid factor including H0 = without humic acid 0 g/plant, H1 = commercial humic acid 2g/plant, H2 = humic acid 1 g/plant, H3 = humic acid 2 g/plant, and H4 = humic acid 3 g/plant. Meanwhile, the factor of soil type consists of two types: T1 = Regosol and T1 = Latosol.

FINDINGS AND DISCUSSION

The properties of the soil observed after treatment include soil pH, electrical conductivity, and soil organic carbon content. The treatment of the humic acid level has a significant effect on soil pH. The magnitude of the impact depends on the soil type, the level of humic acid, and the type of soil. It was detected by analysis of variance (ANOVA) as shown in Table 1, which revealed a significant interaction influencing the soil pH ($P < 0.3448^*$). On the other hand, the electrical conductivity was affected independently by the soil types (P < 0.3646) and humic acid concentration (P<0.0303*). There was no interaction between soil types and humic acid concentration in affecting the electrical conductivity.

Table 1. Results of Analysis of Variance for pH, EC, and C-organic after treatment with various levels of humic acid in the Latosol and Regosol soils

Source of variation	**P-value**		
	Variable: pH	**Variable: EC**	**Variable: C-organic**
Humic acid	0.0008**	0.0303*	0.00315**
Soil types	0.4710*	0.3646*	1.68299E-07**
Interaction	0.3448*	0.5206ns	0.0155**

Note: ** significantly different at α=1%, * significantly different at α=5%, ns=not significant

The pH ranged from 6.4 to 7.2. (Figure 1). All humic acid applications from coal-extracted sources (H2, H3, and H4) show lower pH compared to the control (H0). Humic acid treatment with commercial humic acid (H1) resulted in the highest pH, ranging from 7.1 to 7.2. All pH value is classified as neutral (BBSDLP, 2023), which is suitable for common vegetable crops.

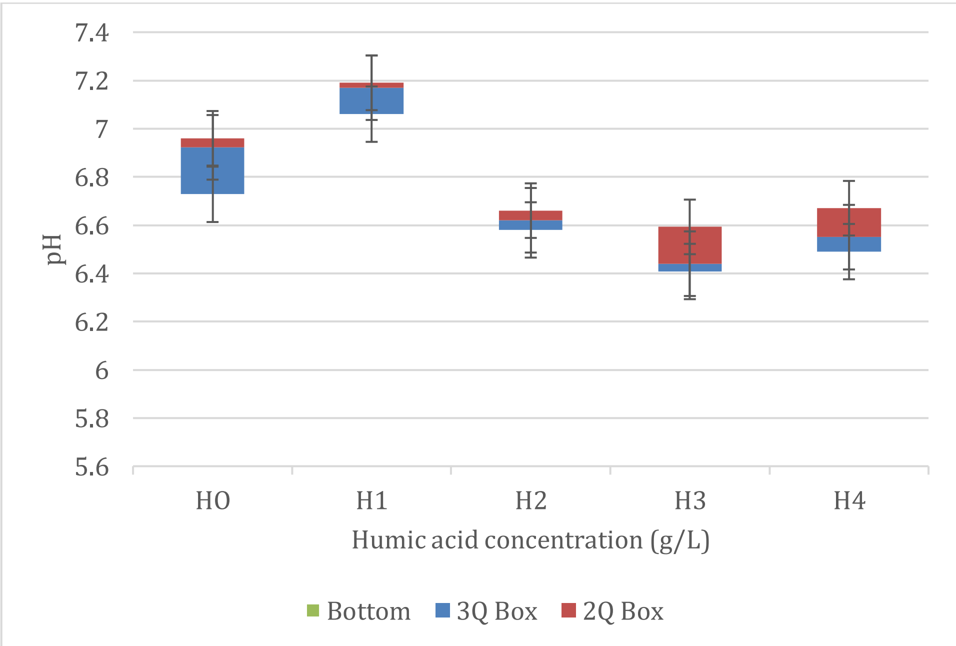

Figure 1. Boxplot of Soil Ph After Humic Acid Treatments

The C-organic contents of the soil after humic acid treatment ranged from 2% to 3% (Figure 2). All are classified as moderate level (BBSDLP, 2023). This status was appropriate for crop growth.

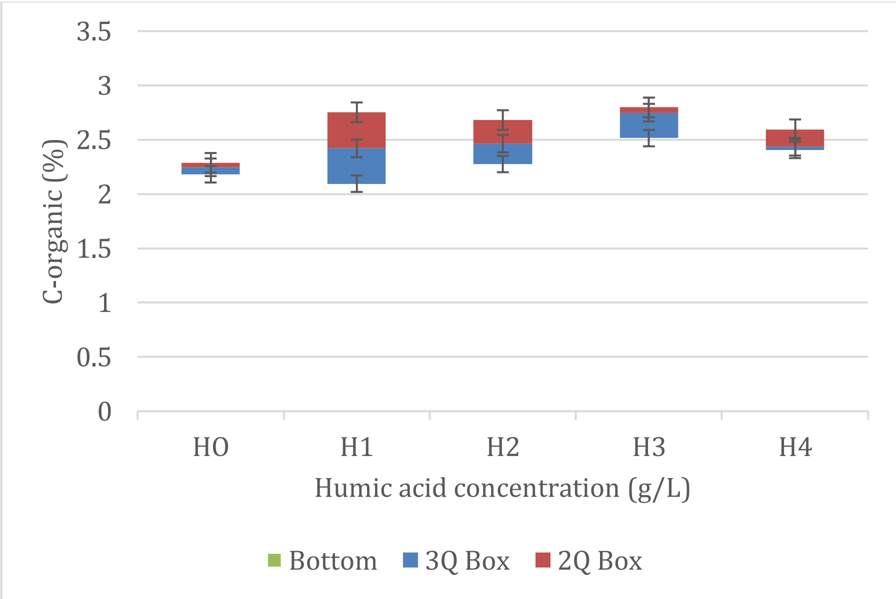

Figure 2. Boxplot of Soil Organic Carbon Contents After Humic Acid Treatments

The electrical conductivity of the soil ranged from around 75 µS/cm to 400 µS/cm (Figure 3). It was classified as moderate to high (BBSDLP, 2023).

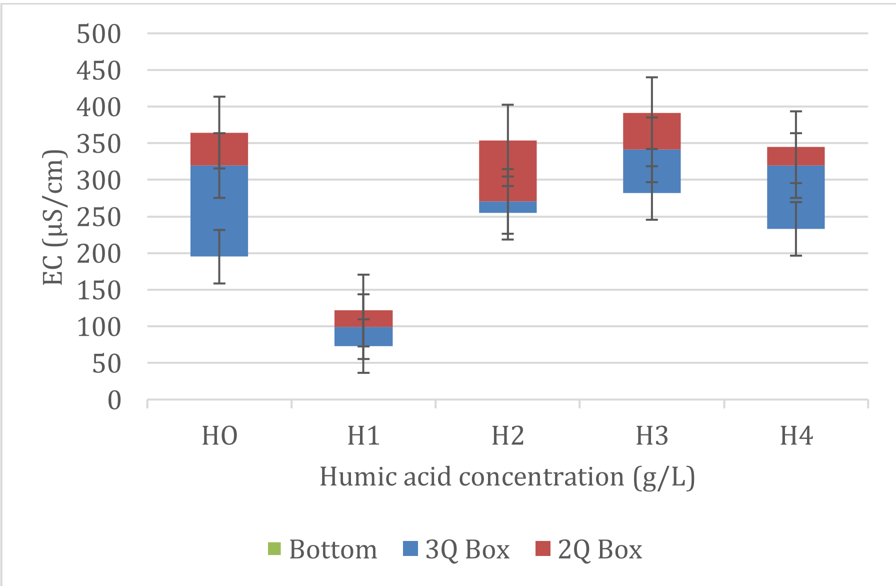

Figure 3. Boxplot of Soil Electric Conductivity After Humic Acid Treatments

The quantitative response of humic acid application was shown in the ANOVA of plant height and leaf number data (Table 2). Humic acid concentration significantly affected the plant height ($P<9.57E-05^{**}$), but not for leaf number. Regosol and Latosol significantly affected plant height ($P < 0.001^{**}$) and leaf number ($P < 0.011^{**}$).

Table 2. Results of Analysis of Variance for plant height and leaf number per plant after treatment with various levels of humic acid in the Latosol and Regosol soils

Source of variation	**P-value**	
	Variable: plant height	**Variable: leaf number**
Humic acid	9.57E-05**	0.177ns
Soil types	0.001**	0.011**
Interaction	0.108ns	0.868ns

Note: ** significantly different at α=1%, * significantly different at α=5%, ns=not significant.

The effect of humic acid application was qualitatively reflected in the good performance and growth of the mustard crop. The higher concentration of humic acid resulted in better vigor and growth of the mustard crop (Figures 4 and 5). Both pictures reflected a better response of humic acid treatment in Latosol soil (Figure 4) than in Regosol soil (Figure 5). Furthermore, the research results show that the growth of mustard plants exhibited diverse growth patterns. Plant performance indicates that a higher dose of humic acid yields a more pronounced growth effect in both Latosol soil (T2) (Figure 4) and Regosol soil (T1) (Figure 5).

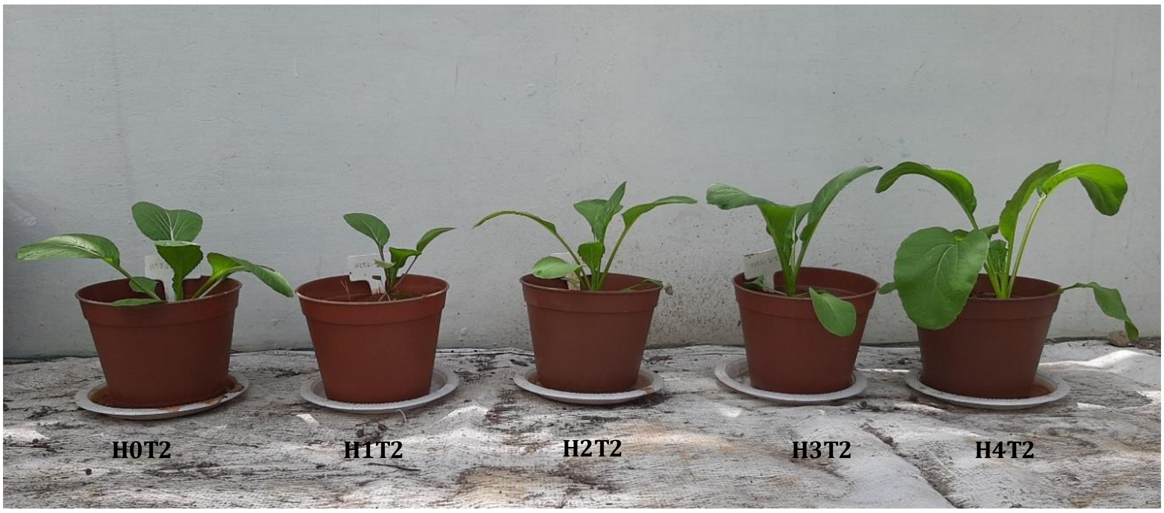

Figure 4. Performance of mustard crop at 14 days after transplanting on the Latosol (T2) soil (Sequence from left to right: humic acid treatments H0, H1, H2, H3, H4).

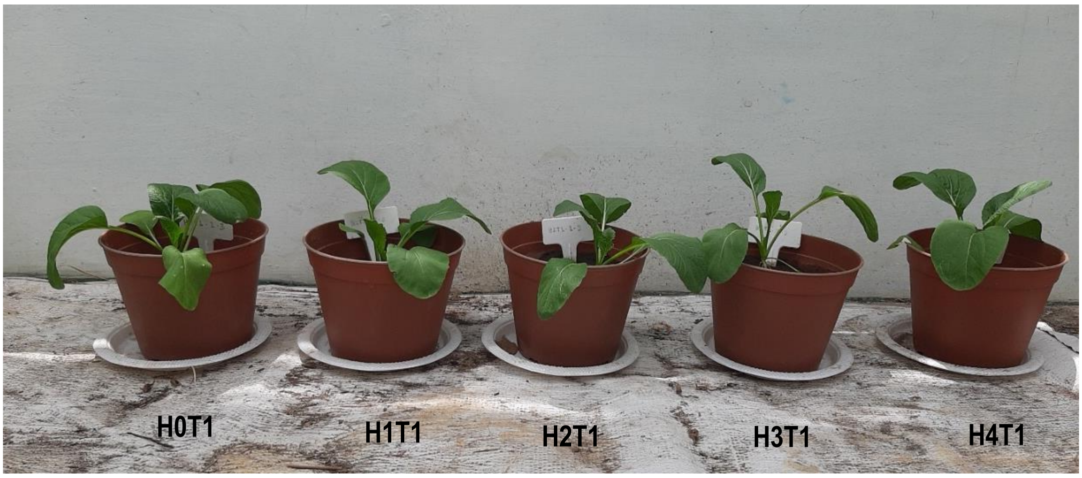

Figure 5. Performance of mustard crop at 14 days after transplanting on the Regosol (T1) soil (Sequence from left to right: humic acid treatments H0, H1, H2, H3, H4)

Figure 6. Performance of mustard crop at 14 days after transplanting on the Regosol (T1) and Latosol (T2) soil, combined with humic acid (H0 and H1)
(Sequence from left to right: H0T2, H1T2, H1T1, H0T1)

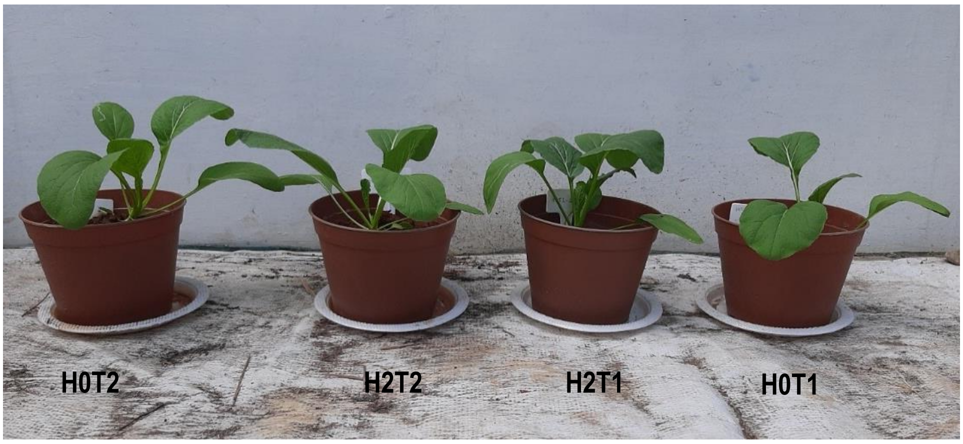

Figure 7. Performance of mustard crop at 14 days after transplanting on the Regosol (T1) and Latosol (T2) soil, combined with humic acid (H0 and H2)
(Sequence from left to right: (H0T2, H2T2, H2T1, H0T1)

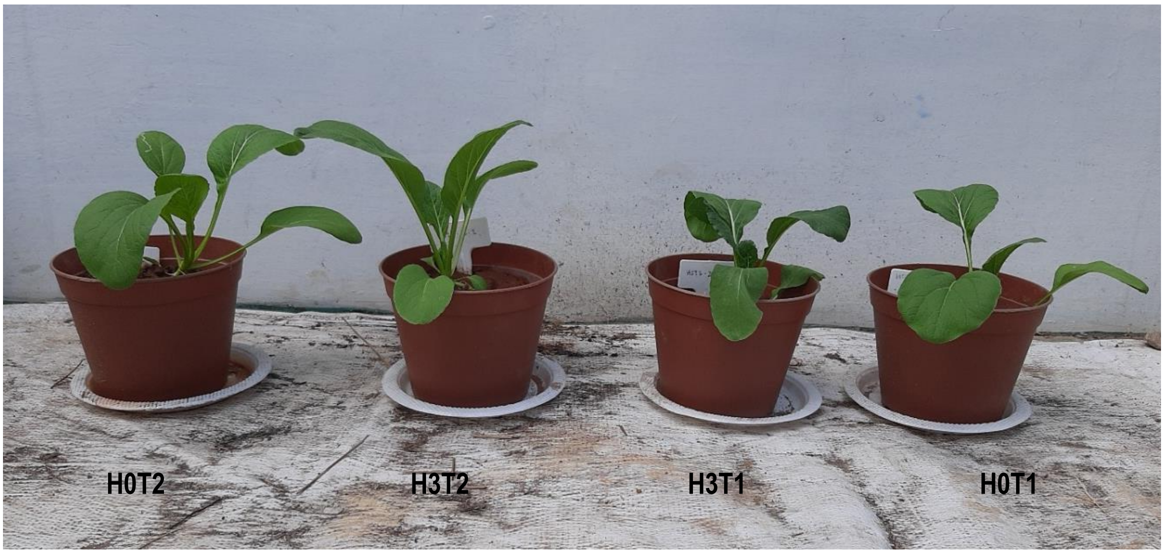

Figure 8. Performance of mustard crop at 14 days after transplanting on the Regosol (T1) and Latosol (T2) soil, combined with humic acid (H0 and H3)
(Sequence from left to right: H0T2, H3T2, H3T1, H0T1)

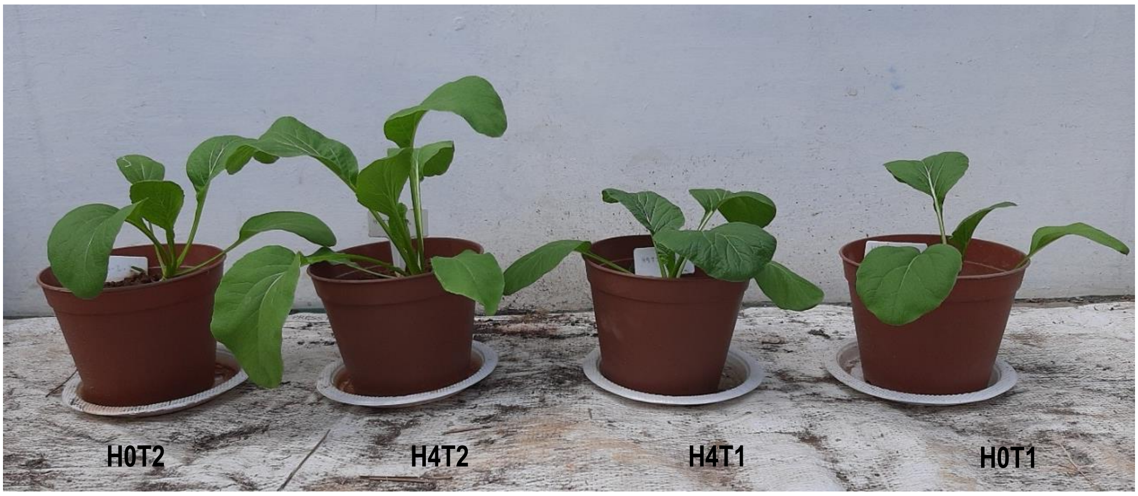

Figure 9. Performance of mustard crop at 14 days after transplanting on the Regosol (T1) and Latosol (T2) soil, combined with humic acid (H0 and H4)
(Sequence from left to right: H0T2, H4T2, H4T1, H0T1)

The level of leaf greenness was also identified based on the R.H.S. Color Chart (RHS, 2005). The higher concentration of huic acid resulted in a greener leaf colour (Figure 10).

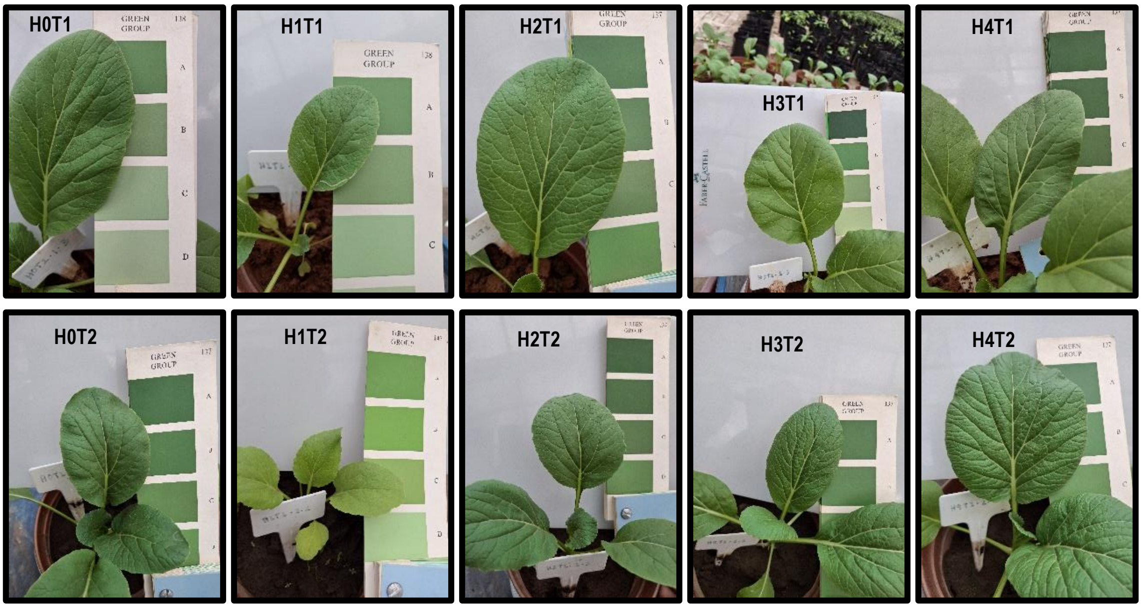

Figure 10. Leaf colour variation of mustard crop at 14 days after transplanting on the Regosol (T1) and Latosol (T2) soil, applied with humic acid (H0 and H1). Colour score based on The R.H.S. Color Chart (RHS, 2005)

CONCLUSIONS

The application of coal-extracted humic acid has a positive effect on soil chemical properties, enhancing plant performance and growth. The humic acid application resulted in a neutral soil pH, moderate to high electrical conductivity, and moderate C-organic contents.

LIMITATIONS & FURTHER RESEARCH

The limitation of the research was that it had not yet found the optimum dose of humic acid. Therefore, future research should focus on determining the optimal dose of humic acid for crop growth and yield. It is also challenging to investigate the use of humic acid combined with any nutrient sources for food crops other than mustard, particularly those with a longer age and cultivated in the field.

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