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Humic acid from *Melastoma affine* D. Don compost enhances key chemical properties of tropical coastal Entisols and Inceptisols

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Abstract The study demonstrated that the application of humic acid derived from *Melastoma affine* D. Don up to a rate of 4000 mg kg^{-1} increased total soil organic carbon (TSOC), total soil nitrogen (TSN), exchangeable potassium (K), and cation exchange capacity (CEC) of Entisols and Inceptisols from a tropical coastal area. However, humic acid application had no effect on soil available PO_4 or electrical conductivity (EC) in either soil. In contrast, soil pH decreased significantly with the humic acid application. An application rate of 1000-2000 mg kg^{-1} was sufficient to improve key soil properties while minimizing further pH reduction. Entisols revealed greater response in enhancing TSN, K, and CEC while Inceptisols had higher increase in TSOC. At highest humic acid concentration (4000 mg $kg^{-1)}$, Inceptisols increased TSOC by 93% higher than the control whereas Entisols only by 68%. Moreover, at the same rate, Entisols showed 49% and 35% increase in TSN and exchangeable K, respectively while no significant change in TSN and a 12.5% increase in K was observed in Inceptisols. These results indicates that humic acid derived from *Melastoma* compost had strong potential to improve chemical properties of coastal soil such as Entisols and Inceptisols, contributing a sustainable strategy for soil quality improvement.

Keywords: Humic acid, *Melastoma* compost, Entisols, Inceptisols, Coastal area

Introduction

Sustainable agricultural productivity is highly dependent on the quality of the soil. Healthy soil provides growing media and sufficient nutrients for crop growth. However, insufficient nutrient and suboptimal condition of soil properties constraint plant productivity. Entisols and Inceptisols are common soil orders found in tropical region like Indonesia. Entisols usually have a thin profile, sandy textural classification, low cation exchange capacity, (CEC) and low organic matter content. Likewise, Inceptisols typically has more developed

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profile with a variation of texture, moderate CEC and often high in soil acidity and phosphate fixation (Soil Survey Staff, 2014). Previous study indicated that Entisols from tropical coastal area of Bengkulu have 41.5% sand with insufficient levels of N, P, and K (Muktamar *et al*., 2022a). On the other hand, Inceptisols exhibits high clay content (63.3%) but low N, P, and K. In general, both soils have low CEC, low base saturation (BS), and high exchangeable aluminum (Al). Appropriate fertility management is necessary to improve their productivity potential (Katsumi *et al*., 2016).

Organic ameliorant such as humic acid is commonly used to improve soil quality, including physical, chemical and biological properties of the soil. Humic acid is one of humic substances with a dark colored fraction. This acid is rich in functional groups, mainly carboxyl and phenolic groups. Previous studies indicated that humic acid improves soil buffering capacity, enhances CEC, chelates toxic heavy metal, resists plant disease and increases plant nutrient availability (Ren *et al*., 2022; Muktamar *et al*., 2021; Haouas, *et al*., 2021, Ampong *et al*., *2022*). Furthermore, the application of humic acid improves N mineralization, solubilizes phosphate fixation, and increases cation retention, thus enhance soil productivity and health (Jin *et al*., 2024; Santi *et al*., 2024; Hua *et al*., 2008). Humic acid can be derived from various sources, including weed compost.

A potential source of humic acid is *Melastoma affine D. Don* compost. These weed species are abundantly found in marginal lands and possess relatively high content of lignin. *Melastoma* biomass contains 70% lignin while its compost has 38% (Suci *et al*., 2025). *Melastoma* biomass humification yields humic substance rich in humic acids with stable aromatic structure. Humic acid improves soil chemical properties more effective than fresh organic matter. Overall, using *Melastoma* as compost offers a humus source along with assisting to control the spread of this weed in agricultural areas (Rusli *et al*., 2022).

Numerous previous studies have indicated that applying humic acid enhances soil properties, but they generally focused on using humic acid generated from peat, animal waste compost, coal, or common organic biomass (Swanda *et al*., 2015; Ban *et al*., 2025). Study using humic acid derived from *Melastoma* compost is limited, even though this weed is abundantly available in agricultural lands and high potential for organic fertilizer. Additionally, most studies focus only one soil order, limiting the information on different response to other soil orders. This study focuses on two different soil order, Entisols and Inceptisols with distinct inherent characteristics. The present study aimed to evaluate the effect of *Melastoma*-derived humic acid on selected chemical properties of Entisols and Inceptisols from a tropical coastal area and to compare the response of both soils to different humic acid dosages.

Materials and methods

Soil and weed collection

Inceptisols samples were collected from Air Napal District, Central Bengkulu Regency, Bengkulu Province, Indonesia (10 m above sea level; 3°39′23″S, 102°13′4″E). Entisols samples were taken from Muara Bangkahulu District, Bengkulu City (3 m above sea level; 3°45′22″S, 102°16′1″E). The Inceptisols represent soils with a high clay content, whereas the Entisols have a high sand content. For each soil order, approximately 25 kg of soil from the 0–20 cm depth was compositely sampled from five spots. The sampling sites were dominated by oil palm (*Elaeis guineensis*), grasses, and broadleaf weeds, including *Melastoma*. The soil samples were air-dried for two days, ground, sieved through a 0.5 mm screen, and stored at room temperature until analysis.

The initial characteristics of both soil samples were determined as follows: organic carbon (C) by the Walkley–Black method; total soil nitrogen (TSN) by the Kjeldahl method; available phosphorus (P) by the Bray I method; exchangeable potassium (K) by flame photometry; calcium (Ca) and magnesium (Mg) by the EDTA titration method; exchangeable aluminum (Al) by titration after extraction with 1 N KCl; cation exchange capacity (CEC) by 1 N NH_4OAc extraction; pH using a pH meter in a 1:1 soil-to-distilled water suspension; electrical conductivity (EC) using a conductivity meter; and soil texture by the pipette method (BPT, 2009). The initial characteristics of the Inceptisols and Entisols are presented in Table 1.

Table 1. Initial characteristics of soil samples used in the experiment

Soil Characteristics	Entisols	Inceptisols
TSOC (g kg^{-1})	14.60	22.90
TSN (g kg^{-1})	1.10	2.90
Available phosphate (mg kg^{-1})	3.20	4.34
Exchangeable K (cmol kg^{-1})	0.23	0.35
Exchangeable Ca (cmol kg^{-1})	0.75	0.64
Exchangeable Mg (cmol kg^{-1})	0.23	0.44
Exchangeable Al (cmol kg^{-1})	0.21	1.50
CEC (cmol kg^{-1})	9.60	15.89
pH H_2O (1:1)	5.96	4.54
EC (uS cm^{-1})	240	61.5
Sand (%)	89.05	20.31
Silt (%)	8.97	18.84
Clay (%)	1.98	60.84

Melastoma biomass was collected from the same oil palm plantation as the Inceptisols samples. The weed was harvested approximately 100 kg from the area of 1 ha within oil palm stands. Weed biomass, then was air-dried for a week in shaded area. Finally, the biomass was cut into 3-5 pieces.

Compost and humic acid preparation

The weed biomass was incorporated homogeneously with ~1 kg of cattle manure, bio-activator and placed into composting bags. The mixture was incubated for 6 weeks, turned every week and watered when necessary. After the incubation, harvested mature compost was air-dried and sieved through a 0.5 mm screen.

Humic acid extraction was prepared by mixing 200 g of *Melastoma* compost with 200 ml of 0.1N NaOH. The mixture was transferred into a 500 ml Erlenmeyer, concealed with aluminum foil and shaken for 24 h. After shaking, 6 ml concentrated NaCl was added and the solution was incubated for next 24 h. After incubation, the solution was filtered using Whatman paper. The remainder was acidified to pH 1-2 using sulfuric acid. The solution then was heated in a water bath for 30 minutes at 60^{o}C. The solution was incubated for another 24 h, before being filtered. The remaining solid (humic acid) was collected and oven-dried at 60^{o}C until reaching constant weight.

Experimental design and procedure

The study used a Completely Randomized Design (CRD) with two factors and three replications. The first factor included dosage of humic acid generated from *Melastoma* compost with 5 concentrations (0 (control), 1000, 2000, 3000, and 4000 mg kg^{-1}). The second factor was two samples (Inceptisols and Entisols).

The experimental procedure was as follows: a hundred g of each soil sample was homogeneously incorporated with allocated dosage humic acid and placed in a 100 ml beaker. The mixture was moistened to field capacity moisture content by adding distilled water. Assigned beakers were randomly placed in a 1.5 m high wooden rack in the laboratory. The sample was incubated for 14 days with additional water as required every two days to sustain field capacity moisture content. After 14 days, the sample was air-dried, ground, and sieved with 0.5 mm screen. The sample was examined for TSOC using Walkley and Black method, TSN with Kjedahl method, available PO4 using Bray I method, exchangeable K using extraction by 1N ammonium acetate before detection with flame-photometer, EC using conductimetric method, pH using pH meter at soil to distilled water ratio of 1:1, and CEC using extraction with 1N ammonium acetate.

Data analysis

Data were analyzed using the analysis of variance (ANOVA) at significant level of 5% using SAS for Academics. Duncan's Multiple Range Test at significant level of 5% was assigned for mean comparison.

Results

Soil health and ecosystem sustainability is highly dependent on the content and dynamic of organic C in soil. The experiment revealed that the application of humic acid increased TSOC in both Entisols and Inceptisols (Table 2). The application of 4000 mg kg^{-1} humic acid resulted in the highest TSOC content, even though it was not significantly different from the 2000 and 3000 mg kg^{-1} treatments for Entisols and not significantly different from the 3000 mg kg^{-1} for Inceptisols. The increase in organic C was more prominent in Inceptisols than in Entisols. Compared with the control, the 4000 mg kg^{-1} humic acid dosage increased organic-C by 68% in Entisols and 93% in Inceptisols, respectively. Notably, TSOC content of Inceptisols was approximately double that observed in Entisols.

Table 2. Total soil organic carbon (TSOC) and total soil nitrogen (TSN) in Entisols and Inceptisols after the application of humic acid

Humic Acid Dosage (mg kg^{-1})	**TSOC (g kg^{-1})**		**TSN (g kg^{-1})**	
	Entisols	Inceptisols	Entisols	Inceptisols
0	16.37 ± 3.35 a	26.43 ± 3.81 a	1.23 ± 0.09 ab	2.80 ± 0.07 a
1000	15.57 ± 1.33 a	29.47 ± 2.02 ab	1.20 ± 0.18 a	2.87 ± 0.40 a
2000	20.93 ± 1.66 ab	36.97 ± 0.92 b	1.50 ± 0.17 bc	2.83 ± 0.23 a
3000	22.27 ± 2.76 ab	50.77 ± 3.38 c	1.77 ± 0.13 cd	3.33 ± 0.50 a
4000	27.47 ± 1.33 b	51.00 ± 3.30 c	1.83 ± 0.11 d	3.33 ± 0.21a

Note: Numbers followed by the same letter at the same column is not significantly different using DMRT at 5%

The application of humic acid from *Melastoma* compost significantly increased TSN in Entisols but had no significant influence in Inceptisols (Table 2). The highest TSN in Entisols was with the 4000 mg kg^{-1} humic acid treatment, even though it was not significantly different from the 3000 mg kg^{-1} treatment. In Entisols, the dosage of 4000 mg kg^{-1} increased TSN by 49% compared with the control. In general, as with TSOC, Inceptisols contained approximately twice the TSN of Entisols.

Humic acid application did not significantly influence soil available PO_4 both in Entisols and Inceptisols (Tabel 3). Available PO4 ranged from 7.37 to 9.12 mg kg^{-1} in Entisols and from 7.41 to 10.28 mg kg^{-1} in Inceptisols, with both soils generally containing very low content of available PO_4. In contrast, exchangeable K increased significantly with humic acid application in both soils. The highest exchangeable K was observed in 4000 mg kg^{-1} treatment for both soils, although it was not significantly different from 3000 mg kg^{-1} treatment. Entisols exhibited a greater response on humic acid in releasing K, with a 23% increase in exchangeable K at 4000 mg kg^{-1} dosage compared with the control whereas Inceptisols was 12.5% for the same treatment.

Table 3. The effect of humic acid on available PO_4 and exchangeable K in Entisols and Inceptisols

Humic Acid Dosage (mg kg^{-1})	Availbale PO_4 (mg kg^{-1})		Exchangeable K (cmol$_c$ kg^{-1})	
	Entisols	Inceptisols	Entisols	Inceptisols
0	7.37 ± 0.64 a	7.41 ± 0.30 a	0.22 ± 0.01 a	0.32 ± 0.01 a
1000	8.15 ± 0.37 a	8.72 ± 1.06 a	0.24 ± 0.03 ab	0.34 ± 0.01 ab
2000	8.16 ± 0.83 a	9.61 ± 1.13 a	0.24 ± 0.02 ab	0.35 ± 0.02 b
3000	8.90 ± 0.43 a	9.92 ± 1.19 a	0.26 ± 0.01 b	0.36 ± 0.02 b
4000	9.12 ± 0.67a	10.28 ± 1.06 a	0.27 ± 0.02 b	0.36 ± 0.01 b

Note: Numbers followed by the same letter at the same column is not significantly different using DMRT at 5%

The study also showed that humic acid derived from *Melastoma* compost did not significantly affect the C/N ratio of Entisols, which ranged from 12.67 to 14.90 (Table 4). In contrast, rising dosages of humic acid significantly increased the C/N ratio in Inceptisols, with the highest value recorded at the 4000 mg kg^{-1} treatment, although it was not significantly different from the 3000 mg kg^{-1} treatment. Inceptisols showed a greater response to humic acid application, with a 64% increase in C/N ratio at 4000 mg kg^{-1} compared with the control.

Additionally, both Entisols and Inceptisols became more acidic with humic acid application within the dosage range used in this experiment (Table 4). A marked decrease in pH in Entisols was observed at the 4000 mg kg^{-1} treatment, with a decline of 0.68 pH units compared with the control. In contrast, the pH decline in Inceptisols was more gradual, with only a 0.2 unit decrease at 4000 mg kg^{-1} compared with the control. These results indicated that Entisols are more sensitive to humic acid application than Inceptisols.

Table 4. C/N ratio and soil pH in Entisols and Inceptisols as affected by the application of *Melastoma* compost derived humic acid

Humic Acid Dosage (mg kg^{-1})	C/N Ratio		pH	
	Entisols	Inceptisols	Entisols	Inceptisols
0	12.67 ± 2.14 a	9.47 ± 1.84 a	6.98 ± 0.01 a	4.94 ± 0.07 a
1000	13.03 ± 1.57 a	10.27 ± 1.07 a	6.93 ± 0.17 a	4.79 ± 0.05 b
2000	13.30 ± 2.62 a	12.63 ± 0.82 ab	6.78 ± 0.05 a	4.79 ± 0.04 b
3000	14.13 ± 2.37 a	15.47 ± 3.46 b	6.70 ± 0.11a	4.67 ± 0.03 c
4000	14.90 ± 2.71 a	15.57 ± 2.68 b	6.30 ± 0.28 b	4.66 ± 0.03 c

Note: Numbers followed by the same letter at the same column is not significantly different using DMRT at 5%

Increasing CEC is essential for improving the productivity of tropical soils. The study showed that the application of humic acid significantly increased CEC in both soils used in this experiment (Table 5). The highest CEC was recorded in the 4000 mg kg^{-1} treatment for both Entisols and Inceptisols, although it was not significantly different from the 3000 and 2000 mg kg^{-1} treatments. Entisols were more responsive to humic acid application, with a 77% increase in CEC at 4000 mg kg^{-1} compared with the control, whereas Inceptisols showed a 28% increase for the same treatment. Table 5 also shows that EC was not affected by the application of humic acid derived from *Melastoma* compost in either Entisols or Inceptisols. EC ranged from 160.67 to 185.33 µS cm^{-1} in Entisols and from 42.53 to 44.27 µS cm^{-1} in Inceptisols. However, EC values in Entisols were much higher than those in Inceptisols.

Table 5. The effect of humic acid derived from *Melastoma* compost on CEC and EC of Entisols and Inceptisols

Humic Acid Dosage (mg kg^{-1})	CEC (cmol$_c$ kg^{-1})		EC (µS cm^{-1})	
	Entisols	Inceptisols	Entisols	Inceptisols
0	10.23 ± 0.51 a	21.64 ± 2.47 a	185.33 ± 26.7 a	44.27 ± 12.2 a
1000	15.01 ± 1.09 b	21.91 ± 2.60 a	182.33 ± 26.5 a	46.40 ± 11.4 a
2000	17.21 ± 1.05 c	26.30 ± 1.47 b	172.33 ± 23.3 a	42.93 ± 9.4 a
3000	17.25 ± 0.24 c	26.39 ± 1.40 b	172.00 ± 25.2 a	42.53 ± 9.7 a
4000	18.07 ± 1.00 c	27.71 ± 2.36 b	160.67 ± 11.7 a	49.87 ± 7.5 a

Note: Numbers followed by the same letter at the same column is not significantly different using DMRT at 5%

Discussion

The study showed that the application of humic acid derived from *Melastoma* compost increased TSOC in both Entisols and Inceptisols. Higher dosages of humic acid contributed greater amounts of TSOC to the soil. This result is related to the addition of carbon from humic acid, as also reported by Wandansari *et al*. (2023). Notably, the increase in TSOC was more pronounced in Inceptisols than in Entisols. This difference is associated with the chemical and physical characteristics of the two soils.

Inceptisols, with their higher clay content, can bind the functional groups of humic acid through metal bridging (Spark, 2003) or via ligand exchange between an O-containing functional group and Al or Fe at the surface of aluminosilicates (Sposito, 2008), thereby preventing decomposition by microorganisms. Another important characteristic of Inceptisols is their high exchangeable Al content, which can form covalent bonds with the functional groups of humic acid, producing alumino–organo complexes that protect the organic matter from decomposition (Maffia *et al*., 2025). Ifansyah (2013) reported that the addition of humic acid linearly decreased soluble Al and dissolved Fe in acidic soils. Another possible mechanism is the coprecipitation of humic acid via its functional groups on Al or Fe hydro-oxides (Totsche *et al*., 2018). Inceptisols in coastal area of Bengkulu contain mineral kaolinite and gibbsite (Muktamar *et al*., 2022b). Therefore, through these mechanisms organic C might stay longer in the soil. On the other hand, low clay and high sand content in Entisols leads to more porous, consequently having higher oxygen supply. This condition leads to faster organic matter decomposition in Entisols.

The application of humic acid enhanced total soil nitrogen (TSN) and exchangeable K (Table 2). The enhancement might be associated with that humic acid stimulates the activity of microbes in the soil (Lamactud *et al*., 2022; Rui *et al*., 2024; Santi *et al*., 2024), speeding up organic matter mineralization. Previous studies confirmed that applying humic acid increases the availability of nitrogen (Rathor *et al*., 2024; Rui *et al*., 2024) and exchangeable K in the soil (Ganem and Eleiwi, 2025).

Even though Inceptisols had higher initial TSN, slower humic substance decomposition in the soil lead to smaller increase of the element than Entisols. Higher sand in Entisols can promote faster rate of decomposition which, in turn, stimulate faster organic N mineralization as indicated in the comparable C/N ratio of the soil for all humic acid dosages. Enhancement of K follows similar mechanism where faster rate of organic matter decomposition in Entisols also provides a higher increase in exchangeable K compared with Inceptisols.

On the other hand, pH of both soil samples declined with the application of humic acid. The reduction of pH is related to the direct addition of acidity from humic acid. Entisols experienced more significant decrease with the greatest application dosage reduced pH by 0.68 units while Inceptisols by 0.20 units. The different response of both soils might be associated with the weaker buffering capacity of Entisols due to their lower clay and organic matter (organic C) as well as higher sand content. As reported by Jeon *et al*. (2023) and Wei *et al*. (2022), organic matter and clay content regulates pH buffering capacity. Both characteristics control protonation and deprotonation reaction when there are acidic and alkaline inputs to the system. These findings are in-line to those reported by Ali and Mindari (2016), where applying humic acid lowered pH in alkaline soils. However, humic acid application enhanced pH in acidic soils (Ren *et al*., 2022).

Additionally, the study revealed that humic acid application prominently increased soil CEC. This result is attributable to enhancement of negative charge from humic acid which is rich in functional groups, mainly carboxyl and phenolic groups (Spark, 2003). Under favorable pH environment, these particular functional groups can dissociate protons, leaving negative charges in the particular groups. This mechanism rises negative charges on soil particles which in turn, increasing CEC. In this study, Entisols had relatively higher increase in CEC than Inceptisols. This result is possibly associated with lower initial content of CEC and organic C in Entisols which is comparably more significant negative charge increase from humic acid. Previuos studies also showed that the application of humic acid enhances CEC of the soil (Siregar *et al*., 2023; Hartina *et al*., 2025).

In conclusion, total soil organic carbon (TSOC), total soil nitrogen (TSN), cation exchange capacity (CEC) and exchangeable K in both Entisols and Inceptisols prominently increased with the application of humic acid derived from *Melastoma* compost, but soil-available PO_4 and electrical conductivity (EC) were not affected. In contrast, soil pH lowered with the similar application. To prevent further decrease in soil pH, the humic acid application of 1000–2000 mg kg^{-1} is sufficient. Inceptisols exhibited higher increase in TSOC than Entisols but the opposite pattern was found in TSN, exchangeable K and CEC. These results suggest that using humic acid derived from *Melastoma* compost can be a potential strategy to improve chemical properties of coastal soils such as Entisols and Inceptisols, promoting sustainable agricultural practices.

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Conflicts of interest

The authors declare no conflict of interest.

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