Growth and Yield Response of Soybean (*Glycine max* (L.) Merril) to Application of Water Hyacinth Compost (*Eichornia crassipes*) and SP-36 Fertilizer in Ultisols

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ABSTRACT

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| Fertilization is one of the key factors in soybean cultivation to increase growth and yield, particularly when using organic materials such as compost and inorganic fertilizers like SP-36. The study aimed 1) to evaluate the combined effect of compost and SP-36 fertilizer on soybean growth and yield, 2) determine the optimal compost dosage for improving soybean growth and yield, 3) identify the most effective SP-36 fertilizer dosage for enhancing soybean growth and yields. This research was conducted from October 2024 to February 2025 in Bentiring Permai, Bengkulu City, Indonesia at an altitude of 24.7 m above sea level. The experiment used a Randomized Complete Block Design (RCBD) with three replications and two factors: water hyacinth compost and SP-36 fertilizer, each applied at four levels. The first factor was the dose of water hyacinth compost (K), with levels as follows 0,15, 30, and 45 tons/ha. The second factor was the SP-36 fertilizer dose, with the following levels: 0, 70, 140 and 210 kg/ha. The study demonstrated that water hyacinth compost significantly influenced several growth and yield variables of soybean. The optimal dose was found to be 45 tons/ha, which had a notable positive effect on plant height, number of leaves, number of branches, number of filled pods, seed weight per plant, plant dry weight, and root dry weight. In contrast, the application of SP-36 fertilizer did not significantly affect any of the observed variables. These findings provide a valuable basis for recommending the use of water hyacinth compost at a dose of 45 tons/ha to enhance soybean growth and yield on acidic Ultisols. |

*Keywords: Organic fertilizer, Soybeans, SP-36 Fertilizer, Ultisol, Water Hyacinth Compost*

1. INTRODUCTION

Soybean (*Glycine max* L. Merril) is a vital legume crop widely used in East Asian foods like tofu, tempeh, and soy sauce. It serves as a primary source of high-quality plant-based protein and oil, containing essential amino acids beneficial for human health (Jidani, 2011). Soybean seeds are nutritionally rich, providing protein, fats, vitamins, and minerals such as phytic acid, making them an affordable and accessible nutrient source (Li and Qi, 2022).

Bengkulu Province, Indonesia, is predominantly characterized by acidic Ultisols, which account for approximately 89.87% of its suboptimal agricultural land (Sarwani, 2013). This prevalence underscores Ultisol as the dominant soil type in the region. Given its inherent constraints—including low pH, poor nutrient availability, and high aluminum toxicity—targeted soil management strategies are essential to enhance fertility and support optimal crop productivity (Purwanto et al., 2021). Effective interventions, such as organic amendments and lime application, are critical to mitigate these limitations and maximize agricultural yields on Ultisols (Ayodele and Shittu, 2014; Dejene et al., 2023).

Ultisols are highly weathered, acidic mineral soils characterized by reddish-yellow to dark red coloration, clayey texture, and poor fertility (Sanchez, 2019). These soils exhibit a pH below 5, low cation exchange capacity (CEC), and base saturation, along with high aluminum toxicity and low organic carbon content (Brady et al., 2008). A critical limitation is phosphorus (P) fixation due to binding with iron oxides and kaolinite, rendering P unavailable to plants (Wang et al., 2015). Consequently, aluminum toxicity and phosphorus deficiency represent the primary constraints for crop production in Ultisols (Siregar & Nugroho, 2021; He et al., 2011).

Fertilizers are categorized into organic and inorganic types based on their origin and nutrient composition (Rashmi et al., 2020). Organic fertilizers, derived from natural sources like animal manure, compost, and plant residues, enhance soil structure and microbial activity while slowly releasing nutrients (Singh et al., 2020). In contrast, inorganic fertilizers such as urea (N), SP-36 (P), and KCl (K) are industrially produced for rapid nutrient availability (Hera, 1995). While inorganic fertilizers boost immediate plant growth, excessive use can degrade soil quality and cause environmental pollution (Jote, 2023). Sustainable practices combining both fertilizer types are recommended for optimal crop production and soil health maintenance (Sharma and Chetani, 2017; Chejara et al., 2021). Organic manures, such as farmyard manure (FYM), vermicompost, and poultry manure, play a vital role in improving various aspects of soil health (Dotaniya et al., 2020). The organic inputs enhance soil physical properties (Khandagle et al., 2019a), chemical properties (Khandagle et al., 2019b), and biological properties (Yashona et al., 2018). Further, the regular application of organic manures helps increase soil organic carbon content (Aher et al., 2019). The enhanced organic carbon acts as a habitat for variety of microbes and enhances the spore life of the beneficial microbes in adverse conditions which is crucial for long-term soil fertility and climate resilience (Argal et al., 2015). The release of nutrients from the mineralization of added organics enhances yield and nutrient uptake of the crops (Mandale et al., 2019). These improvements in soil properties contribute significantly to support sustainable agriculture production. Besides improvement in soil properties and crop yield, the organic inputs also known for enhancing the nutritional properties of the crop produce (Aher et al., 2018; Yashona et al., 2018).

SP-36 is a water-soluble phosphorus (P) fertilizer that rapidly supplies P to plants, addressing P deficiency in agricultural soils (Samreen and Kausar, 2019; Bindraban et al., 2020). However, its high solubility increases the risk of P fixation by aluminum (Al) and iron (Fe) in acidic soils, reducing its availability to plants and decreasing fertilizer efficiency (Wang et al., 2021). Recent studies suggest combining SP-36 with organic amendments to mitigate P fixation and improve long-term soil P availability (Chen et al., 2021; Hu et al., 2023).

Phosphorus application, through both organic and inorganic (SP-36) fertilizers, significantly improves soybean yield by enhancing seed mass (Ngui et al., 2024; Wu et al., 2024). Organic fertilizers release humic acids during decomposition, which chelate aluminum (Al) and iron (Fe), thereby increasing phosphorus (P) availability in soils (Xiong et al., 2023).

Compost is decomposed organic matter (leaves, straw, grass, crop residues, manure) that enhances soil quality by providing essential plant nutrients (Brichi et al., 2023; Kassa et al., 2025). Water hyacinth, a fast-growing weed, demonstrates remarkable productivity, water hyacinth to produce biochar, high-quality bio-fertilizer, animal feed, and several other valuable products (Jha et al., 2024). When composted, it contains valuable nutrients, C-organic, total N, P, and K. Optimal application improves soil chemistry, increasing pH and nutrient availability (Begum et al., 2022). Precise dosing is crucial for maximizing plant growth and yield.

2. material and methods

2.1 Time, Location Site, And Research Design

This research was conducted from October 2024 to January 2025 in Bentiring Permai Bengkulu City at an altitude of 24.7 m above sea level.This study used a randomized complete block design (RCBD) with two factors. The first factor was the dose of water hyacinth compost (K) consisting of 4 levels, namely K0 =0 tons/ha, K1 = 15 tons/ha, K2 = 30 tons/ha, and K3 = 45 tons/ha. The second factor was the dose of SP-36 fertilizer (S) consisting of 4 levels S0 = 0 kg/ha, S1 = 10.5 70 kg/ha, S2 = 140 kg/ha, and S3 = 210 kg/ha.

**2.2 Compost Preparation**

The composting process of water hyacinth began by chopping it into small pieces measuring 0.5–2 cm using a machete. The chopped material was then stacked, with cow dung placed in the center of the pile to accelerate decomposition. The pile was moistened by evenly pouring 5 liters of a clean water and EM4 mixture, ensuring uniform moisture distribution through thorough mixing. The moistened material was then placed into large burlap sacks. Every three days, the contents were removed and stirred to accelerate the decomposition process. Once composting was complete, the compost was sieved using a 0.5 cm mesh to remove impurities. The finished compost was then filtered and weighed according to the treatment requirements for each experimental plot.

**2.3 Land Preparation**

Land preparation began with manually clearing the area of weeds and plant debris using tools such as hoes, sickles, and machetes. Once the land was cleared, plot marking was carried out using a hoe, with each plot measuring 1.5 m x 0.6 m (length x width).

**2.4 Planting**

Planting was carried out in the morning by placing 2–3 soybean seeds into holes 2–3 cm deep with the plant spacing of 20 cm x 30 cm. Furadan was applied to each planting hole to protect the seeds from ants and other soil-dwelling insects, after which the holes was covered with soil.

**2.5 Harvesting**

Soybean was harvested when most of the stems and pods turn brownish-yellow, and the leaves had yellowed and begun to fall. Harvesting was done by pulling the entire plant from the ground, removing any remaining soil, and collecting the plants for further analysis.

**2.6 Observed Variables**

In this study, several variables were observed, including plant height (cm), number of leaves, number of branches, days to flowering, days to harvest, shoot fresh weight (g), roots fresh weight (g), shoot dry weight (g), roots dry weight (g), number of filled pods, number of empty pods, seed weight per plant (g), and weight of 100 seeds (g)

**2.7 Data Analysis**

The collected data was statistically analyzed using Analysis of Variance (ANOVA) with an F-test at the 5% significance level. Variables showing a significant effect was further analyzed using the Orthogonal Polynomial.

3. results and discussion

**3.1 Soybean Plant Growth Pattern**

**3.1.1 Plant Height**

*Water hyacinth compost (K); K0 = 0 tons/ha, K1 = 15 tons/ha, K2 = 30 tons/ha, K3 = 45 tons/ha. SP-36 (S); S0 = 0 kg/ha, S1 = 70 kg/ha, S2 = 140 kg/ha, S3 = 210 kg/ha.*

**Figure 1. Soybean plant height growth pattern 2-6 Weeks After Planting (WAP)**

The study demonstrated that soybean fertilized with a combination of water hyacinth compost and SP-36 fertilizer exhibited better growth compared to unfertilized plants. Specifically, the control (K0S0) had the lowest average plant height of 76 cm. In contrast, the treatment with the highest fertilizer dosage (K3S3) achieved an average height of 82 cm. This result indicates a positive linear growth trend, where increased fertilizer application correlates with enhanced plant height. Fertilizers, including SP-36 (a phosphate-based fertilizer), supply essential macronutrients such as phosphorus (P), which is critical for root development, energy transfer (ATP), and photosynthesis (Schachtman et al., 1998). Water hyacinth compost also contributes organic matter and micronutrients, improving soil structure and nutrient retention (Ndimele et al., 2011). The linear increase in plant height with higher fertilizer doses aligns with the Law of the Minimum (Liebig’s Law), which states that plant growth is limited by the scarcest resource (van der Ploeg et al., 1999). Adequate phosphorus (from SP-36 and compost) likely reduced growth-limiting factors. Excessive fertilization can lead to diminishing returns or toxicity, but within the tested range (up to K3S3), the dose-response relationship remained positive, suggesting that the applied levels were within the optimal nutrient range. The findings implies that balanced fertilization enhances soybean growth, emphasizing the importance of integrated nutrient management combining organic (compost) and inorganic (SP-36) sources for sustainable agriculture.

**3.2 Analysis Of Variance**

The results of the ANOVA showed that there was no interaction between compost and SP-36 fertilizer on all observed variables. Compost treatment affected the variables of plant height, number of leaves, number of branches, shoot dry weight, roots dry weight, number of filled pods, and seed weight per plant. SP-36 fertilizer treatment did not have a significant effect on all observed variables (Table 1). The variables that had an effect were further tested using Orthogonal Polynomials.

**Table 1. Sumarry of Analysis of Variance**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Observed Variables | Treatments | | |  |
| Compost | SP-36 | Interaction | CV(%) |
| (K) | (S) | (K x S) |  |
| Plant Height 6 WAP | 18.00 \*\* | 1.81 ns | 0.71 ns | 3.08 |
| Number of Leaves | 6.89 \*\* | 2.43 ns | 1.37 ns | 8.58 |
| Number of Branches | 13.66 \*\* | 0.76 ns | 0.51 ns | 10.89 |
| Flowering Time | 0.41 ns | 9.21 ns | 0.37 ns | 5.56 |
| Harvest Time | 1.17 ns | 2.19 ns | 0.50 ns | 2.71 |
| Shoot Fresh Weight | 1.11 ns | 1.19 ns | 0.40 ns | 9.43 |
| Root Fresh Weight T | 1.97 ns | 0.65 ns | 1.02 ns | 14.81 t |
| Shoot Dry Weight | 4.17 \* | 0.22 ns | 1.16 ns | 12.41 |
| Root Dry Weight T | 3.62 \* | 0.34 ns | 1.56 ns | 14.47 t |
| Number of Filled Pods | 16.61 \*\* | 0.41 ns | 57.79 ns | 16.00 |
| Number of Empty Pods | 1.32 ns | 0.42 ns | 1.10 ns | 23.31 |
| Seed Weight per Plant | 11.43 \*\* | 2.67 ns | 2.28 ns | 24.25 |
| Weight 100 Seeds | 1.96 ns | 0.46 ns | 1.61 ns | 16.16 |
| F-Table ( 5%) | 2.9 | 2.9 | 2.21 |  |

*CV = Coefficient Variation, \* = Significant Different (5%), \*\* = Highly Significant Different (1%), ns = No Significant Different (5%), T = Transformed Data.*

**3.3 Effect of Water Hyacinth Compost Dosage on Growth and Yield of**

**Soybean**

The results of the analysis of variance (ANOVA) of water hyacinth compost showed significant differences in soybean growth and yield component, including plant height, number of leaves, number of branches, shoot dry weight, roots dry weight, filled pods number and seed weight per plant.

A

B

C

**Figure 2. Relationship between water hyacinth compost dosage and Plant height (A),**

**Number of Leaves (B), Number of Branches (C)**

The significant linear regression (y = 0.0213x + 80.353; R² = 0.817) between water hyacinth compost dosage and plant height demonstrates a strong, predictable growth response. This dose-dependent improvement aligns with findings by Khoirya et al. (2025), who reported enhanced nutrient mineralization and auxin production from organic composts, directly stimulating cell elongation. The absence of a growth plateau suggests no nutrient saturation occurred within the tested range, consistent with Liebig's Law of the Minimum (van der Ploeg et al., 1999).

The ANOVA results further validate compost's significant effects on key growth parameters (plant height, leaves, branches, and biomass). These findings inline with that reported by Yuliana et al. (2025), where organic amendments improved soil physicochemical properties, facilitating sustained nutrient uptake. The high R² value (0.817) indicates that compost dosage is a dominant growth-limiting factor, supporting its use as a scalable organic fertilizer in sustainable agriculture.

A

B

**Figure 3. Relationship between water hyacinth compost and Plant Dry Weight**

**(A), Root Dry Weight (B)**

The regression analysis revealed contrasting relationships between water hyacinth compost dosage and plant growth parameters. For plant dry weight (Figure 3A), the weak correlation (y = 0.0017x + 4.4993; R² = -0.0193) indicates that compost application explained only 1.93% of the variability, suggesting minimal influence on shoot biomass accumulation. This result aligns with findings by Suci et al. (2025), who demonstrated that water hyacinth compost primarily enhances nutrient availability for root development rather than aerial biomass. In contrast, the strong linear relationship for root dry weight (Figure 3B: y = 0.0347x + 1.288; R² = 0.9514) implies that 95.14% of root biomass variation was attributable to compost dosage. This pronounced effect on roots from the compost's nutrient content and hormone-like substances (e.g., auxins) that preferentially stimulate root proliferation (Jindo et al., 2012). The differential response between organs reflects distinct nutrient partitioning strategies, where roots capitalize on compost-derived resources more efficiently than shoots.

Plants demonstrate distinct allocation patterns between roots and shoots, typically prioritizing root growth under nutrient-limited conditions to enhance resource acquisition (Poorter et al., 2012), a response potentially triggered by water hyacinth compost's rich soluble carbon compounds. This root-focused development is further amplified by compost-derived auxins and cytokinins that disproportionately stimulate root cell division and elongation (Arancon et al., 2004). The root absorption of immobile nutrients like phosphorus from compost limits their translocation to shoots (Richardson & Simpson, 2011), with typically <20% of acquired P being allocated aboveground (Wang et al., 2021) due to rapid immobilization in root tissues (Nziguheba & Smolders, 2008).

A

C

**Figure 4. Relationship between water hyacinth compost and the Number of**

**Filled Pods (A), Seed Weight/Plant (B)**

Water hyacinth compost application significantly enhanced plant productivity, as demonstrated by positive dose-response relationships for both pod formation (y = 0.2063x + 32.053; R² = 0.5071) and seed weight (y = 0.0156x + 1.577; R² = 0.6485). These regression models indicate that 50.71% and 64.85% of the variability in filled pod number and seed weight, respectively, can be attributed to compost dosage, suggesting its effectiveness as an organic amendment for improving yield components.

The K0S0 treatment exhibited limited soybean growth due to nutrient-deficient ultisol soil (total N: 0.31%; available P: 4.71%; pH: 4.63), consistent with findings that acidic, low-fertility soils inhibit plant development (Osman et al., 2018). In contrast, K3S3 treatment with water hyacinth compost (1.48% N, 1.25% P, 0.17% K) significantly improved growth parameters, aligning with Moe et al. (2019) report on its high macronutrient content on rice and soybean (Perkasa and Utomo, 2016). The nutrient content of water hyacinth compost was 28.75% organic-C, 1.75% total N, 16.43 C/N ratio, 0.54% P, 2.58% K as reported by Septiaswin et al. (2021). The compost's efficacy from its organic matter, enhances soil properties and nutrients through microbial decomposition (Bashir et al., 2021). Composting represents one of the earliest applications of effective microorganisms (EM) in environmental management. Plant and animal waste residues have been successfully composted using EM to produce biofertilizers (Aseel et al, 2024). As demonstrated by Zhou et al. (2020), such organic amendments increase water retention and ultimately crop yields (Agegnehu et al., 2016) while maintaining environmental sustainability.

Organic fertilizers enhance overall soil quality by improving nutrient availability, physicochemical properties, and microbial activity. They supply essential macro- and micronutrients while promoting soil structure, porosity, and water retention through organic matter decomposition. Water hyacinth compost, in particular, increases soil aeration and drainage due to its high organic content (Begum et al., 2022; Canning, 2025). These improvements in soil health directly support plant growth and productivity by enhancing root development and nutrient uptake efficiency.

**3.4 Effect of SP-36 Fertilizer Dosage on Soybean Plant Growth and Yield**

Table 2 Showed That Sp-36 Fertilization Did Not Significantly Influence Any Measured Soybean Growth And Yield Component (P > 0.05).

**Table 2. Effect of SP-36 fertilizer dose on soybean growth and yield component**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Growth component | | | | | | | |
| Dosage kg/ha | PH | LN | NB | FT | HT | SFW | SDW |
| 0 | 76 | 54 | 5 | 31 | 86 | 6.0 | 2.3 |
| 70 | 80 | 58 | 6 | 30 | 87 | 6.0 | 3.2 |
| 140 | 82 | 60 | 6 | 30 | 88 | 6.0 | 2.5 |
| 210 | 81 | 63 | 7 | 29 | 86 | 5.8 | 3.2 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Dosage (kg/ha) | Yield component | | | | | |
| RFW | RDW | FPN | EPN | SWPP | SW |
| 0 | 5.9 | 1.5 | 34 | 8 | 1.7 | 0.42 |
| 70 | 4.9 | 1.7 | 42 | 9 | 2.1 | 0.41 |
| 140 | 6.4 | 1.7 | 43 | 8 | 2.1 | 0.39 |
| 210 | 6.7 | 1.8 | 54 | 10 | 2.9 | 0.41 |

*PH = plant height (cm), LN = leaves number, NB = number of branches, FT = flowering time (days), HA = harvesting time (days), SFW = shoot fresh weight (g), SDW = shoot dry weight (g), RFW = root fresh weight (g), RDW = root dry weight (g), FPN = filled pod number, EPN = empty pod number, SWPP = seed weight per plant (g), SW= 100 seed weight (g)*

Table 2 indicates that plant height, number of leaves, number of branches, and flowering time exhibited only minor variations across different application rates. The tallest plants were observed at a dose of 140 kg/ha (82 cm), while the shortest were at 0 kg/ha (76 cm). However, these differences were not statistically significant. Similarly, the number of leaves and branches showed a slight increase with higher SP-36 doses, but the trend was inconsistent across treatments. Flowering occurred slightly earlier at the highest dose (210 kg/ha), at 29 days after planting, compared to 31 days in the control treatment. Nonetheless, this variation remained within the range of normal fluctuation and did not suggest a significant effect of phosphorus application.

The non significant differences among SP-36 fertilizer treatments can be attributed to phosphorus (P) immobilization phenomena in Ultisols. These soils are characterized by high aluminum (Al) and iron (Fe) content, which readily bind P to form plant-unavailable compounds (Kadir and Priatna, 2001; Ifansyah, 2014). Water hyacinth compost application may exacerbate P immobilization, as its phenolic and lignin compounds can form complexes with soil minerals, further reducing SP-36-derived P availability (Gashamura, 2009; Osoro et al., 2013). This mechanism explains the non-significant plant response to varying SP-36 doses despite fertilizer application.

Additionally, the decomposition process of water hyacinth compost can stimulate microbial activity that competes with plants for phosphorus (P) uptake. Soil microorganisms utilize P for their growth, which may lead to the fixation of P from SP-36 in microbial biomass before it becomes available for plant (Richardson & Simpson, 2011). A study by Salas et al. (2003) on Ultisols also reported that the addition of fresh organic matter could increase short-term P immobilization. Thus, the interaction between water hyacinth compost and SP-36 inhibits P release rather than enhancing its availability for plants.

Borggaard et al. (1990) found that soils with high iron (Fe) and aluminum (Al) oxide content tend to strongly bind phosphorus (P), particularly under low pH conditions. Water hyacinth compost alone may be insufficient to neutralize soil acidity or reduce P adsorption sites, resulting in a limited response to SP-36 fertilizer. This is supported by Qayyum et al. (2015), who demonstrated that organic amendments alone, without additional soil ameliorants (such as lime, biochar, and compost), are ineffective in enhancing P availability in acidic soils. The lack of a significant effect from SP-36 fertilizer is likely due to P immobilization caused by the interaction between water hyacinth compost and the chemical properties of Ultisols. To improve P fertilizer efficiency, alternative strategies—such as liming or phosphate-solubilizing biofertilizers—should be considered to reduce P fixation (Qayyum et al., 2015). These findings highlight the importance of an integrated approach in managing P in problematic soils like Ultisols.

4. Conclusion

The combined application of water hyacinth-derived compost and SP-36 phosphate fertilizer did not produce significant synergistic or antagonistic effects on the growth and yield of soybean. The 45 tons/ha water hyacinth compost dosage showed optimal performance, significantly enhancing growth and yield of soybean as indicated by plant height, leaves and branches number, shoot dry weight, pods number and seed weight. SP-36 fertilizer dosage showed no significant effect on soybean growth and yield components.

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References

Agegnehu, G., Nelson, P. N., & Bird, M. I. (2016). Crop yield, plant nutrient uptake, and soil physicochemical properties under organic soil amendments and nitrogen fertilization on Nitisols. Soil and Tillage Research, 160, 1–13.<https://doi.org/10.1016/j.still.2016.02.003>

Aher, S. B., Lakaria, B. L., Singh, A. B., & Kaleshananda, S. (2019). Soil aggregation and aggregate associated carbon in a Vertisol under conventional, organic and biodynamic agriculture in Semi-Arid Tropics of Central India. Journal of the Indian Society of Soil Science, 67(2), 183-191.

Aher, S. B., Lakaria, B. L., Singh, A. B., Kaleshananda, S., & Yashona, D. S. (2018). Nutritional quality of soybean and wheat under organic, biodynamic and conventional agriculture in semi-arid tropical conditions of Central India. Indian Journal of Agricultural Biochemistry, 31(2), 128-136.

Arancon, N. Q., Edwards, C. A., Bierman, P., Welch, C., & Metzger, J. D. (2004). Influences of vermicomposts on field strawberries: 1. Effects on growth and yields. Bioresource Technology, 93(2), 145-153. <https://doi.org/10.1016/j.biortech.2003.10.014>

Argal, M. S., Rawat, A. K., Aher, S. B., & Rajput, P. S. (2015). Bioefficacy and shelf life of Rhizobium leguminosarum loaded on different carriers. Applied Biological Research, 17(2), 1-7.

Aseel, N. A., Hassan, F. M., & Hyder, N. H. (2024). Evaluation of microbial activity in organic solid fraction during composting process to biofertilizer using composting bin methods. Iraqi Journal of Agricultural Sciences, 55(6), 1927–1935.

Ayodele, O. J., & Shittu, O. S. (2014). Fertilizer, lime, and manure amendments for ultisols formed on coastal plain sands of southern Nigeria. Agriculture, Forestry and Fisheries, 3(6), 481-488.

Bashir, O., Ali, T., Baba, Z. A., Rather, G. H., Bangroo, S. A., Mukhtar, S. D., ... & Bhat, R. A. (2021). Soil organic matter and its impact on soil properties and nutrient status. In Microbiota and biofertilizers, Vol 2: Ecofriendly Tools for Reclamation of Degraded Soil Environs (pp. 129–159). Springer.

Begum, S. L., Himaya, S. M. M. S., & Afreen, S. M. M. S. (2022). Potential of water hyacinth (*Eichhornia crassipes*) as compost and its effect on soil and plant properties: A review. Agricultural Reviews, 43(1), 20-28.

Bindraban, P. S., Dimkpa, C. O., & Pandey, R. (2020). Exploring phosphorus fertilizers and fertilization strategies for improved human and environmental health. Biology and Fertility of Soils, 56(3), 299-317.

Borggaard, O. K., Jørgensen, S. S., Moberg, J. P., & Raben-Lange, B. (1990). Influence of organic matter on phosphate adsorption by aluminium and iron oxides in sandy soils. Journal of Soil Science, 41(3), 443-449.

Brady, N. C., Weil, R. R., & Weil, R. R. (2008). The nature and properties of soils (Vol. 13, pp. 662-710). Upper Saddle River, NJ: Prentice Hall.

Brichi, L., Fernandes, J. V., Silva, B. M., Vizú, J. D. F., Junior, J. N., & Cherubin, M. R. (2023). Organic residues and their impact on soil health, crop production and sustainable agriculture: A review including bibliographic analysis. Soil Use and Management, 39(2), 686-706.

Canning, A. (2025). A review on harnessing the invasive water hyacinth (*Eichhornia crassipes*) for use as an agricultural soil amendment. Land, 14(5), 1116.

Chejara, S., Malik, K., Rani, M., & Bhardwaj, A. K. (2021). Integrated nutrient management: Concept, constraints, and advantages for a sustainable agriculture. Journal of Natural Resource Conservation and Management, 2(2), 85-94.

Chen, M., Zhang, S., Liu, L., Wu, L., & Ding, X. (2021). Combined organic amendments and mineral fertilizer application increase rice yield by improving soil structure, P availability and root growth in saline-alkaline soil. Soil and Tillage Research, 212, 105060.

Dejene, D., Yitbarek, T., & Jembere, A. (2023). Determination of lime requirement with compost on acidic ultisols for wheat crop in the Gurage zone of Ethiopia. Applied and Environmental Soil Science, 2023(1), 4307448.

Dotaniya, C. K., Yashona, D. S., Aher, S. B., Rajput, P. S., Doutaniya, R. K., Lata, M., & Mohbe, S. (2020). Crop performance and soil properties under organic nutrient management. International Journal of Current Microbiology and Applied Sciences, 9(4), 1055-1065.

Gashamura, F. R. (2009). Effects of manure from water hyacinth on soil fertility and maize performance under controlled conditions in Rwanda. African Journal of Agricultural Research, 4(11), 1259–1266.

He, G., Zhang, J., Hu, X., & Wu, J. (2011). Effect of aluminum toxicity and phosphorus deficiency on the growth and photosynthesis of oil tea (*Camellia oleifera* Abel.) seedlings in acidic red soils. Acta Physiologiae Plantarum, 33, 1285-1292.

Hera, C. (1995). The role of inorganic fertilizers and their management practices. Fertilizer research, 43, 63-81.

Hu, W., Zhang, Y., Xiangmin, R., Fei, J., Peng, J., & Luo, G. (2023). Coupling amendment of biochar and organic fertilizers increases maize yield and phosphorus uptake by regulating soil phosphatase activity and phosphorus-acquiring microbiota. Agriculture, Ecosystems & Environment, 355, 108582.

Ifansyah, H. (2014). Soil pH and solubility of aluminum, iron, and phosphorus in Ultisols: The roles of humic acid. Journal of Tropical Soils, 18(3), 203–208. https://doi.org/10.5400/jts.2013.18.3.203

Jha, K., Wu, B., Aziz, S. Q., Ahmed, H. G., & Ahmed, M. S. (2024). Sustainable solutions for water hyacinth invasion: Characteristics, impacts, control, and utilization. World Journal of Advanced Engineering Technology and Sciences, 12(1), 047-058.

Jindo, K., Martim, S. A., Navarro, E. C., Pérez-Alfocea, F., Hernandez, T., Garcia, C., ... & Canellas, L. P. (2012). Root growth promotion by humic acids from composted and non-composted urban organic wastes. Plant and Soil, 353, 209-220. https://doi.org/10.1007/s11104-011-1024-3

Jote, C. A. (2023). The impacts of using inorganic chemical fertilizers on the environment and human health. Org. Med. Chem. Int. J, 13, 555864.

Kadir, S., & Priatna, S. J. (2001). Characteristics of Ultisols under different wildfire history in South Sumatra, Indonesia: I. Physico-chemical properties. Tropics, 10(4), 565–580. https://doi.org/10.3759/tropics.10.565

Kassa, Y., Amare, A., Nega, T., Alem, T., Gedefaw, M., Chala, B., ... & Tibebe, D. (2025). Water hyacinth conversion to biochar for soil nutrient enhancement in improving agricultural product. Scientific Reports, 15(1), 1820.

Khandagle, A., Dwivedi, B. S., Aher, S. B., Dwivedi, A. K., Yashona, D. S., & Jat, D. (2019a). Effect of long-term application of fertilizers and manure on soil properties. Journal of Soils and Crops, 29(1), 97-104.

Khandagle, A., Dwivedi, B. S., Aher, S. B., Dwivedi, A. K., Yashona, D. S., Mohbe, S., & Panwar, S. (2019b). Distribution of nitrogen fractions under long term fertilizer and manure application in a vertisol. Bioscience Biotechnology Research Communications, 12(1), 186-193.

Li, Y., & Qi, B. (Eds.). (2022). Phytochemicals in Soybeans: Bioactivity and Health Benefits. CRC Press.

Mandale, P., Lakaria, B. L., Aher, S. B., Singh, A. B., & Gupta, S. C. (2019). Phosphorous concentration and uptake in maize varieties cultivated under organic nutrient management. International Journal of Agricultural & Statistical Sciences, 15(1), 311-315.

Moe, K., Htwe, A. Z., Thu, T. T. P., Kajihara, Y., & Yamakawa, T. (2019). Effects on NPK status, growth, dry matter and yield of rice (*Oryza sativa*) by organic fertilizers applied in field condition. Agriculture, 9(5), 109. https://doi.org/10.3390/agriculture9050109

Ndimele, P. E., Kumolu-Johnson, C. A., & Anetekhai, M. A. (2011). The invasive aquatic macrophyte, water hyacinth (*Eichhornia crassipes* [Mart.] Solms-Laubach: Pontederiaceae): Problems and prospects. Research Journal of Environmental Sciences, 5(6), 509-520.

Ngui, M. E., Lin, Y. H., Wei, I. L., Wang, C. C., Xu, Y. Z., & Lin, Y. H. (2024). Effects of the combination of biochar and organic fertilizer on soil properties and agronomic attributes of soybean (*Glycine max* L.). Plos one, 19(9), e0310221.

Nziguheba, G., & j.scitotenv.2007.09.031Smolders, E. (2008). Inputs of trace elements in agricultural soils via phosphate fertilizers in European countries. Science of the Total Environment, 390(1), 53-57. https://doi.org/10.1016/

Osman, K. T. (2018). Acid soils and acid sulfate soils. In Management of soil problems (pp. 283–306). Springer. https://doi.org/10.1007/978-3-319-75527-4\_11

Osoro, N., Muoma, J. O., Amoding, A., Mukaminega, D., Muthini, M., Ombori, O., & Maingi, J. M. (2013). Effects of water hyacinth (*Eichhornia crassipes* [Mart.] Solms) compost on growth and yield parameters of maize (*Zea mays*). Journal of Agricultural Science and Technology, 3(3), 193–201.

Perkasa, A. Y., & Utomo, T. W. (2016). Effect of various levels of NPK fertilizer on the yield attributes of soybean (*Glycine max* L.) varieties. Journal of Tropical Crop Science, 3(1), 1–8.

Poorter, H., Niklas, K. J., Reich, P. B., Oleksyn, J., Poot, P., & Mommer, L. (2012). Biomass allocation to leaves, stems and roots: Meta-analyses of interspecific variation and environmental control. New Phytologist, 193(1), 30-50. <https://doi.org/10.1111/j.1469-8137.2011.03952.x>

Purwanto, S., Gani, R. A., & Suryani, E. (2021). Characteristics of Ultisols derived from basaltic andesite materials and their association with old volcanic landforms in Indonesia. SAINS TANAH-Journal of Soil Science and Agroclimatology, 17(2), 135-143.

Qayyum, M. F., Ashraf, I., Abid, M., & Steffens, D. (2015). Effect of biochar, lime, and compost application on phosphorus adsorption in a Ferralsol. Journal of Plant Nutrition and Soil Science, 178(4), 576-581.

Rashmi, I., Roy, T., Kartika, K. S., Pal, R., Coumar, V., Kala, S., & Shinoji, K. C. (2020). Organic and inorganic fertilizer contaminants in agriculture: Impact on soil and water resources. Contaminants in Agriculture: Sources, Impacts and Management, 3-41.

Richardson, A. E., & Simpson, R. J. (2011). Soil microorganisms mediating phosphorus availability: Update on microbial phosphorus. Plant Physiology, 156(3), 989-996. <https://doi.org/10.1104/pp.111.175448>

Richardson, A. E., & Simpson, R. J. (2011). Soil microorganisms mediating phosphorus availability: Update on microbial phosphorus. Plant Physiology, 156(3), 989–996.

Salas, A. M., Elliott, E. T., Westfall, D. G., Cole, C. V., & Six, J. (2003). The role of particulate organic matter in phosphorus cycling. Soil Science Society of America Journal, 67(1), 181–189.

Samreen, S., & Kausar, S. (2019). Phosphorus Fertilizer: The Original and Commercial. Phosphorus: Recovery and Recycling, 81.

Sanchez, P. A. (2019). Properties and Management of Soils in the Tropics. Cambridge University Press.

Sarwani, M. (2013). Characteristics and management of Ultisols for agricultural development in Indonesia. Journal of Tropical Soils, 18(1), 1-10…cek Faidah

Schachtman, D. P., Reid, R. J., & Ayling, S. M. (1998). Phosphorus uptake by plants: From soil to cell. Plant Physiology, 116(2), 447-453. <https://doi.org/10.1104/pp.116.2.447>

Septiaswin, H., Fuskhah, E., & Budiyanto, S. (2021). Growth and production of soybean (*Glycine max* L.) due to watering frequency and various compositions of cow manure and water hyacinth compost. Buana Sains, 21(1), 77–86.

Sharma, A., & Chetani, R. (2017). A review on the effect of organic and chemical fertilizers on plants. Int. J. Res. Appl. Sci. Eng. Technol, 5(2), 677-680.

Singh, T. B., Ali, A., Prasad, M., Yadav, A., Shrivastav, P., Goyal, D., & Dantu, P. K. (2020). Role of organic fertilizers in improving soil fertility. Contaminants in agriculture: sources, impacts and management, 61-77.

van der Ploeg, R. R., Böhm, W., & Kirkham, M. B. (1999). On the origin of the theory of mineral nutrition of plants and the Law of the Minimum. Soil Science Society of America Journal, 63(5), 1055-1062. <https://doi.org/10.2136/sssaj1999.6351055x>

Wang, Q., Liao, Z., Yao, D., Yang, Z., Wu, Y., & Tang, C. (2021). Phosphorus immobilization in water and sediment using iron-based materials: a review. Science of the Total Environment, 767, 144246.

Wang, Y. L., Gao, Z., Wang, Y., Zhang, Y. H., Zhuang, X. Y., & Zhang, H. (2015). Phosphorus availability and transformation as affected by repeated phosphorus additions in an Ultisol. Communications in Soil Science and Plant Analysis, 46(15), 1922-1933.

Wang, Y., Krogstad, T., Clarke, J. L., Hallama, M., Øgaard, A. F., Eich-Greatorex, S., ... & Clarke, N. (2016). Rhizosphere organic anions play a minor role in improving crop species' ability to take up residual phosphorus (P) in agricultural soils low in P availability. Frontiers in Plant Science, 7, 1664. <https://doi.org/10.3389/fpls.2016.01664>

Wu, Z., Chen, X., Lu, X., Zhu, Y., Han, X., Yan, J., ... & Zou, W. (2024). Impact of combined organic amendments and chemical fertilizers on soil microbial limitations, soil quality, and soybean yield. Plant and Soil, 1-18.

Xiong, Q., Wang, S., Lu, X., Xu, Y., Zhang, L., Chen, X., ... & Ye, X. (2023). The effective combination of humic acid phosphate fertilizer regulating the form transformation of phosphorus and the chemical and microbial mechanism of its phosphorus availability. Agronomy, 13(6), 1581.

Yashona, D. S., Mishra, U. S., & Aher, S. B. (2018). Response of pigeonpea (Cajanus cajan) to sole and combined modes of zinc fertilization. Journal of Pharmacognosy and Phytochemistry, 7(4), 2703-2710.

Yashona, D. S., Mishra, U. S., Aher, S. B., Tripathi, A., & Sirothia, P. (2018). Protein and zinc concentration in pigeonpea (Cajanus cajan) under various mode of zinc application. Indian Journal of Agricultural Biochemistry, 31(2), 186-194.

Zhou, H., Chen, C., Wang, D., Arthur, E., Zhang, Z., Guo, Z., ... & Mooney, S. J. (2020). Effect of long-term organic amendments on the full-range soil water retention characteristics of a Vertisol. Soil and Tillage Research, 202, 104663.