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Enhancing soil chemical properties and sweet corn productivity using humic acid extracted from tropical weed compost in acidic Inceptisols

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Abstract The study revealed that humic acid addition to NPK fertilization improved chemical properties of acidic Inceptisols and sweet corn productivity. The addition enhanced soil pH by 3.7% and reduced exchangeable Al by 8,5%. Additionally, humic acid derived from Melastoma compost showed higher soil pH and CEC than that extracted from cogon grass compost. Humic acid application at the dose of 0.2 gkg^{-1} exhibited the highest soil pH, increasing by 5.5% and the lowest exchangeable Al, declining by 8.7%, compared to NPK fertilizer alone. The study also demonstrated that the addition of humic acid improved sweet corn vegetative growth with an increase in plant height, stem diameter, leaf area, and shoot dry weight. Humic acid derived from Melastoma compost produced higher plant height, stem diameter, and shoot dry weight than that extracted from cogon grass compost. Likewise, the addition of humic acid at 0.2 gkg^{-1} exhibited higher plant height, stem diameter, leaf area, and shoot dry weight than NPK fertilization alone. The study further indicated that the addition of humic acid significantly increased husked ear weight by 30.1% and sweetness by 12.6%, but it did not affect ear length, ear diameter, and unhusked ear weight. Also, humic acid-derived Melastoma compost resulted in higher husked ear length, husked ear weight, and kernel sweetness than humic acid-extracted cogon grass compost, whereas unhusked ear length, unhusked ear diameter, husked ear diameter, and unhusked ear weight remained comparable between the two humic acid sources. The humic acid application at 0.2 gkg^{-1} dose significantly produced higher husked ear weight and sweetness than that at 0.1 gkg^{-1} dose, indicating a sufficient dose to achieve the highest sweet corn yield. The study confirms that the addition of humic acid extracted from weed compost improves sweet corn productivity, supporting sustainable agriculture.

Keywords: Acid soil, Cogon grass, Composting, Humification, Melastoma

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Introduction

Inceptisols are soil order commonly found in tropical regions such as Indonesia, contributing around 37.5% of the mainland (Muyassir *et al*., 2012). This soil often has low pH, low organic matter, high aluminum (Al) saturation, and low P availability. According to Suhemi *et al*. (2022), Inceptisols discovered in the tropical of Kalimantan had low fertility, characterized by organic-C levels of 1.34-1.50%, total-N of 0.19-0.21%, available P ranging from 3.58 to 15.52 $mgkg^{-1}$, CEC between 8.57 and 9.56 $cmolkg^{-1}$, Al saturation at 38.51and 42.22%, with pH ranging from 4.02 to 4.12. The main constraint of this soil is high Al saturation, causing toxicity to sweet corn and low P availability. The condition is further aggravated by low N availability. Aluminum toxicity in plants is associated with restricted root growth and reduced physiological and agronomic plant parameters (Steiner *et al*., 2025; Szoke *et al*., 2024; Cruz, 2023). The symptoms will be more severe when the nutrient availability in the soil is limited.

On the other hand, sweet corn (*Zea mays* var Saccharata) demands high nutrient input for its rapid growth and high biomass production. Nitrogen, phosphorus, and potassium are essential for vegetative growth, ear formation, and good quality sweet corn yield. Furqoni (2025) found that sweet corn requires 333 kg NPK fertilizer, 176 kg urea, and 61 kg KCl to gain high yield with good relative agronomic effectiveness (RAE). Limited nutrient availability in soil, such as acidic Inceptisols, often becomes the main limiting factor for sweet corn productivity.

Humic acid is main fraction in humic substances, rich in carboxyl and phenolic functional groups (Spark, 2003), enable to improve physical, chemical, and biological properties of soils. Humic acid can increase soil CEC, retain cations, chelate toxic ions such as Al and Fe, and improve nutrient availability (Ampong *et al*., 2022; Matfu'ah *et al*., 2024; Wandansari *et al*., 2023; Muktamar *et al*., 2026), thereby supporting plant growth and development. Also, humic acid can act as a plant stimulant to accelerate plant growth and development. de Souza *et al*. (2025) reported that humic acid application increases root dry weight by 27% and lateral root length by 20% through reactive oxygen species (ROS) hormone signaling in rice. Moreover, humic acid increases crop yield by 12%, nitrogen use efficiency by 27%, and nitrogen uptake by 17% (Ma *et al*., 2024).

Humic acids in agricultural systems are commonly extracted from lignite, peat, lake sediments, and agricultural wastes. Cheng *et al*. (2019) found that hydrothermal extraction from lignite can produce high humic acid yields, depending on reaction time, temperature, coal particle size, and the water-to-coal ratio. The highest yield, reaching 90.2%, was obtained at a coal particle size of 0.18–0.25 mm, a temperature of 190 °C, and an extraction time of 7 h. Likewise,

Wu *et al*. (2025) suggested that humic acid contents varied among peat types, with woody, herbaceous, and mossy peat containing 54.33%, 44.67%, and 15.00% humic acid, respectively. Nevertheless, the continuous exploitation of these raw materials may lead to environmental degradation. In this context, weed biomass represents an underutilized and relatively unexplored alternative source of humic acid. Cogon grass and Melastoma, which are widely distributed in tropical marginal lands, have considerable potential as locally available raw materials for humic acid production. Therefore, the extraction and application of humic acid from weed compost deserve further investigation as a low-cost, sustainable, and locally based alternative for agricultural use. The study aimed to evaluate the improvement of chemical properties and sweet corn productivity under the application humic acid extracted from cogon grass and Melastoma compost in acidic Inceptisols.

Materials and methods

Soil sample collection

Soil samples were collected from a palm oil plantation in Pasar Berbah Village, Air Napal District, North Bengkulu Regency, Bengkulu Province (3º39'16'' S and 102º12'13' E) at 20 m above sea level. Soil profile characterization showed that the soil was classified as Inceptisols. A composite soil sample totalling 650 kg was taken from the surface layer at a depth of 0-20 cm, representing the cultivated topsoil used for subsequent plant growth media preparation. The sample was then air-dried for two days, ground, and screened through a 2 mm sieve. The soil was characterized with 22.9 gkg^{-1} organic carbon, 2.90 gkg^{-1} total soil nitrogen, 4.34 $mgkg^{-1}$ available P, 0.35 $cmolkg^{-1}$ exchangeable K, 15.89 $cmolkg^{-1}$ CEC, 1.5 $cmolkg^{-1}$ exchangeable Al, pH of 4.54, and EC of 61.5 uS m^{-1}. Moreover, the soil had 60.32% clay, 20.84% silt and 18.84% sand (Suci *et al*., 2025).

Weed biomass collection and composting preparation

Melastoma (*Melastoma affine* D. Don) biomass, representing broadleaf weeds, was collected from Pantai Panjang seashore, City of Bengkulu, at 5 m above sea level, while *Imperata cylindric*a L. (cogon grass) biomass, representing grass, was taken from the Crop Production Experiment Station, University of Bengkulu, at 15 m above sea level. Approximately 250 kg of biomass was sampled, sliced in approximately 3 mm pieces, and air-dried under shading area for two days. Biomass was homogeneously mixed with 5 kg manure

(as starter) and bio-activator. The mixture was placed in a composting container and incubated for 6 weeks. The composting substrate was turned weekly throughout the six-week incubation period to ensure adequate aeration, stimulate uniform decomposition, and reduce excess heat produced by microbial activity during the composting process. At the end of the incubation, the matured compost was homogenized, air-dried under shading environment, ground, and sieved with 0.5 mm screen to provide a homogeneous material prior to characterization and humic acid fractionation. Cogon grass compost had 338.3 gkg^{-1} organic-C, 13.7 gkg^{-1} total-N, 9.5 gkg^{-1} total- P, 24.7 gkg^{-1} total-K, 4% cellulose, 2% hemicellulose, 44% lignin, 5.69% humic acid, and 3.75% fulvic acid, with C/N ratio of 31.39 and pH of 8.37 (Suci *et al*., 2026). Moreover, Melastoma compost contained 464.0 gkg^{-1} organic-C, 28.4 gkg^{-1} total-N, 5.4 gkg^{-1} total- P, 17.5 gkg^{-1} total-K, 4% cellulose, 6% hemicellulose, 38% lignin, 3.65% humic acid, and 4.60% fulvic acid, with C/N ratio of 16.34 and pH of 7.81 (Suci *et al*., 2025).

Humic acid fractionation

Humic acid was fractionated from the compost according to the following procedure: 200 g of compost was extracted with 200 ml of 0.1N NaOH in a 500 ml Erlenmeyer. The suspension was then shaken for 24 h, followed by the addition of 6 ml NaCl and incubated for 24 h. The mixture was filtered using Whatman filter paper. The filtrate was acidified using sulfuric acid until reaching a pH of 1-2. Before subsequent 24 h incubation, the acidified suspension was heated in a water bath at 60 ^{o}C. After the second incubation, the suspension was filtered with Whatman filter paper. The precipitate solid, identified as humic acid, was collected and oven-dried at 60 ^{o}C until constant weight. The fractionation procedure was repeated until sufficient humic acid was obtained for the experiment.

Experimental design and treatment

The greenhouse experiment was conducted during the dry season in 2026 at the Experimental Station, Faculty of Agriculture, University of Bengkulu. The experiment was designed as a Completely Randomized Design (CRD) with 8 treatments and 3 replications. Treatments included T0 (control, without fertilizer), T1 (recommended NPK fertilizer), T2 (NPK+0.1 gkg^{-1} humic acid from cogon grass compost, AH), T3 (NPK+0.2 gkg^{-1} humic acid from cogon grass compost, AH), T4 (NPK+0.3 gkg^{-1} humic acid from cogon grass compost, AH), T5 (0.1 gkg^{-1} humic acid from Melastoma compost, AM), T6 (0.2 gkg^{-1}

humic acid from Melastoma compost, AM), T7 (0.3 gkg^{-1} humic acid from Melastoma compost, AM). Recommended NPK fertilizer for sweet corn was 350 $kgha^{-1}$ urea, 150 $kgha^{-1}$ TSP, and 75 $kgha^{-1}$ KCl (Kementerian Pertanian, 2021).

Cultivation procedure and variables

Planting media were prepared according to the procedure as follows: 10 kg of prepared soil sample was homogeneously incorporated with 13.8 g of dolomite, 21 g of vermicompost, and the assigned humic acid according to the treatment structure. The mixture was placed in the polybag and incubated for a week, with watering every day to maintain field capacity moisture content. Polybags were randomly positioned in the greenhouse at a spacing of 75 × 20 cm.

After the media incubation, two sweet corn seeds of the Romanza F1 variety were sown in each polybag at 2 cm depth and covered with soil. The planting media were regularly watered to field capacity to support sweet corn growth. Thinning was carried out 2 weeks after planting, retaining one vigorous seedling per polybag. Weeds were removed manually when necessary, while disease and insects were controlled using pesticide applications by spraying the plants every week. Sweet corn was harvested at 78 days after planting, indicated by fully developed silks that had turned brown and the kernels exuded a milky liquid when pressed. Growth and yield variables included plant height, leaf number, stem diameter, leaf area, shoot fresh weight, shoot dry weight, chlorophyll, husked and unhusked ear lengths, husked and unhusked ear diameters, husked and unhusked ear weights, and sweetness.

After harvest, approximately 100 g of soil was collected from each treatment, air-dried, ground, and passed through a 0.5 mm sieve. The prepared samples were analyzed for organic C using the Walkley and Black method, total soil N using the Kjeldahl method, and available P using the Bray I method. Exchangeable K was extracted with 1N ammonium acetate and quantified using a flame photometer. Cation exchange capacity (CEC) was determined by extraction with 1N ammonium acetate followed by distillation and titration. Exchangeable Al was extracted with 1N KCl and subsequently determined by titration, whereas soil pH was measured using a pH meter at a 1:1 soil-to-distilled water ratio. The soil C/N ratio was calculated based on the organic C and total N contents (Eviati *et al.,* 2023).

Data analysis

Observed data were subjected to Analysis of Variance (ANOVA) at a confidence level of 95% using SAS OnDemand for Academics. Post hoc analysis used orthogonal contrasts at the same confidence level.

Results

Selected soil chemical properties

Soil chemical properties are main factors in determining soil fertility and plant productivity. The main constraints of acidic Inceptisols are low pH, low plant nutrient availability, and high Al saturation in soil, which is toxic to plants. The application of humic acid can alleviate these constraints. The study showed that fertilization is necessary to improve soil chemical properties such as soil pH, organic-C, total soil N, available P, exchangeable K, and CEC, as indicated in Table 1 ($p<0.05$), even though the soil C/N ratio and exchangeable Al were not affected by the fertilization. The highest increase was observed in available P, reaching 16.1%, followed by CEC (14.9%), soil total N (7.4%), organic-C (7.0%), and soil pH (3.5%). On the other hand, exchangeable Al slightly decreased (2.2%).

Results indicated that after sweet corn harvest, the addition of humic acid to NPK fertilization substantially increased soil pH and reduced exchangeable Al; however, it did not affect soil organic C, total soil N, available P, exchangeable K, C/N ratio, or CEC (Table 1). The addition of humic acid increased soil pH by 3.7% and decreased exchangeable Al by 8.5% compared with NPK fertilization alone. Similarly, humic acid derived from Melastoma compost produced a greater increase in soil pH than that derived from cogon grass compost, with an increase of 0.33 pH units for Melastoma compost compared with 0.18 pH units for cogon grass compost. The increase in soil pH was followed by a reduction in exchangeable Al, with humic acid derived from cogon grass compost decreasing exchangeable Al by 10.9% and that derived from Melastoma compost decreasing it by 7.8%.

Table 1. Selected soil chemical properties after the addition of humic acid from cogon grass and Melastoma compost to NPK fertilizer

Treatment	pH	Organic-C (gkg^{-1})	Total Soil N (gkg^{-1})	Available P ($mgkg^{-1}$)	Exch K (gkg^{-1})	C/N ratio	CEC ($cmolkg^{-1}$)	Exch Al ($mgkg^{-1}$)
Control (T0)	5.44	26.67	2.50	16.37	119.6	10.67	20.03	130.5
NPK (T1)	5.37	27.33	2.67	17.83	154.8	10.27	22.10	137.7
NPK+0.1AH (T2)	5.43	28.67	2.73	18.33	159.9	10.50	22.63	128.7
NPK+0.2AH (T3)	5.58	29.17	2.73	18.40	156.0	10.67	22.37	125.1
NPK+0.3AH (T4)	5.65	29.33	2.74	18.17	159.8	10.77	22.43	118.8
NPK+0.1AM (T5)	5.60	28.33	2.63	17.57	152.1	10.77	23.70	131.4
NPK+0.2AM (T6)	5.75	28.33	2.67	17.70	153.3	10.63	23.54	126.9
NPK+0.3AM (T7)	5.76	28.67	2.63	17.87	150.9	10.90	24.27	125.1
Orthogonal Contrast	Probability*							
Control vs Treatments	0.004	0.023	0.002	0.0002	0.037	0.967	0.0006	0.415
T1 vs T2, T3, T4, T5, T6, T7	0.0001	0.077	0.658	0.619	0.978	0.240	0.144	0.006
T1 vs T2, T3, T4	0.0013	0.047	0.224	0.215	0.839	0.340	0.613	0.003
T1 vs T5, T6, T7	0.0001	0.183	0.678	0.733	0.878	0.211	0.032	0.024
T2, T3, T4 vs T5, T6, T7	0.0006	0.294	0.031	0.035	0.614	0.658	0.020	0.176
T1 vs T2, T5	0.0107	0.187	0.769	0.792	0.942	0.381	0.190	0.091
T1 vs T3, T6	0.0001	0.114	0.559	0.569	1.000	0.360	0.290	0.011
T1 vs T4, T7	0.0001	0.067	0.769	0.630	1.000	0.184	0.129	0.002

Note: AH= Humic Acid from Cogon grass Compost; AM=Humic Acid from Melastoma Compost; *= significance when <0.05

The study also demonstrated that soil pH, available P, total soil N, and CEC differed significantly between humic acid derived from Cogon grass compost and that derived from Melastoma compost (Table 1). In contrast, organic C, exchangeable K, C/N ratio, and exchangeable Al were comparable between the two humic acid sources. Humic acid derived from Melastoma compost resulted in higher soil pH and CEC but lower total soil N and available P than humic acid derived from cogon grass compost. Specifically, soil pH and CEC under humic acid derived from Melastoma compost were 2.7% and 6.1% higher, respectively, whereas total soil N and available P were 3.4% and 7.6% lower, respectively, than those under humic acid derived from cogon grass compost.

Additionally, increasing the humic acid application dose increased soil pH and reduced exchangeable Al; however, it did not significantly influence organic C, total soil N, available P, exchangeable K, or CEC (Table 1). The highest soil pH and the lowest exchangeable Al were observed at the humic acid dose of 0.2 gkg^{-1}, which did not differ significantly from the 0.3 gkg^{-1} dose. This finding indicates that humic acid application at 0.2 gkg^{-1} was sufficient to increase soil

pH and reduce exchangeable Al to levels more favorable for plant growth. Compared with NPK fertilization without humic acid addition, this dose increased soil pH by 5.5% and decreased exchangeable Al by 8.7%.

Sweet corn vegetative components

The improvement of soil chemical properties increases sweet corn growth and yield through enhancement of nutrient availability, CEC and soil pH, and alleviation of Al toxicity in acidic soil. Fertilization in acidic Inceptisols significantly increased sweet corn plant height, leaf number, stem diameter, leaf area, shoot fresh and dry weights, and chlorophyll content ($p<0.05$), as shown in Table 2. Likewise, the addition of humic acid in acidic Inceptisols exhibited an increase in plant height, stem diameter, leaf area, and shoot dry weight, but it did not influence shoot fresh weight, leaf number, and chlorophyll content compared to NPK fertilizer alone. The increases reached 13.9% for plant height, 14.4% for stem diameter, 12.2% for leaf area, and 22.2% for shoot dry weight. Compared with NPK fertilizer alone, the addition of humic acid derived from Melastoma compost resulted in greater increases in vegetative growth variables than humic acid derived from cogon grass compost, with increases of 95.9% for plant height, 171.4% for leaf number, 51.8% for stem diameter, 22.5% for leaf area, 79.9% for shoot fresh weight, and 83.5% for shoot dry weight.

Humic acid derived from Melastoma compost produced greater vegetative growth responses than humic acid derived from cogon grass compost (Table 2). Plant height, stem diameter, and shoot dry weight were significantly higher under Melastoma-derived humic acid, whereas leaf number, leaf area, shoot fresh weight, and chlorophyll content were comparable between the two humic acid sources. Compared with plants treated with cogon grass-derived humic acid, those receiving Melastoma-derived humic acid were 8.1% taller, had 5.3% greater stem diameter, and accumulated 11.3% higher shoot dry weight.

Increasing the humic acid application dose significantly improved several sweet corn growth variables (Table 2). Compared with NPK fertilizer alone, humic acid application at 0.2 gkg^{-1} significantly increased plant height, stem diameter, leaf area, and shoot dry weight ($p<0.05$), but did not significantly influence leaf number, shoot fresh weight, or chlorophyll content. However, the response at this dose did not differ significantly from that at the higher dose of 0.3 gkg^{-1}. Humic acid application at 0.2 gkg^{-1} increased plant height by 16.8%, stem diameter by 13.0%, leaf area by 12.6%, and shoot dry weight by 28.8%. These results indicate that 0.2 gkg^{-1} humic acid was sufficient to increase sweet corn vegetative growth.

Table 2. Effect of humic acid derived from cogon grass and Melastoma composts on sweet corn vegetative growth

Treatment	PH (cm)	LN	SD (mm)	LA (cm^2)	SFW (g)	SDW (g)	CHL (mg l^{-1})
Control (T0)	154.7	11.8	16.69	911.1	134.2	37.76	30.21
NPK (T1)	166.0	12.5	18.16	934.9	175.1	44.98	27.22
NPK+0.1AH (T2)	167.3	12.8	20.57	997.5	188.3	49.15	29.78
NPK+0.2AH (T3)	197.8	12.8	20.32	1067.0	197.9	56.37	31.28
NPK+0.3AH (T4)	179.8	13.3	19.83	1053.1	182.9	50.56	30.43
NPK+0.1AM (T5)	194.7	13.5	21.71	1086.2	183.1	54.04	26.96
NPK+0.2AM (T6)	190.0	13.5	20.72	1039.1	208.7	59.47	31.93
NPK+0.3AM (T7)	205.2	14.3	21.52	1111.2	212.3	60.23	23.86
Orthogonal Contrast				Probability*			
Control vs Treatments	0.004	0.022	<0.0001	0.013	0.0004	<0.0001	0.563
T1 vs T2, T3, T4, T5, T6, T7	0.023	0.138	0.0007	0.018	0.133	0.004	0.467
T1 vs T2, T3, T4	0.128	0.422	0.0063	0.054	0.304	0.033	0.228
T1 vs T5, T6, T7	0.007	0.053	0.0002	0.012	0.076	0.001	0.891
T2, T3, T4 vs T5, T6, T7	0.047	0.090	0.0341	0.277	0.251	0.027	0.135
T1 vs T2, T5	0.166	0.316	0.0007	0.062	0.477	0.054	0.683
T1 vs T3, T6	0.017	0.316	0.0040	0.042	0.073	0.002	0.135
T1 vs T4, T7	0.022	0.056	0.0026	0.014	0.144	0.007	0.979

Note: AH= Humic Acid from Cogon grass compost; AM=Humic Acid from Melastoma Compost; PH=Plant Height; LN=Leaf Number; SD=Stem Diameter; LA=Leaf Area; SDW=Shoot Fresh Weight; SDW=Shoot Dry Weight; CHL= Chlorophyll. *= significance when <0.05.

Sweet corn yield traits

Enhancement of sweet corn yield is highly related to plant growth during the vegetative and reproductive stages. Optimum vegetative growth increases photosynthetic capacity and stimulates water and nutrient absorption, thereby subsequently supporting assimilate production and translocation for ear formation and kernel filling. Fertilization with NPK combined with humic acid significantly increased ear length, ear diameter, ear weight, and the sweetness level of sweet corn kernels compared to without fertilization (Table 3).

Moreover, the addition of humic acid to NPK fertilizer enhanced husked ear weight and sweetness, but it did not affect ear length, ear diameter, and unhusked ear weight. Compared to NPK fertilizer alone, the increase in husked ear weight was 30.1%, while sweetness was 12.6%. Addition of humic acid from cogon grass did not influence the yield components observed in this study; however, that of Melastoma significantly increased husked ear weight and sweetness.

Table 3. Sweet corn yield components under the application of humic acid derived from cogon grass and Melastoma compost

Treatment	UEL (cm)	HEL (cm)	UED (mm)	HED (mm)	UEW (gplant^{-1})	HEW (gplant^{-1})	SWN (brix)
Control (T0)	24.48	11.42	31.17	30.30	107.83	74.87	11.67
NPK (T1)	28.45	16.68	45.00	39.87	153.90	100.33	10.83
NPK+0.1AH (T2)	27.62	14.88	45.32	42.27	138.53	110.83	11.00
NPK+0.2AH (T3)	29.53	16.67	47.82	42.33	159.87	128.27	12.67
NPK+0.3AH (T4)	28.02	15.85	44.60	39.75	152.63	124.00	11.33
NPK+0.1AM (T5)	26.57	17.30	46.65	41.38	149.13	135.03	12.67
NPK+0.2AM (T6)	27.78	18..15	45.40	40.78	141.90	131.35	12.00
NPK+0.3AM (T7)	30.67	19.13	51.35	44.58	184.30	153.47	13.50
Orthogonal Contrast				Probability*			
Control vs Treatments	0.027	<0.0001	<0.0001	0.002	0.0157	0.001	0.546
T1 vs T2, T3, T4, T5, T6, T7	0.958	0.764	0.502	0.507	0.501	0.012	0.026
T1 vs T2, T3, T4	0.972	0.433	0.756	0.619	0.742	0.092	0.175
T1 vs T5, T6, T7	0.949	0.189	0.347	0.457	0.354	0.003	0.006
T2, T3, T4 vs T5, T6, T7	0.967	0.008	0.369	0.723	0.393	0.027	0.023
T1 vs T2, T5	0.465	0.628	0.752	0.563	0.967	0.084	0.128
T1 vs T3, T6	0.910	0.543	0.607	0.617	0.696	0.034	0.029
T1 vs T4, T7	0.629	0.498	0.347	0.498	0.163	0.005	0.023

Note: AH= Humic Acid from Cogon grass compost; AM=Humic Acid from Melastoma Compost; UEL=Unhusked Ear Length; HEL=Husked Ear Length; UED=Unhusked Ear Diameter; HED=Husked Ear Diameter; UEW=Unhusked Ear Weight; HEW= Husked Ear Weight; SWN=Sweetness. *= significance when <0.05.

Results also showed that humic acid derived from Melastoma compost produced greater improvements in selected yield components than humic acid extracted from cogon grass compost (Table 3). Specifically, Melastoma-derived humic acid resulted in higher husked ear length, husked ear weight, and kernel sweetness, whereas unhusked ear length, unhusked ear diameter, husked ear diameter, and unhusked ear weight remained comparable between the two humic acid sources. Compared with cogon grass-derived humic acid, Melastoma-derived humic acid increased husked ear length by 15.3%, husked ear weight by 15.6%, and sweetness by 9.1%.

Increasing the humic acid application dose improved selected sweet corn yield components, specifically husked ear weight and kernel sweetness (Table 3). Compared with NPK fertilizer alone and the addition at a dose of 0.1 $mgkg^{-1}$, the addition at 0.2 gkg^{-1} dose considerably increased husked ear weight and sweetness, while ear length, ear diameter, and unhusked ear weight were not significantly influenced. The response at 0.2 gkg^{-1} was also comparable to that at 0.3 gkg^{-1}, showing that the lower dose was adequate to reach the greatest yield-related traits. Generally, humic acid addition increased yield quality more consistently than ear size, with the greatest results detected for husked ear weight and sweetness.

Discussion

The study revealed that after sweet corn harvest, the application of humic acid to NPK fertilization increased soil pH and reduced exchangeable Al while it did not influence soil organic C, total soil N, available P, exchangeable K, C/N ratio, and CEC. The increase in soil pH is associated with the formation of Al-organo complexes between functional groups such as carboxyl and phenolic in humic acid and Al (Hiradate and Yamaguchi, 2003; de Melo *et al*., 2016), reducing proton release from Al hydrolysis. This process also contributes to lower exchangeable Al in soil. Previous study suggested that humic acid derived from *Centrosema pubescen* decreased exchangeable Al by 22.1% compared to the control (Kasifah and Syamsia, 2015). Interestingly, soil CEC increased with the addition of humic acid from Melastoma compost, but it was not affected by that of cogon grass compost. These results indicate that the effectiveness of humic acid in increasing soil CEC depends on the humic acid raw materials. Muscolo *et al*. (2022) reported that humic acid derived from leonardite, lignite, soil, coal, peat, and vermicompost had different compositions of functional groups, such as carboxyl-C, O-Aryl-C, aromatic-C, and O-alkyl-C, which differently influence the growth and metabolism of pinus. A study by Suci *et al*. (2026) also showed that application of humic acid from cogon grass compost to soil up to the dose of 1.0 gkg^{-1} did not influence CEC, but it significantly increased at higher doses.

At harvest, total N, available P, and exchangeable K in soil treated with NPK fertilizer alone were comparable to those in soil receiving NPK fertilizer combined with humic acid. This finding is in line with the incubation study using sandy and clayey soils by Muktamar *et al*. (2026), who found that humic acid application up to 1.0 g kg^{-1} did not significantly influence total N, available P, or exchangeable K, even though total N and exchangeable K increased at higher doses. In the present study, the insignificant differences in these nutrients after harvest may suggest that the additional N, P, and K available through humic acid

application were absorbed by sweet corn during vegetative growth and reproductive development.

The study also showed that the addition of humic acid to NPK fertilization increased sweet corn growth and yield. Sweet corn growth improvement included plant height, stem diameter, leaf area, and shoot dry weight, while yield traits were husked ear weight and sweetness. However, the addition did not influence leaf number, shoot fresh weight, chlorophyll content, ear length, ear diameter, and unhusked ear weight. The increase in sweet corn growth and yield is attributed to the improvement of the rhizosphere environment for sweet corn growth. The reduction of exchangeable Al in soil alleviates its toxicity and improves soil pH, thereby nutrient availability. Using chlorophyll fluorescence imaging techniques, Szoke *et al*. (2024) reported that decreasing Al concentration in solution media increased photosynthetic corn parameters, with the most severe toxicity at the highest Al concentration of 400 μM.

Sweet corn growth performance is also related to the increase in nutrient availability for plant uptake. CEC increase in treatment NPK fertilizer combined with humic acid may enhance cation nutrients such as NH_4^+ and K^+, therefore reducing their loss and retaining their availability for plants. Ampong *et al*. (2022) concluded that carboxyl and phenolic functional groups contributed to negatively charged sites, adsorbing cations and co-transporting them to plant roots. Humic acid can also provide energy for microbes, stimulating their activities (Guo *et al*., 2025; Maffia *et al*., 2025; Santi *et al*., 2024). Higher microbial activity might speed up soil organic matter breakdown and nutrient mineralization, enhancing nutrient availability. Moreover, humic acid controls root growth by fast reactive oxygen species (ROS)-dependent signaling, thereby promoting root growth and elongation for nutrient uptake (Zandonadi *et al*., 2025). Specifically, Li *et al*. (2025) confirmed that humic acid treatment improved soil water storage, thereby increasing water use efficiency in maize. Results of this study are consistent with those reported by Eryigit and Husamalddin (2023), where humic acid application increased corn stem diameter and leaf area, while it did not influence leaf number.

The study also revealed that the addition of humic acid extracted from Melastoma compost had greater plant height, stem diameter, shoot dry weight, husked ear length, husked ear weight, and sweetness level than that from cogon grass compost, while other observed crop variables were comparable between both sources. These results suggest that the addition of Melastoma compost-derived humic acid is more effective in improving sweet corn productivity. In the present study, pH and CEC were higher in soil treated with humic acid from Melastoma compost than in soil treated with humic acid extracted from cogon

grass compost, thereby promoting a more favorable rhizosphere environment for root growth and nutrient uptake.

The contrasting responses of the two sources of humic acid may also be due to variations in elemental composition and symmetrical properties of functional groups. Previous study confirmed that humic acid characteristics differ in the nature and abundance of the number of groups, such as aromatic, carbonyl, and carboxyl, depending on the raw material used (Garcia *et al*., 2019; Al-Faiyz, 2017). Another study also suggested that elemental composition varies among humic acids derived from agricultural waste composts (Unsal and Ok, 2001; Lanno *et al*., 2022). These differences might, therefore, lead to variable impacts on plant root interaction and rhizosphere environment. Further characterization of functional groups and molecular composition of Melastoma and cogon grass compost-extracted humic acids is necessary, along with their interactions with plant roots. Such information can therefore support a better understanding of the growth-enhancing effect reported in this study with humic acid extracted from Melastoma and its impact on yield components. In all cases, the increase in humic acid doses applied improved sweet corn growth and yield; however, the highest responses were obtained at 0.2 gkg^{-1}. This suggested that higher doses probably had only a limited effect on the sweet corn yield in acidic Inceptisols and may have contributed to decreasing soil pH. For example, Muktamar *et al*. (2026) reported that humic acid application at more than 1.0 gkg^{-1} decreased the pH of Entisols and Inceptisols.

In conclusion, the addition of humic acid to NPK fertilization improved the chemical properties of acidic Inceptisols, with the greatest response attained in soil pH and CEC. Combined NPK fertilizer and humic acid also improved sweet corn productivity, indicated by an increase in plant height, stem diameter, shoot dry weight, husked ear length, husked ear weight, and level of sweetness. Moreover, the addition of humic acid from Melastoma compost was more effective in improving sweet corn productivity than humic acid derived from cogon grass compost, with the greatest responses seen in husked ear length, husked ear weight, and level of sweetness. Humic acid at a dose of 0.2 gkg^{-1} is adequate to improve sweet corn productivity. This finding suggests that humic acid extracted from tropical indigenous weed compost is capable of improving nutrient availability and sweet corn productivity, supporting sustainable soil management to reduce dependency on synthetic agricultural inputs.

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Conflicts of interest

The authors declare no conflicts of interest.

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