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Research Article

The role of humic acid from various composts in improving degraded soil fertility and maize yield

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Abstract

Humic acids play a crucial role in ion exchange and metal ion complexes; therefore, they are potentially useful in improving soil fertility and crop yield. This study aimed to explore the role of humic acid (HA) from various composts in improving degraded soil fertility and maize yield. A field experiment was conducted on Inceptisols having low soil organic carbon, nitrogen and available phosphorus contents. Eight treatments of HA formulas and one control were arranged in a randomized block design with three replications. The HA formulas used were combinations of two doses of HA (0.15 and 0.20% of soil on w/w base) and four types of HA (HA extracted from bagasse compost, HA extracted from water hyacinth compost, HA extracted from market waste compost, and commercial HA). The results showed that the HA application increased 16-97% of soil organic carbon, total nitrogen, available phosphorus, exchangeable potassium and calcium compared to the control. The formula of commercial HA at 0.15% was the best treatment for inhibiting soil fertility degradation in agricultural land. The best maize yield of 15.13 t ha^{-1} and starch content of 63.54% was obtained from the application of commercial HA at 0.20%.

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Introduction

The government has set a food security program as a top priority in agricultural development policies. However, efforts to achieve food self-sufficiency are faced with the problem of the declining quality of land resources, thus threatening the sustainability of the agricultural sector. It was reported that the area of critical land in Indonesia reached 14.01 million hectares in 2018 (Ministry of Environment and Forestry, 2018). Moreover, this value will continue to increase if intensive land use and management have not applied the principles of soil conservation. In addition to converting agricultural land to non-agricultural activities, the practice of agricultural cultivation itself can also impact land degradation, including land management activities, the use of fertilizers and pesticides that are not environmentally friendly, as well as the monoculture cropping pattern used. The decrease in carrying capacity and pollution of agricultural land will undoubtedly affect the decline in crop yield. Land degradation is a temporary or permanent process of decreasing land productivity, characterized by a decrease in physical, chemical, biological, and ecological functions (Sitorus et al., 2011). Land degradation is manifested through erosion, soil compaction, decreased soil organic matter content, loss of nutrients, and a decrease in the population of microorganisms (Dragović and Vulević, 2020). Nurida and Jubaedah (2014) reported that land degradation resulted in soil organic matter in Indonesia being at low to deficient levels. Even in some places, the organic carbon content is already at a critical level, less than 1%. Meanwhile, soil organic carbon content is one of the critical indicators affecting land quality and sustainability (Ghaemi et al., 2014; Barnwal et al., 2021). It is stated that the agricultural system can be sustainable if the organic carbon content of the soil is more than 2% (Lal, 2015).

One of the ways to improve degraded agricultural land is by adding soil amendments. Soil amendments are synthetic or natural materials, organic or inorganic, in solid or liquid form, which are used to improve the quality of degraded soil in terms of physical and biochemical functions (Dariah et al., 2015). One of the organic soil amendments that can be used is humic acid (HA). HA is a complex organic compound formed through the decomposition process of organic matter. HA can be extracted from compost (Spaccini et al., 2019); mineral soil (Urdiales et al., 2018), peat (Klavins et al., 2019); or coal (de Souza and Braganca, 2018). These organic compounds are essential in increasing soil stability and fertility, leading to increased growth and absorption of plant nutrients (Noroozisharaf and Kaviani, 2018; Ampong et al., 2022).

The application of HA through the soil is said to improve the physical, chemical, and biological properties of the soil (Page et al., 2020), increase the efficiency of fertilization (Ye et al., 2020), and reduce the mobility of heavy metal contamination by precipitating it (Wu et al., 2017). However, considering the amount and quality of HA varies, it is necessary to consider the availability of HA in the field, its potential as a source of soil amendment, and the ease with which farmers can apply it. Nardi et al. (2021) and Sible et al. (2021) reviewed that the chemical structure and dose of HA application determine its effect on soil and plants. Rose et al. (2014) added that among the factors analyzed in most greenhouse experiments, HA source had a significant effect on root and shoot growth, while the application dose only significantly affected shoot growth. Furthermore, to evaluate the role of HA on degraded land, direct field studies are needed, primarily to determine the effect of modifications on the effectiveness of HA on environmental factors and land management, including plant species, annual weather patterns, soil types, and soil fertility management. Applying HA to the soil is expected to increase soil organic matter and improve the quality of degraded land, which can increase the productivity of strategic commodities and accelerate the achievement of sustainable food security in Indonesia.

This study aimed to elucidate the effect of the application of humic acid from various composts on degraded soil fertility and maize yield.

Materials and Methods

This research was conducted in the experimental field of Politeknik Pembangunan Pertanian Malang, East Java, Indonesia. Geographically, the experiment field is located at 7°51’17”S-112°40’43”E, and has an elevation of 598 m above sea level (asl). The experimental field is appropriate for maize cultivation with a monthly rainfall of 11-589 mm and daily mean temperature of 22.5-26.2 °C, and average humidity of 66-95%. The soil type of the experimental field used is classified as Typic Dystrudepts (Soil Survey Staff, USDA, 2014), with the following characteristics: pH H_2O (1:1) = 5.97, pH KCl (1:1) = 4.91, organic C = 0.70%, total N = 0.09%, total P = 98.57 mg 100 g^{-1}, available P = 9.50 ppm, exchangeable K = 0.36 cmol$_{(+)}$ kg^{-1}, exchangeable Na = 0.61 cmol$_{(+)}$ kg^{-1}, exchangeable Ca = 6.98 cmol$_{(+)}$ kg^{-1}, exchangeable Mg = 1.76 cmol$_{(+)}$ kg^{-1}, CEC = 24.58 cmol$_{(+)}$ kg^{-1}, water content of field capacity = 0.42 cm^3 cm^{-3}, water content of permanent wilting capacity = 0.29 cm^3 cm^{-3}, texture = clay loam, bulk density = 1.25 g cm^{-3}, particle density = 2.40 g cm^{-3}, and total microorganism = 5.95x10^6 CFU g^{-1}

Treatments tested were the combinations of types and doses of humic acid (HA), namely: F1 (0.15% of HA extracted from bagasse compost, F2 (0.20% of HA extracted from bagasse compost), F3 (0.15% of HA extracted from water hyacinth compost, F4 (0.20% of HA extracted from water hyacinth compost), F5 (0.15% of HA extracted from market waste compost), F6 (0.20% of HA extracted from market waste compost), F7 (0.15% of commercial HA), F8 (0.20% of commercial HA), and one control treatment (without HA). The nine treatments were arranged in a randomized block design with three replicates. The bagasse compost was obtained from the Kebon Agung sugar factory, the water hyacinth biomass was collected from the Selorejo reservoir, and the market organic waste was obtained from the traditional market of Karangploso, Malang Regency.

HA extraction method used was the modification of Stevenson (1994), especially using NaOH as a base solution to extract organic waste compost (alkali extraction method). As additional information, differences in types of HA compost significantly affect the content of functional groups and the ratio of E4/E6 (ratio of the absorbances at 465 nm and at 665 nm). The highest total acidity and phenolic groups of HA were found in market waste compost (1,208 and 1,108 cmol kg^{-1}, respectively), while the highest E4/E6 ratio was found in bagasse compost (2.87). Furthermore, the highest yield and C-humic content of HA compost were found in the bagasse compost (7.01% and 0.26%, respectively). The HA compost used in this research had an infrared spectrum at wave numbers 2,927.94-2,941.44 cm^{-1} (for aliphatic C-H stretching for $–CH_2$, $–CH_3$), 1,602.85-1,614.42 cm^{-1} (for aromatic C–C groups); 1,508.33-1,512.19 cm^{-1} (for COO⁻symmetric stretching or N–H deformation and –C=N stretching), 1,452.5 cm^{-1} (for aliphatic C–H groups), and 694.37-819.75 cm^{-1} (for C–H surface deformation and vibration).

The plot size was 150 x 300 cm with a height of 30 cm. Furthermore, planting maize was about 5 cm deep and filling each hole with two seeds. One gram of Furadan insecticide was added to each planting hole. The spacing row used was 75 x 25 cm (Nur et al., 2018). The basal fertilizers given to the maize plant were 300 kg Urea (N fertilizer) ha^{-1}, 175 kg SP-36 (P fertilizer) ha^{-1}, and 100 kg KCl (K fertilizer) ha^{-1} (Tuherkih and Sipahutar, 2008). Then other plant maintenance actions, such as hoarding and integrated pest control, were adjusted to conditions in the field.

The vegetative variables measured were plant height, number of leaves, and stem diameter at 8 weeks after planting (WAP); while root length and number of primary roots were measured after harvest. Furthermore, a microscopic examination of the root samples was carried out using a trinocular stereo microscope (Euromax SB 1903-P) and an electron microscope (FEI, type: Inspect-S50). The generative variables measured were the number of cobs per plant, cob length, cob diameter, rows number of cob, 1,000-grain weight, starch content, and yield per hectare. Plant biomass measured was the fresh and dry weight of the shoots and roots. Post-harvest soil analysis began with collecting soil samples from each pot. After air-drying, the soil sample was ground and filtered using a 0.2 mm sieve. The chemical properties analyzed included soil pH, organic C (the Walkley and Black method), total N (the micro-Kjeldahl method), available P (spectrophotometry), exchangeable K and Na (flame photometry), Ca and Mg (wet oxidation method using Atomic Absorption Spectrophotometer), and cation exchange capacity (ammonium acetate compulsory displacement method).

Data obtained were subjected to the Analysis of Variance (ANOVA). The post hoc test was carried out using Duncan's Multiple Range Test (DMRT) method at the 95% confidence level of $\alpha = 0.05$.

Results and Discussion

Soil characteristics of dryland Inceptisols affected by the humic acid application

Effects of HA on the soil characteristics of the dryland Inceptisols after harvesting maize are presented in Table 1. The application of HA significantly affected soil pH, organic C content, macronutrient availability, and CEC. The range of soil pH was neutral (6.90-7.15). This value is the ideal pH for most plants to grow optimally due to the availability of organic compounds, nutrients and minerals, as well as the activity of microorganisms and enzymes under optimum conditions (Neina, 2019). Khaidem and Meetei (2018) reported that macronutrients (such as nitrogen, potassium, phosphorus, calcium, magnesium, and sulfur) are more readily available in the pH range of 6.5-8.0, while micronutrients are more readily available in the slightly acidic range (5.0-7.0).

Based on the criteria for improving the initial soil fertility (Table 1, and Regulation of the Agriculture Minister No. 79 of 2013 concerning Guidelines for Land Suitability in Food Crop Commodities), the F7 treatment gave the highest mean pH value compared to other treatments. This treatment had an average value of 1.79% organic C content, 0.17% total N, 60.17 ppm available P, and 36.02 cmol$_{(+)}$ kg^{-1} CEC. Compared to the control, this treatment increased the content of organic C, N, and P nutrients by 43.8%, 50.0%, and 97.3%. The value obtained was higher than that of Li et al. (2019), who reported an average value of 1.43% for organic C, 0.12% for total N, and 36.77 ppm for available P, with the addition of humic acid fertilizer at a dose of 1,000 kg ha^{-1}.

In addition to directly increasing soil carbon content, applying HA into the soil contributes to soil C sequestration. The potential of soil C sequestration is positively correlated with the amount of humic substance in the soil (Swift, 2001). The addition of these organic compounds automatically catalyzes the further humification process. HA has the ability to prevent the decomposition process by microorganisms while supporting the population and activity of microorganisms, including autotrophic bacteria (Liang et al., 2017). Autotrophic bacteria, such as nitrifying or sulfur bacteria, can also fix C from CO_2, thereby indirectly increasing soil C sequestration. Likewise, with nitrogen, the application of HA with urea fertilizer improved the soil total N content while reducing the loss of N in the form of ammonia. According to Dong et al. (2009), in the urea mineralization process, HA plays a role in inhibiting urease activity, which converts urea into NH_3, by producing a lower urea hydrolysis rate, thereby increasing the availability of N under plant needs. According to Guo et al. (2022), the carboxyl group and the phenolic hydroxyl group of HA interact with the urea amide group to form a complex with high stability, which can increase the availability of NH_4^+–N and NO_3^-–N in the soil. This, of course, also increases the efficiency of N fertilization and suppresses N loss in the form of N_2O (Shen et al., 2020). Therefore, the indirect benefit of adding large amounts of HA to the soil is to mitigate the effects of climate change from the impact of greenhouse gases.

In improving soil quality, HA plays a role in changing the CEC in the soil colloid system. HA can increase the specific surface area of soil colloids to absorb exchangeable cations and accelerate the disintegration of soil minerals (Mindari et al., 2014). In addition, the carboxyl and phenolic hydroxyl groups in these organic compounds dissociate to produce many anions that directly contribute to CEC. Yang et al. (2021) reported that the higher the molecular weight and the more complex the humic substance, the higher the affinity for metal ions (Yang et al., 2021).

Table 1. Effect of humic acid application on soil characteristics of dryland Inceptisols after harvest 15 WAP.

Treatments	**pH H_2O**	**pH KCl**	**Organic C (%)**	**Total N (%)**	**Available P (ppm)**	**Exchangeable cations ($cmol_{(+)}$ kg^{-1})**				**Cation Exchange Capacity (CEC) ($cmol_{(+)}$ kg^{-1})**
						K	**Ca**	**Mg**	**Na**	
K	7.10 bc	5.85 c	1.25 a	0.11 a	30.50 a	0.24 a	15.53 a	6.75 ab	0.22 ab	35.64 cd
F1	7.02 b	5.73 b	1.49 bc	0.14 b	52.50 d	0.32 bc	15.81 a	6.50 a	0.22 ab	36.13 cd
F2	7.05 bc	5.70 ab	1.67 de	0.14 b	41.00 b	0.30 ab	16.72 ab	6.94 abc	0.28 cd	32.14 ab
F3	7.10 bc	5.80 c	1.79 e	0.16 b	50.50 cd	0.41 d	17.70 b	7.07 abc	0.29 cd	34.79 bc
F4	7.15 c	5.85 c	1.56 cd	0.20 c	45.50 bc	0.28 ab	16.90 ab	7.77 c	0.33 d	29.39 a
F5	6.90 a	5.65 a	1.45 bc	0.14 b	45.50 bc	0.29 ab	16.65 ab	6.42 a	0.20 a	29.34 a
F6	7.05 bc	5.80 c	1.75 e	0.16 b	49.00 cd	0.40 d	20.03 c	7.59 bc	0.25 bc	38.84 d
F7	7.00 ab	5.80 c	1.79 e	0.17 b	60.17 e	0.37 cd	18.22 b	6.68 a	0.19 a	36.02 cd
F8	6.90 a	5.80 c	1.42 b	0.21 c	40.50 b	0.35 bcd	17.49 b	6.73 ab	0.33 d	35.57 cd

Note: The number displayed is the average value; Numbers followed by the same letters in the same column showed no significant differences based on the DMRT Test at α = 0.05; F1 (bagasse compost HA 0.15%); F2 (bagasse compost HA 0.20%); F3 (water hyacinth compost HA 0.15%); F4 (water hyacinth compost HA 0.20%); F5 (market waste compost HA 0.15%); F6 (market waste compost HA 0.20%); F7 (commercial HA 0.15%); F7 (commercial HA 0.20%); K (control).

Olaetxea et al. (2018) added that HA is also able to form stable natural complexes (or chelates) with metals (M–HA) so that it can increase the solubility and potential bioavailability of macro and micronutrients needed by plants. HA has a strong ability to absorb exchangeable cations (K^+, Ca^{2+}, Mg^{2+} and others), but is not easily leached by percolation water.

Data presented in Table 2 show that the highest mean exchangeable K, Ca and Mg were found in F6, which were 0.40, 20.03, and 7.59 $cmol_{(+)}$ kg^{-1}, respectively. Another study found that the ability of HA to form an M–HA complex can directly increase the availability of P nutrients by forming a P–M–HA hetero-ligand complex (Urrutia et al., 2012). Furthermore, along with the increased nutrient in the form available to plants, it is possible for nutrient uptake by plant roots to occur through increased ATPase activity in the plasma membrane (PM). According to Reid and Hayes (2003), the mechanism of nutrient uptake by plants occurs in two ways. Firstly, is active, which requires metabolic energy due to the movement of nutrients against their electrochemical gradient. The second is passive, without requiring energy because nutrients enter with water absorbed by plants. With this definition, cation nutrient absorption is almost always passive, while anion nutrient absorption is active.

Effect of humic acid application on growth and yield of maize

The effect of HA on the growth and yield of BISI-2 hybrid maize on a dryland Inceptisols in the field is presented in Table 2. The results showed that almost all parameters were significantly affected by the HA application, except for the leaves number, the number of primary roots, cobs number and cobs length per plant, and fresh weight of shoots per plot. In general, the best treatment which had relatively high values of the many parameters observed was the F8 treatment. The treatment gave an average stem diameter of 2.13 cm, root length of 39.53 cm, cob diameter of 4.28 cm, 1,000-grain weight of 435.53 g (≈43.55 g 100 grain^{-1}), dry maize yield of 15.13 t ha^{-1} (≈10.54 t ha^{-1} of shelled maize), dry biomass of 1.88 kg plot^{-1}, and starch content of 63.54%. The percentage increase in maize yield achieved in this treatment was 3.82% compared to the control (without HA). Interestingly, the highest grain yield was found in the HA application from market waste compost both in doses of 0.15% and 0.20% (F5 and F6; Table 2). This indicates that HA from market waste compost is more effective and efficient for improving the grain yield of maize. Rahouma (2021) obtained similar results, namely the average of 2.13 cm for stem diameter, 4.26 cm for cob diameter, 41.21 g for 100 grain, and 6.95 t ha^{-1} for maize yield. In addition, the average value of 1,000 grain weight and dry shelled maize obtained in this study was higher than the potential yield of BISI-2 hybrid maize (i.e., ±265 g for 1,000 grain and 8.9 t ha^{-1} of dry shelled maize) (Aqil et al., 2012).

In general, the application of HA resulted in an increasing maize growth and yield as compared to the control. The increase in maize growth and yield with the HA addition was due to HA's direct or indirect effect on the soil-plant system. The indirect impact is these organic compounds' role in improving the rhizosphere's quality (including aggregation, aeration, availability of water and nutrients, and microorganism activity). Meanwhile, the direct effect is the role of HA on plant growth and development as a form of interaction of these organic compounds with cell membranes on the root surface (which in turn affects shoot and root growth through regulation of major pathways by hormones and effectors) (Morard et al., 2011; Erro et al., 2016). Furthermore, the role of HA in promoting growth and root modification was shown by its ability to induce the proliferation of adventitious–lateral roots and root hairs through the activation of the main signaling pathways regulated by auxin and nitric oxide in roots (Trevisan et al., 2010; Mora et al., 2012), as well as regulation of reactive oxygen species (ROS) at the cellular level and the expression of responsive superoxide dismutase (SOD) genes in the cytosol (García et al., 2016). This is also in line with the results of microscopic observations, which showed that the volume of root hairs in the treatment with HA was higher than the control (Figures 1 and 2). This change in root morphology also affected the increase in plant root biomass, where the highest value was found in the F8 treatment, which reached 865 g plot^{-1}.

Roots allocate most of their energy to multiply and lengthen fine (or lateral) roots to maximize absorption capacity. According to Comas et al. (2013), coarse roots of plants function as a barrier and form the overall root system architecture, as well as controlling root depth and the ability of plants to grow in the soil layer. Furthermore, the nodal roots (or supporting roots in maize) that develop from the bottom of the stem provide an additional role in finding water sources, especially at the end of the rainy season. Meanwhile, fine roots are the most active part of the root system in absorbing water and nutrients, where this type of root covers most of the surface area of plant roots. Strong root growth also long and dense root hairs are the main characteristics to ensure the efficient acquisition of macro and micronutrients in soils having low fertility levels. An increase in root hair length and density was directly proportional to a greater soil phosphorus absorption capacity and a higher yield potential in soils with limited P availability (Wang et al., 2016). Furthermore, the increase in plant shoot growth is part of the important role of cytokinins and mineral nutrients translocated from roots to shoots. This effect is closely related to the increased activity of plasma membrane H^+–ATPases and nitric oxide in root-to-shoot translocation (Mora et al., 2010).

Table 2. Effect of humic acid application on growth, yield, biomass and starch content in maize.

Treatments	**Plant height (cm)**	**Leaves number (strand)**	**Stem diameter (cm)**	**Root length (cm)**	**Primary Roots (branch)**	**Cobs number**	**Cob length (cm)**	**Cob diameter (cm)**	**Rows number of cob**
K	215.40 a	13.6 a	1.85 a	33.40 a	34.60 a	1.80 a	17.33 a	4.27 ab	11.53 a
F1	232.80 bc	13.6 a	1.94 ab	34.20 b	34.60 a	1.80 a	17.87 a	4.28 ab	11.80 ab
F2	240.53 c	14.3 a	2.03a b	40.40 d	36.93 a	2.00 a	18.07 a	4.28 ab	11.33 a
F3	217.27 a	13.7 a	1.88 a	35.20 ab	34.20 a	1.80 a	17.27 a	4.25 ab	11.80 ab
F4	225.33 ab	13.8 a	1.90 a	36.00 ab	34.67 a	1.87 a	17.67 a	4.33 ab	12.73 b
F5	230.13 b	13.6 a	1.91 a	36.93 bc	34.53 a	1.80 a	17.33 a	4.39 b	12.13 ab
F6	218.00 a	13.6 a	1.98 ab	35.40 ab	35.13 a	1.87 a	17.40 a	4.29 ab	11.93 ab
F7	219.33 a	13.9 a	1.98 ab	36.47 b	36.80 a	1.80 a	18.33 a	4.21 a	11.53 a
F8	219.40 a	13.7 a	2.13 b	39.53 cd	35.40 a	1.80 a	17.80 a	4.28 ab	11.47 a

Treatments	**1000 grain weight (g)**	**Starch content (%)**	**Shoot fresh weight (g plot^{-1})**	**Root fresh weight (g plot^{-1})**	**Shoot dry weight (g plot^{-1})**	**Root dry weight (g plot^{-1})**	**Maize yield with husks (t ha^{-1})**	**Maize yield without husks (t ha^{-1})**	**Grain yield (t ha^{-1})**
K	355.97 a	61.0 a	1480.0 a	816.7 abc	923.3 a	618.3 ab	18.93 a	14.55 a	9.87 a
F1	418.27 bc	66.6 c	1585.0 a	876.7 bcd	1030.0 abc	690.0 b	18.82 a	14.73 ab	10.22 ab
F2	424.90 c	62.8 ab	1581.7 a	921.7 d	1046.7 bc	693.3 b	19.14 ab	14.83 ab	10.40 ab
F3	435.53 c	72.3 d	1476.7 a	771.7 a	950.0 ab	570.0 a	20.27 cd	15.39 b	10.36 ab
F4	431.30 c	71.0 d	1446.7 a	783.3 abc	933.3 a	550.0 a	20.20 cd	15.47 b	10.54 abc
F5	367.17 ab	63.0 ab	1481.7 a	813.3 ab	993.3 abc	606.7 ab	19.74 abc	14.96 ab	11.61 c
F6	362.50 ab	64.5 bc	1466.7 a	795.0 ab	980.0 abc	583.3 a	19.45 abc	14.87 ab	11.32 bc
F7	451.77 c	63.7 b	1635.0 a	910.0 cd	1083.3 c	691.7 b	20.83 d	15.21 ab	10.35 ab
F8	435.53 c	63.5 ab	1525.0 a	1091.7 e	1015.0 abc	865.0 c	20.15 bcd	15.13 ab	10.03 a

Note: The number displayed is the average value. Numbers followed by the same letters in the same column showed no significant differences based on the DMRT Test at $\alpha = 0.05$; F1 (bagasse compost HA 0.15%); F2 (bagasse compost HA 0.20%); F3 (water hyacinth compost HA 0.15%); F4 (water hyacinth compost HA 0.20%); F5 (market waste compost HA 0.15%); F6 (market waste compost HA 0.20%); F7 (commercial HA 0.15%); F7 (commercial HA 0.20%); K (control).

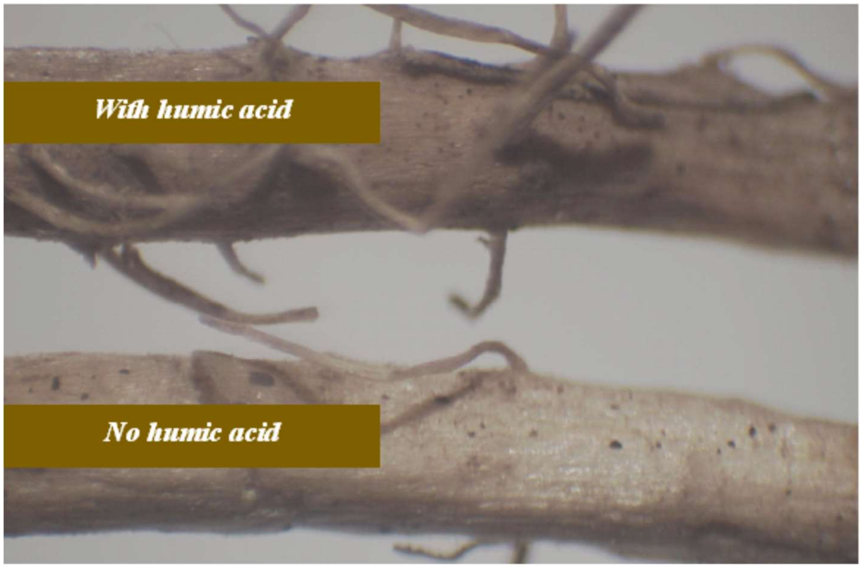

Figure 1. Micrograph of maize roots treated with and without humic acid using a trinocular stereo microscope (20x magnification).

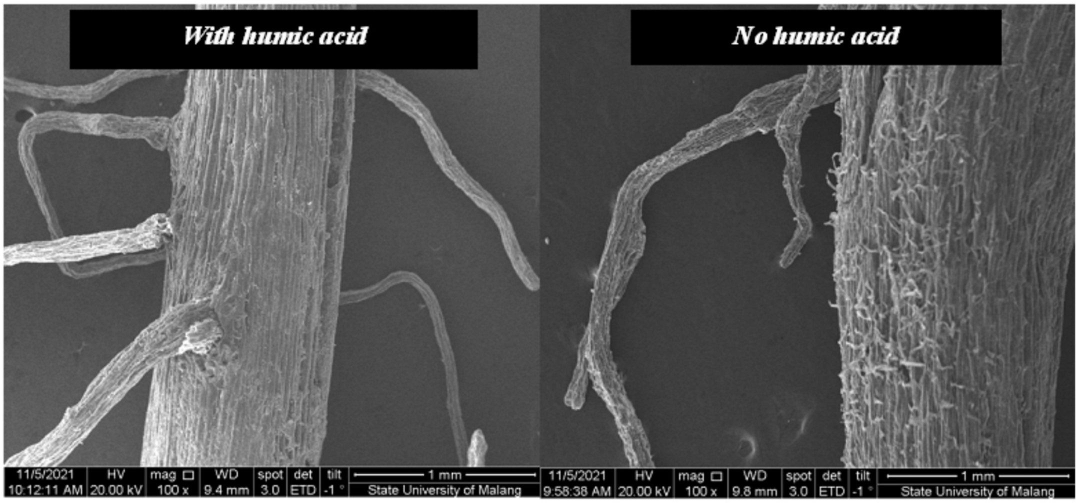

Figure 2. SEM micrograph of maize roots treated with and without humic acid (Bars 1 mm).

In addition to the effect of increasing H+-ATPase activity, which causes an increase in cytokinin concentration, the impact of HA on shoot growth is also related to an increase in hydraulic conductivity, which is influenced by abscisic acid (Olaetxea et al., 2019). Cytokinin plays a role in maintaining the pluripotency of the shoot apical meristem, which provides stem cells for the generation of leaf primordia in the early stages of leaf formation. During the leaf aging stage, cytokinin reduces sugar accumulation, increases chlorophyll synthesis, and prolongs the photosynthetic period of leaves (Wu et al., 2021). Based on the results, the highest value of shoot biomass was found in the F7 treatment, reaching 1,083.33 g plot^{-1}.

Conclusion

The use of humic acid as a soil amendment significantly improved soil fertility compared to the control. The F7 treatment gave the highest mean value for soil organic C (1.79%), total N (0.17%), available P (60.17 ppm), and CEC (36.02 cmol$_{(+)}$ kg^{-1}), while F6 gave the highest mean value for exchangeable K (0.40 cmol$_{(+)}$ kg^{-1}), exchangeable Ca (20.03 cmol$_{(+)}$ kg^{-1}) and exchangeable Mg (7.59 cmol$_{(+)}$ kg^{-1}). All parameters of growth and yield of BISI-2 hybrid maize were significantly affected by the use of humic acid, except for the leaves number, the number of primary roots, the cobs number and cobs length per plant, and the fresh weight of shoots. In general, F8 was the best formula, where the treatment had an average stem diameter of 2.13 cm, root length of 39.53 cm, cob diameter of 4.28 cm, weight of 1,000 dry kernels of 435.53 g, maize yield of 15.13 t ha^{-1}, total dry weight of biomass of 1.88 kg $plot^{-1}$, and starch content of 63.54%.

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