

Application of Humic Acid and Gypsum Enhances Soil Nutrient Availability and Tomato Yield in Mangrove-Derived Saline Soils

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Submitted May 02Nd 2025, and Accepted August 23Th 2025

Abstract

Background: High soil salinity in mangrove forests, caused by seawater intrusion, poses a major challenge to agricultural productivity. This study aims to address this issue by evaluating the effects of humic acid and gypsum application on organic matter availability and tomato yield (*Solanum lycopersicum* L.). These two materials were chosen for their potential synergistic effects: humic acid is known to improve cation exchange capacity and soil structure, while gypsum serves as an effective source of calcium and sulfur, which are essential for reducing salinity and improving acidic soil conditions. **Methodology:** The research was conducted at the Laboratory and Greenhouse of the Faculty of Agriculture, Brawijaya University, using sandy saline soil sourced from a mangrove forest area. The study followed a Completely Randomized Design (CRD) with a factorial pattern. Data analysis was performed using the F-test, followed by the Least Significant Difference (LSD) test at a 5% significance level. **Findings:** The results showed that the combined application of humic acid and gypsum significantly influenced the growth, productivity, and nitrogen uptake of tomato plants. The H3G3 treatment (0.124 g humic acid and 18.75 g gypsum) yielded the highest number of fruits, with an average of 14.33 fruits per plant, which was significantly higher than the control group. Additionally, the highest vitamin C content (37.84%) was found in the treatment using 0.124 g of humic acid alone. The combination of humic acid and gypsum proved effective in improving saline mangrove soil by reducing salinity and increasing the availability of essential nutrients like nitrogen and phosphorus. **Contribution:** This research suggests that utilizing these two materials can be an efficient and sustainable remediation strategy for saline land, potentially transforming unproductive areas into viable agricultural land. However, these findings are limited to greenhouse conditions and similar soil types. The primary contribution of this study is providing scientific evidence for the synergy between humic acid and gypsum in enhancing soil quality and crop yield within the specific ecosystem of mangrove soil.

Keywords: Gypsum; Humic Acid; Productivity; Remediation; Tomato Plants



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<https://doi.org/10.36987/jpbn.v11i3.7671>

INTRODUCTION

Mangrove forests are unique ecosystems found in transitional zones between land and sea, commonly known as brackish swamps or tidal forests. Located along coastlines and river estuaries in tropical regions, they play a vital ecological role. The soil in these areas is shaped by climate, parent material, living organisms, topography, and time, and serves as a key medium for plant growth by supplying a wide range of nutrients for both plants and microorganisms [Lovelock et al., 2020](#)). Due to constant tidal inundation, mangrove soils are often characterized by high salinity and low pH, typically ranging between 5.5 to 7.0, which poses a significant challenge for most agricultural crops [\(Afele et al., 2019\)](#).

Soil salinity in these environments can be improved through the application of ameliorating materials. Substances commonly used to reduce soil salinity include gypsum, rice straw, zeolite, and humic acid. The primary function of these amendments is to alleviate salt toxicity and improve both the physical and chemical properties of the soil, typically by binding toxic ions [\(Adame et al., 2021\)](#). The application of soil ameliorants plays a crucial role in mitigating excessive salt levels, which are particularly problematic in mangrove areas where soils are naturally saline due to tidal seawater inundation. This saline environment poses a significant challenge for most agricultural crops [\(Ghassemi et al., 2020\)](#).

Mangrove species have developed specific physiological adaptations to either excrete or compartmentalize salt, enabling them to survive under high salinity conditions [\(Alongi, 2015\)](#). In contrast, tomato plants (*Solanum lycopersicum*) are classified as glycophytes and are highly sensitive to saline environments. Unlike mangroves, tomatoes lack effective mechanisms to tolerate high salt concentrations and are therefore prone to osmotic and ionic stress under such conditions [\(Negrao et al., 2019\)](#). These stresses adversely affect seed germination, vegetative growth, and ultimately reduce both the yield and quality of the fruit. For example, studies have shown that salinity levels can lead to a 25-50% reduction in tomato fruit yield compared to non-saline conditions.

Tomato plants (*Solanum lycopersicum* L.), a key horticultural commodity, are known to exhibit high sensitivity to saline conditions [\(Isnasa, 2017\)](#). While tomatoes can tolerate moderate salinity levels, their growth and fruit quality—including vitamin C and lycopene content—are severely affected when grown in saline soil. Therefore, developing effective remediation strategies for saline land, especially in mangrove soil, is critical for unlocking the agricultural potential of coastal areas.

Various methods have been developed to reclaim saline land using both organic and inorganic amendments. The use of organic materials, such as compost, manure, and biochar, has been reported to effectively improve soil physical properties, increase water retention capacity, and raise organic matter content [\(Amira et al., 2022\)](#). However, their effect on severe salinity is often limited, as organic matter is less effective at displacing Na⁺ ions from the soil exchange complex.

A highly effective and long-standing chemical approach for improving saline-sodic soils is the use of gypsum (CaSO₄·2H₂O). This method works by introducing calcium ions (Ca²⁺) that displace the sodium ions (Na⁺) attached to the soil particles,

enabling these harmful sodium ions to be leached away from the plant roots. (Rengasamy, 2006). Despite its effectiveness, gypsum does not directly increase organic matter content or improve soil structure over the long term.

These limitations of single-approach methods create a significant research gap. While numerous studies have evaluated the effectiveness of gypsum and organic amendments separately, there is a lack of in-depth research specifically exploring the synergy between humic acid and gypsum in saline soil within a mangrove ecosystem for tomato cultivation. This study aims to fill that gap by evaluating how the combination of these two materials can simultaneously improve soil physical, chemical, and biological quality, and the subsequent impact on tomato productivity.

Based on this background, the primary objective of this study is to evaluate the effects of a combined application of humic acid and gypsum on organic matter availability and tomato yield grown in mangrove soil. We hypothesize that the combination of these two materials will work synergistically to improve soil physical and chemical conditions, thereby creating a more fertile environment for plant growth.

METHOD

This study utilized soil from a mangrove forest as the primary growth medium. The soil had a specific texture, described as clayey, loamy, or sandy, with a low maturity level and fine texture. Initial analysis indicated a soil pH ranging from 6 to 8, suggesting a neutral to slightly alkaline condition.

The experimental work was conducted at a home garden located in Tambak Wedi, Kenjeran District, Surabaya City, East Java, with geographical coordinates of 7.234°S and 112.789°E. This location was chosen for its accessibility and ease of monitoring throughout the research period. The climate in the study area is characterized by an average annual temperature of 28°C, average humidity of 75%, and annual rainfall ranging from 1,500-2,000 mm, based on data from the local Meteorological, Climatological, and Geophysical Agency (BMKG, 1991-2020).

Instrument

Several materials and pieces of equipment were prepared to conduct this research. The main materials included mangrove forest soil as the primary growing medium, Servo F1 tomato seedlings as the indicator plant (sourced from PT. East-West Seed Indonesia), and humic acid and agricultural gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) as the soil amendments. The humic acid used had a 50 % concentration, and the agricultural gypsum was purchased from a local agricultural supply store. Additionally, leaf litter compost was prepared to enhance the fertility of the growing medium.

The equipment used consisted of:

- a. Poly bags measuring 40x40 cm (26 cm x 28 cm) to serve as planting containers.
- b. Hoes and shovels for medium preparation.
- c. Scissors for plant maintenance.
- d. A camera and writing tools for data documentation.

- e. A scale for weighing materials.
- f. A mixer for homogenizing the growing medium.

For measuring soil quality parameters, several specific instruments were used:

- a. A pH meter to measure soil acidity.
- b. A spectrophotometer for analyzing macro-nutrients such as Nitrogen (N), Phosphorus (P), and Organic Carbon (C-organic).

Data collection

The experimental data were analyzed using both descriptive and inferential statistics. Descriptive statistics were used to summarize the soil and plant parameters, while inferential statistics, specifically ANOVA (Analysis of Variance), were performed to test for significant differences between treatments. ANOVA was applied to all measured parameters, including soil salinity, pH, Organic Carbon (C-organic) content, Nitrogen (N) content, Phosphorus (P) content, number of fruits, and fruit Vitamin C content.

If the F-value from the ANOVA test showed a significant result at a 5% confidence level, a Least Significant Difference (LSD) test at the same 5% level was then conducted to determine the specific differences between the treatment means.

Measurement Methods

The specific measurement methods used for each parameter were as follows:

- a. pH: Measured using a standard pH meter.
- b. Organic Carbon (C-organic): Determined by the Walkley & Black method using titration. This method involves oxidizing organic carbon with a potassium dichromate solution, and then titrating the remaining dichromate to quantify the amount of carbon.
- c. Nitrogen (N) Content: Measured using the Kjeldahl method. This is a classic method that converts organic nitrogen into ammonium sulfate through a digestion process, which is then quantified by titration.
- d. Phosphorus (P) Content: Measured using the Bray I method with a spectrophotometer. This method is effective for acidic soils and involves extracting available phosphorus with an acidic solution before measuring the color intensity of the resulting solution.
- e. Number of Fruits: Counted directly as quantitative data.
- f. Vitamin C Content: Measured using the iodometric titration method. This is an indirect method where iodine is used to oxidize the ascorbic acid (Vitamin C), and a starch indicator is used to determine the endpoint of the reaction.

Research Timeline and Methodology

This study began with the preparation of the planting medium and the transplanting of tomato seedlings. The entire research process, from planting to harvesting, spanned approximately 3 to 4 months. This duration covered the complete growth cycle of the tomato plants, including both the vegetative phase (growth) and the generative phase (flowering and fruiting). Throughout this period,

data was collected regularly to monitor plant development and the condition of the growing medium.

Experimental Design

This study utilized a factorial Completely Randomized Design (CRD) with two main factors: humic acid dosage (H) and gypsum dosage (G). The experiment included three replicates, for a total of 48 experimental units.

The treatment factors were detailed as follows:

Humic Acid (H) at four levels:

- H0: Control (no humic acid)
- H1: 10 kg/ha (equivalent to 0.062 g per plant)
- H2: 15 kg/ha (equivalent to 0.093 g per plant)
- H3: 20 kg/ha (equivalent to 0.124 g per plant)

Gypsum (G) at four levels:

- G1: 1 ton/ha (equivalent to 6.25 g per plant)
- G2: 2 tons/ha (equivalent to 12.5 g per plant)
- G3: 3 tons/ha (equivalent to 18.75 g per plant)
- G4: 4 tons/ha (equivalent to 25 g per plant)

These treatment factors resulted in 16 treatment combinations applied to each of the three replicates, totaling 48 experimental units. Based on existing literature, a humic acid dosage of 20 kg/ha, as reported by [Ali et al., \(2019\)](#), showed a positive response in tomato growth, with an increase in nutrient availability and uptake. Similarly, an agricultural gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) dosage of 3 tons/ha has been shown to provide optimal results in tomato cultivation ([Alawiyah et al., 2021](#)). Gypsum plays a crucial role in soil improvement, including the reclamation of sodic soil, enhanced aggregation, improved percolation, and a reduction in soil pH.

Statistical Analysis

The experimental data were analyzed using both descriptive and inferential statistics. Descriptive statistics were used to summarize the soil and plant parameters, while inferential statistics, specifically a factorial Analysis of Variance (ANOVA), were conducted to test for differences between treatments. This test was performed to determine the effects of both the interaction and the main effects of the humic acid and gypsum treatments on all measured parameters.

If the F-value from the ANOVA test showed a significant result, a Least Significant Difference (LSD) test at a 5% significance level was then performed to identify specific differences between the treatments. This analytical method is based on the statistical principles outlined by [Field \(2018\)](#).

RESULT

The results of this study demonstrate a significant effect of the combined humic acid and gypsum treatments on improving soil conditions and increasing tomato plant productivity.

Table 1. Summary of Analysis of Variance (ANOVA) Results for Soil and Plant Parameters

Parameter	Main Effect of Humic Acid (H)	Main Effect of Gypsum (G)	Interaction (H x G)
Soil pH	Significant	Significant	Not Significant
C-organic	Significant	Not Significant	Significant
Nitrogen (N)	Significant	Significant	Significant
Phosphorus (P)	Significant	Significant	Significant
Number of Fruits	Significant	Significant	Significant
Vitamin C	Significant	Not Significant	Not Significant

Note: "Significant" indicates a notable difference between treatments based on the ANOVA test ($p < 0.05$).

The table 1 shows that the main effects of humic acid (H) and gypsum (G), as well as their interaction (H x G), had a significant impact on most parameters, including nutrient content (N and P) and fruit yield. This highlights the synergistic relationship between the two amendments in improving soil quality and crop productivity.

Initial Soil Analysis

The analysis of the chemical properties of mangrove forest soil included parameters such as pH, organic carbon (C-organic), nitrogen, available phosphorus (P-available), and available potassium (K-available), as presented in Table 2.

Table 2. Initial Soil Analysis

Parameter	Unit	Analysis Results	Category
pH (H ₂ O)	-	7.49	Slightly alkaline
C-Organic	%	1.36	Low
Nitrogen	%	0.12	Low
Phosphorus	Ppm	13.21	Low
Potassium	Cmol/kg	5.01	High

The initial analysis showed that the chemical characteristics of the mangrove soil used in the study were poor. Although the soil pH was within a moderate range (7.49), indicating a neutral condition, the available organic carbon, nitrogen, and phosphorus contents were very low (Isir et al., 2022). This condition is substantially inadequate to support optimal plant growth. The low availability of phosphorus is due to its strong binding with metal ions like Ca, Mg, Na, and K, which are abundant in saline soils.

These ions form insoluble phosphate compounds, making phosphorus inaccessible to plants—a mechanism supported by various studies (Baligar & Fageria, 2005). Furthermore, the high sand content and low organic matter significantly reduce the soil's water-holding capacity, causing it to dry out quickly (Islam et al., 2016).

These limitations highlight the urgent need for soil improvement. Therefore, this study chose humic acid and gypsum as amendments. Humic acid plays a vital role in increasing organic matter content and improving soil structure, which directly enhances water-holding capacity and nutrient availability. Meanwhile, gypsum serves a dual purpose: it not only reduces salinity by replacing Na^+ ions but also provides Ca^{2+} which can improve soil aggregation and break the bonds of unavailable phosphorus, making it more easily absorbed by plants. Despite these challenges, coastal land still holds great potential to be developed as a strategic agricultural area amid the limitation of fertile land (Sagiarti et al., 2020).

Treatment Effects on Soil pH

The combined application of humic acid and gypsum did not induce a significant change in soil pH. On Day 0 After Planting (DAP), the H3G3 treatment (H3: 0.124 g and G3: 18.75 g) resulted in a pH of 7.70. However, this difference was not statistically significant according to the ANOVA ($p > 0.05$). Similarly, at 70-75 DAP, the pH of this treatment was recorded at 7.32, which again showed no significant change from the initial value. This indicates that over the experimental period, the applied amendments had a negligible effect on the soil's pH dynamics.

The application of humic acid to coastal soils can increase pH due to negatively charged organic compounds that bind cations, thereby reducing hydrogen ions in the soil solution (Firmansyah & Sumarni, 2013). However, the decomposition of organic matter also releases acids that can lower pH, making this effect temporary (Delgado-Andrade et al., 2025).

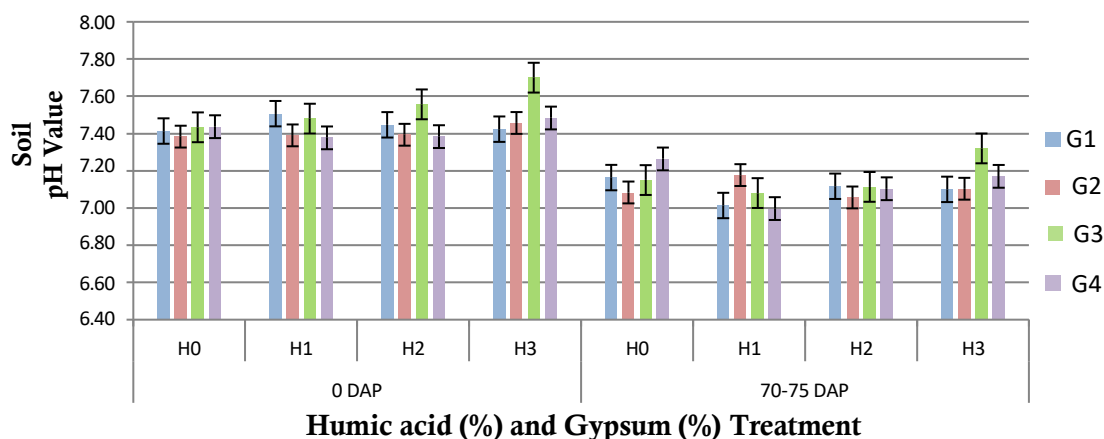


Figure 1. Relationship of Average Soil pH Based on Humic Acid and Gypsum Analysis in Mangrove Soil at 0 and 70–75 Days After Planting (DAP)

Gypsum is effective in improving soil chemical properties by raising pH, reducing heavy metal toxicity, and increasing the availability of nutrients such as phosphorus (P), calcium (Ca), and magnesium (Mg) (Sir & Bolla, 2012). In addition, gypsum improves soil structure and microbial activity, supporting long-term soil fertility (Adame et al., 2021). Nevertheless, the application of humic acid and gypsum did not result in significant pH changes after the growing period, indicating the need for

long-term management (Afeke et al., 2021).

Impact of Treatments on Soil Organic Carbon (C-organic)

The analysis showed that the humic acid and gypsum treatment on Day 0 After Planting (DAP) did not result in a significant difference in soil Organic Carbon (C-organic) content, with a value of 2.55%. However, by 70-75 DAP, the same treatment produced a statistically significant increase, raising the C-organic content to 2.73% (Figure 2).

This significant increase in C-organic content at the end of the study period is consistent with findings from previous research. In line with study by Chen et al., (2021) also found that applying organic amendments like humic acid does not immediately boost C-organic levels in the initial stages. The soil improvement effects of organic materials are gradual and require time to take effect. This increase in C-organic occurred because it takes time for the organic material to decompose. When initially added, the humic acid and plant residues have not yet fully integrated with the soil. Over time, soil microorganisms will break them down. This gradual process is what causes the C-organic content to increase, with the results becoming clearly visible only at the end of the research.

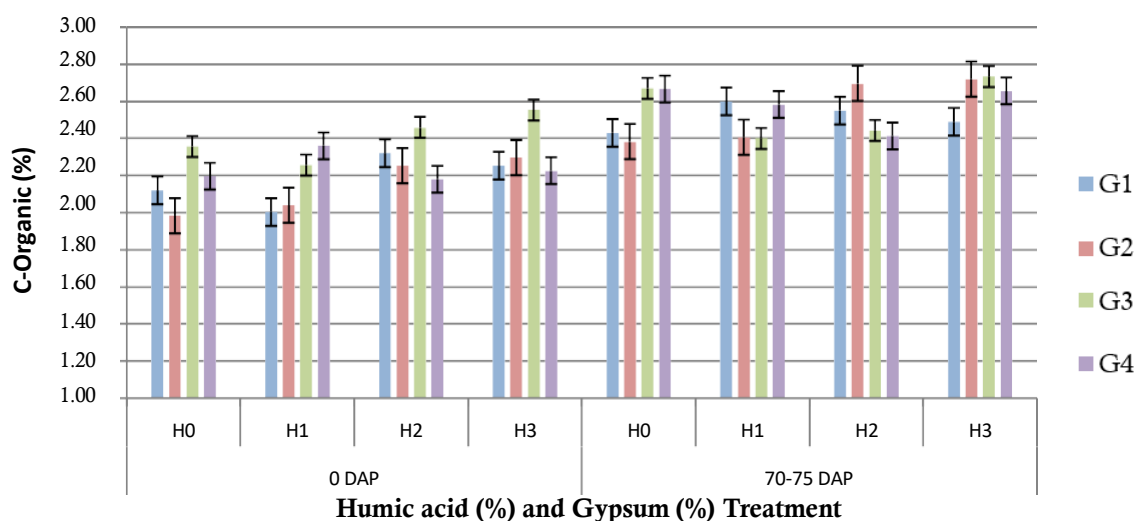


Figure 2. Relationship of Average Soil Organic Carbon Content in Mangrove Soil Treated with Humic Acid and Gypsum at 0 Days After Planting (DAP) and 70–75 Days After Planting

The combination of humic acid and gypsum is capable of increasing soil organic carbon content, which is essential for sustainable fertility as well as maintaining soil and water quality within nutrient and biological cycles. This increase in organic carbon also plays a crucial role in improving soil physical properties and supporting plant productivity (Isrun et al., 2016), with significant results observed at the end of the growing period following the treatment.

Discussion of Treatment Effects on Nitrogen Availability and Tomato Yield

Based on the nitrogen analysis results shown in Figure 3, the treatment combining humic acid and gypsum exhibited a significant difference. At 70–75 Days After Planting (DAP), the treatment with doses H3 (0.124 g) and G3 (18.75 g) produced a nitrogen content of 0.37%. This nitrogen level is considered moderate, indicating that the soil still responds positively to nitrogen fertilization.

A higher dosage of humic acid can reduce nitrogen volatilization by binding it in ligand complexes. This allows for controlled release of nutrients and improves the overall availability of nitrogen in the soil (Lubis et al., 2022). Gypsum also plays a natural role in reducing nitrogen loss, improving compost aeration, and providing essential elements like calcium (Ca) and sulfur (S) crucial for plant growth.

The combination of humic acid and gypsum at the end of the growth period demonstrated a significant synergistic effect on nitrogen availability and overall soil quality (Saputra et al., 2020). This increased nitrogen availability has a direct correlation with enhanced tomato productivity. Nitrogen is a primary macronutrient essential for vegetative growth, chlorophyll formation, and photosynthesis. Optimal nitrogen availability allows plants to develop a strong leaf and stem structure, which ultimately supports the formation of a greater number of larger fruits. The link between high nitrogen uptake and increased tomato yield has been confirmed in various studies (Abayomi et al., 2018). Therefore, the synergistic effect of humic acid and gypsum in boosting nitrogen availability is a key factor behind the significant increase in tomato fruit yield observed in this research.

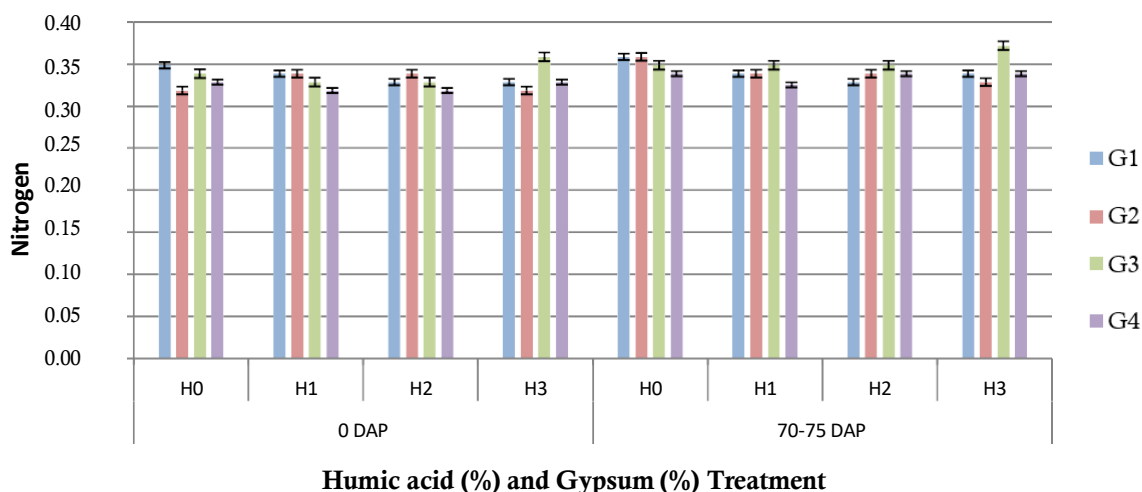


Figure 3. Relationship of Average Available Soil Nitrogen in Mangrove Soil Treated with Humic Acid and Gypsum at 0 Days After Planting (DAP) and 70–75 Days After Planting

Impact of Treatments on Phosphorus Availability

At 0 days after planting (DAP), the combined application of humic acid and gypsum resulted in a phosphorus (P) content of 13.46 ppm for the H3G3 treatment (H3: 0.124 g and G3: 18.75 g). This value showed only a slight increase to 13.55 ppm at 70-75 DAP for the same treatment (Figure 4). While phosphorus is an essential

macronutrient for plants, improving its availability is a major challenge in soil management, especially in saline soils like those found in mangrove ecosystems.

This minimal increase can be attributed to the complex mechanism of phosphorus fixation. In neutral to alkaline soils, phosphate ions tend to bind strongly with cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and other metal ions. This process forms insoluble compounds that are unavailable for plant uptake (Havlin et al., 2014).

Although humic acid and gypsum are known to help mobilize nutrients, the strong fixation process in this soil type limited their effectiveness. Humic acid can chelate metal ions, which reduces phosphorus fixation and increases its availability (Maynard et al., 2020). Gypsum, on the other hand, provides calcium ions that can replace sodium on soil colloids, which indirectly affects phosphorus dynamics. However, some studies also show that high calcium content can contribute to the precipitation of phosphates (Ghassemi et al., 2020), which means the positive and negative effects may have counterbalanced each other. The minimal increase observed in this study suggests that while the treatment did partially counter phosphorus fixation, the soil's natural chemical processes remained dominant.

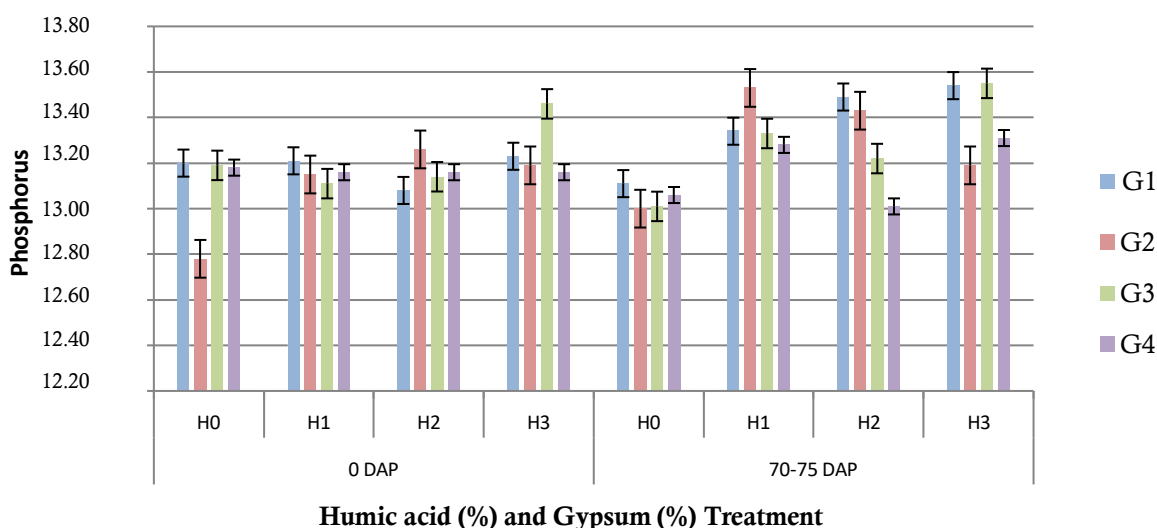


Figure 4. Relationship of Average Available Soil Phosphorus in Mangrove Soil Treated with Humic Acid and Gypsum at 0 Days After Planting (DAP) and 70–75 Days After Planting

Increased gypsum application can reduce erosion and runoff by improving the soil's water infiltration capacity, while also decreasing Al^{3+} toxicity, thereby enhancing phosphorus availability (Suswati, 2012). Humic acid also plays a role in phosphorus fixation and its release from aluminum adsorption, which positively impacts root development (Lisdiyanti et al., 2018). At the end of the growing period, the combined application of humic acid and gypsum showed a significant increase in phosphorus availability and plant growth.

Fruit Count

The research findings demonstrate that the combination of humic acid and gypsum significantly increased the number of tomatoes per plant. The highest average fruit count was observed in the H3G3 (H3: 0.124 g and G3: 18.75 g) and H3G4 (H3: 0.124 g and G4: 25 g) treatments, with both producing an average of 14.33 fruits per plant.

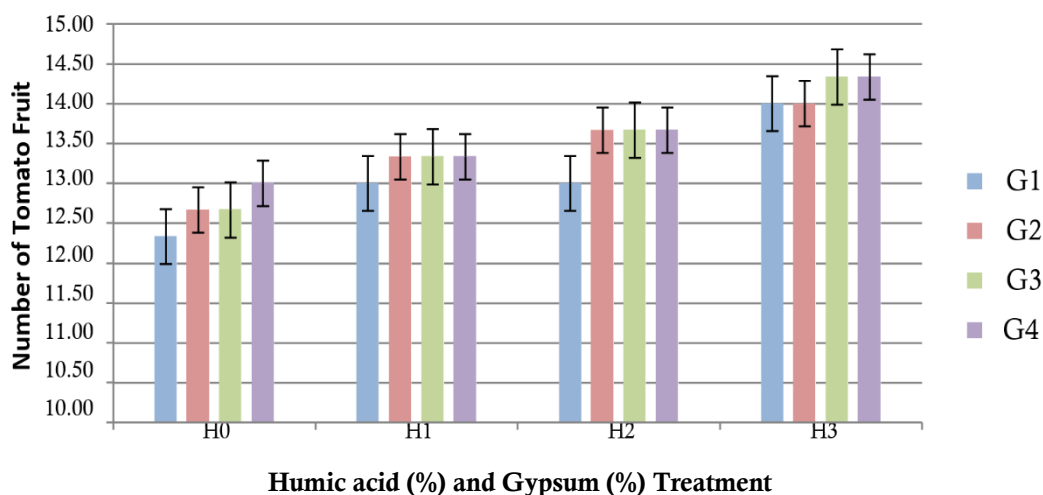


Figure 5. Relationship of Average Tomato Fruit Count in Mangrove Soil Treated with Humic Acid and Gypsum at 70–75 Days After Planting

These results highlight the synergistic effectiveness of optimal humic acid and gypsum dosages in boosting tomato productivity in saline soil (El-Ghamry et al., 2013). The statistical analysis (ANOVA) showed that while treatments H3G3 and H3G4 did not differ significantly from each other, they were both significantly superior to the control and other dosage combinations. This indicates that the humic acid dosage of 0.124 g reached an optimal point in improving soil conditions. The addition of gypsum from 18.75 g (G3) to 25 g (G4) no longer provided a significant additional benefit to the fruit count, suggesting that a saturation point or maximum yield had been reached.

This increase in yield can be attributed to crucial soil improvements. Humic acid, especially at the highest dosage (H3), effectively increased the availability of essential nutrients and improved the soil structure (Jindo et al., 2012). Simultaneously, gypsum served a dual function: it reduced soil salinity and provided the necessary calcium for fruit development. This combination created a healthy root environment, allowing for optimal nutrient and water uptake, which is vital for fruit formation.

Our findings are consistent with relevant literature. A study by Ahmad et al. (2015) showed that applying organic materials, including humic acid, significantly increased the biomass and yield of crops cultivated in degraded land. Similarly, research by Badr et al., (2010) Our study found that the use of gypsum was able to increase tomato yield by reducing salinity stress. Our data strengthens both of these findings, demonstrating that the synergistic effect of

combining both materials can surpass their individual effects in overcoming the unique challenges of mangrove soil, leading to a maximal fruit count.

The application of humic acid can increase soil organic carbon content, while gypsum helps improve phosphorus (P) uptake, which is essential for root growth, flowering, and fruit formation, thereby enhancing crop yield (Mukarromah et al., 2024). Suboptimal temperatures can disrupt the fruit-setting process in tomatoes by causing flower and leaf drop as an adaptive response, resulting in reduced fruit quantity and quality (Alawiyah et al., 2021). Furthermore, vitamin C content in tomatoes is influenced by climatic factors and temperature during both the growth and postharvest phases, making temperature a key determinant of fruit nutritional quality (Saputra et al., 2020).

Analysis of variance on vitamin C content in tomatoes showed that the combination treatment of humic acid and gypsum did not produce significant differences. However, treatment H3G4 yielded the highest average vitamin C content in fresh young tomatoes, at 37.84 %. The high vitamin C level is likely due to fruit maturity, as vitamin C content tends to increase with ripening.

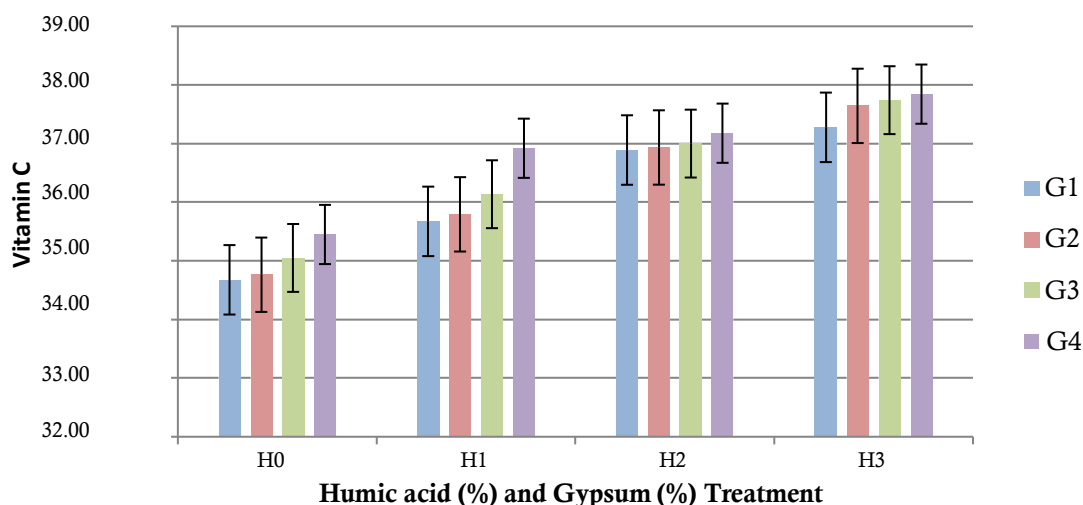


Figure 6. Relationship of Average Vitamin C Content in Tomato Plants Grown on Mangrove Soil Treated with Humic Acid and Gypsum at 70–75 Day After Planting

Observations showed that the vitamin C content of the Servo F1 tomato variety is classified as moderate, likely influenced by planting time and fruit maturity, with harvests at 66, 73, and 75 Days After Planting (DAP) producing optimal vitamin C levels (Amar, 2016). Climatic and environmental conditions, such as planting at the end of the rainy season, harvesting at the beginning of the dry season, and adequate sunlight exposure, also significantly affect the vitamin C content in tomato fruits (Imiliyana, 2020).

CONCLUSION

The combined application of humic acid and gypsum significantly improved the conditions of saline mangrove soil by reducing salinity and increasing the

availability of essential macronutrients, particularly nitrogen and phosphorus. This combination works synergistically in tomato cultivation: humic acid enhances the soil's capacity to retain and absorb nutrients, while gypsum provides calcium and sulfur and effectively mitigates soil salinity issues. The research findings indicate that the combined dosages of H3G3 (0.124 g humic acid and 18.75 g gypsum) and H3G4 (0.124 g humic acid and 25 g gypsum) were the most optimal. These treatments significantly increased the number of tomato fruits, reaching an average of 14.33 fruits per plant. Furthermore, the H3 humic acid treatment alone was found to produce the highest Vitamin C content in the tomatoes, at 37.84%.

From a practical perspective, the H3G3 combination is the most recommended dosage, as it provides comparable results to H3G4 with a more efficient use of gypsum. This study contributes to the body of scientific knowledge by providing empirical evidence that the synergistic effect of humic acid and gypsum can serve as an effective and sustainable remediation strategy for coastal lands. Ultimately, this approach offers a viable solution for converting unproductive land into viable agricultural areas.

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How To Cite This Article, with *APA style* :

Bahiro., B., Mindari, W., & Arifin, M. (2025). Application of Humic Acid and Gypsum Enhances Soil Nutrient Availability and Tomato (*Solanum lycopersicum*) Yield in Mangrove-Derived Saline Soils. *Jurnal Pembelajaran dan Biologi Nukleus*, 11(3), 940-955. <https://doi.org/10.36987/jpbn.v11i3.7671>

Conflict of interest : The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions : All authors contributed to the study's conception and design. Material preparation, data collection and analysis were performed by all authors. The first draft of the manuscript was submitted by [Badriyatul Bahiro]. All authors contributed on previous version and revisions process of the manuscript. All authors read and approved the final manuscript.