Research Article

A Sustainable Plant Pot Using Rice Husk Biochar for Improving Water Retention

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Abstract: This study evaluates the performance of charcoal-based plant pots formulated using rice husk biochar as a sustainable alternative to traditional terracotta pots. Three mixtures with varying charcoal–clay ratios were developed and tested under controlled greenhouse conditions to determine their effects on soil pH stability, moisture retention, plant height, and plant weight. An observational research design was employed, and data were collected weekly over a four-week growth period. Results show that Treatment 2 (150 g charcoal, 40% terracotta clay, 50 g natural adhesive) demonstrated the most stable soil pH range (6.0-7.0), the highest moisture retention, and superior plant growth, producing the tallest plants (20 cm) and the greatest weight (4.0 g). Compared to traditional terracotta pots, charcoal-based pots improved water retention, maintained a more balanced soil environment, and enhanced plant development. These findings highlight the potential of biochar-integrated pots as an environmentally friendly and effective option for gardening and agricultural applications.

Keywords: biochar; rice husk; charcoal-based plant pot; soil moisture retention; pH stability; sustainable agriculture; plant growth performance

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1. Introduction

Biochar has gained increasing attention in recent years as a sustainable material for improving soil quality, enhancing water retention, and reducing agricultural waste. Produced through the pyrolysis of organic residues under limited oxygen, biochar is recognized for its porous structure, high carbon stability, and capacity to influence soil physical and chemical properties (Kozioł et al., 2024). In the Philippines, rice husk biochar is widely accessible due to the country's strong rice production sector. Technologies developed by the Philippine Rice Research Institute (PhilRice) enable continuous and low-emission rice husk carbonization, yielding up to 40% biochar while minimizing environmental impact (Piyathissa et al., 2023; Orge & Abon, 2012).

International and local studies highlight biochar's potential in enhancing soil fertility, nutrient retention, and microbial activity (Lehmann & Joseph, 2015; Shyam et al., 2025). Its porous matrix improves aeration and water-holding capacity, which directly contributes to healthier plant growth. However, despite its widespread agricultural use, there is limited research on incorporating biochar into plant pot structures. Traditional terracotta pots, although breathable and durable, dry soil quickly and allow significant nutrient loss through leaching, resulting in the need for frequent irrigation and fertilizer application. These challenges emphasize the demand for a more sustainable, plant-friendly, and environmentally responsible pot material.

The integration of rice husk biochar into plant pots presents a promising solution, as it may improve moisture retention, stabilize soil pH, and support overall plant health. Developing charcoal-based plant pots can also contribute to waste reduction, resource circularity, and reduced dependency on plastic containers frequently used in gardening.

This study aims to determine the most effective charcoal-clay ratio for producing functional plant pots and to assess how charcoal-based pots influence soil moisture, soil pH stability, plant height, and plant weight compared to traditional terracotta pots. By examining these factors, the study provides insight into the viability of biochar-based containers as sustainable alternatives for horticultural and agricultural applications.

2. Materials and Methods

The study employed an observational experimental design to evaluate the performance of charcoal-based plant pots compared to traditional terracotta pots. Four charcoal-clay mixtures were formulated as treatments and assessed based on soil pH, moisture retention, plant height, and plant weight. All treatments were cultivated under identical conditions to ensure reliable comparison of results. A photo of the actual pots used is provided in figure 1.

Figure 1. Experimental pots representing each treatment (I, II, III, IV).

The primary materials used in the study included: (1) rice husk biochar; (2) terracotta clay (unglazed); (3) natural adhesive (50 g per treatment); (4) water (60 mL per treatment); (5) uniform potting soil; (6) traditional terracotta pots (control); (7) seeds of the same plant species; (8) soil testing kits (pH meter/test strips, moisture meter); and (9) growth measurement tools (ruler, weighing scale).

Four charcoal-clay formulations were developed to evaluate the effect of varying charcoal-to-clay ratios on material performance. In Treatment 1, the mixture consisted of 200 g of charcoal combined with 30% terracotta clay, 50 g of adhesive, and 60 mL of water. Treatment 2 included 150 g of charcoal and 40% terracotta clay, while maintaining the same quantities of adhesive (50 g) and water (60 mL). In Treatment 3, the charcoal content was reduced to 100 g and the terracotta clay proportion increased to 50%, with adhesive and water amounts kept constant. Finally, Treatment 4 contained 50 g of charcoal and 60% terracotta clay, again with 50 g of adhesive and 60 mL of water. This systematic variation in charcoal and clay proportions allowed for comparative analysis of the formulations while controlling for adhesive and moisture content. Figure 2 shows formulating treatments.

Figure 2. Manual mixing of treatment ingredients.

The experiment was conducted inside a controlled greenhouse to ensure consistent temperature, humidity, and sunlight exposure. The greenhouse setting prevented external variables such as rainfall, pests, or temperature fluctuations from influencing the experiment. Figure 3 presents the greenhouse used.

Figure 3. Greenhouse structure used for growing treatments.

Each pot was filled with identical soil composition and planted with seeds of the same species. Equal depth, spacing, and initial watering were standardized across all pots. The pots were arranged in a randomized layout to avoid positional bias from sunlight.

Observations were performed weekly over a four-week period, measuring: (1) soil pH (using pH test kits); (2) moisture levels (using a soil moisture meter); (3) temperature; (4) plant height (measured in cm using a ruler); (5) plant weight (measured in grams using a digital scale); and (6) changes in pot durability (incomplete).

The study did not involve human or animal subjects and therefore did not require ethical approval. All materials used were safe and environmentally compliant.

3. Results

3.1. Soil pH Levels

Soil pH was measured weekly for all treatments to monitor temporal changes associated with the different charcoal-clay formulations, and figure 4 illustrates the measurement procedure. For each sampling event, soil samples were collected from each treatment under identical conditions to ensure consistency.

Figure 4. Measurement of soil pH using a digital pH and moisture meter.

The samples were air-dried, homogenized, and mixed with distilled water at a standardized soil-to-water ratio prior to measurement. A calibrated digital pH meter was used to determine the pH values, with calibration performed before each measurement session using standard buffer solutions. All measurements were conducted in triplicate to enhance reliability and reduce experimental error. This systematic monitoring enabled the assessment of pH fluctuations over time and facilitated comparison among treatments.

At the same time, table 1 shows that Treatment 2 maintained the most stable and optimal pH range (6.0-7.0), suitable for healthy nutrient uptake. Treatment 3 showed elevated alkalinity, while Treatment 4 became increasingly acidic. Traditional terracotta pots demonstrated inconsistent fluctuations across the four-week period. below, figure 5 presents weekly comparison of soil pH under different treatments.

Table 1. Soil pH levels across four weeks.

Treatment	Week 1	Week 2	Week 3	Week 4
Traditional clay	5.5	7	6.5	6
Treatment 1				
Treatment 2	6.5	6	6	7
Treatment 3	6.3	7.5	7.8	7.2
Treatment 4	5.5	4.5	5	5.5

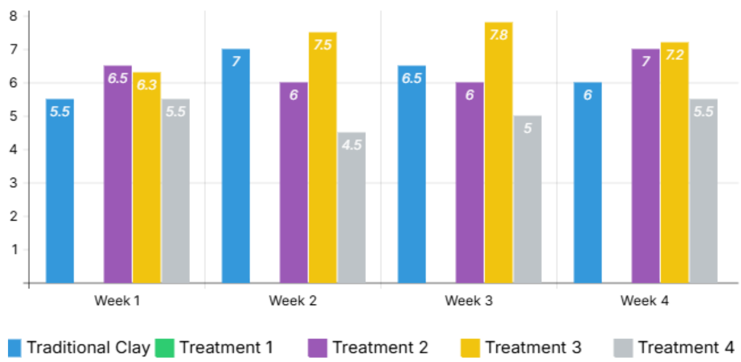

Figure 5. Weekly comparison of soil pH under different treatments.

3.2. Soil Moisture Retention

Moisture conditions were recorded weekly using a soil moisture meter. Table 2 indicates that Treatment 2 consistently retained the most moisture, remaining in the "Wet" or "Wet+" range throughout the experiment. Traditional clay pots dried the fastest, showing "Dry" or "Dry+" levels, while Treatments 3 and 4 displayed inconsistent water retention.

Table 2. Soil pH levels across four weeks.

Treatment	Week 1	Week 2	Week 3	Week 4
Traditional clay	Dry+	Dry+	Dry	Dry+
Treatment 1				
Treatment 2	Wet+	Wet	Wet	Wet
Treatment 3	Wet+	Dry	Wet	Dry
Treatment 4	Wet+	Dry	Wet	Dry

Figure 6 presents the weekly comparison of soil moisture retention across the different treatments. Moisture levels were assessed using a standardized four-point scale, where 1 indicates Dry+, 2 represents Dry, 3 corresponds to Wet, and 4 denotes Wet+. This coding system enabled consistent monitoring of relative moisture conditions over time and facilitated comparison of water retention performance among the treatments throughout the experimental period.

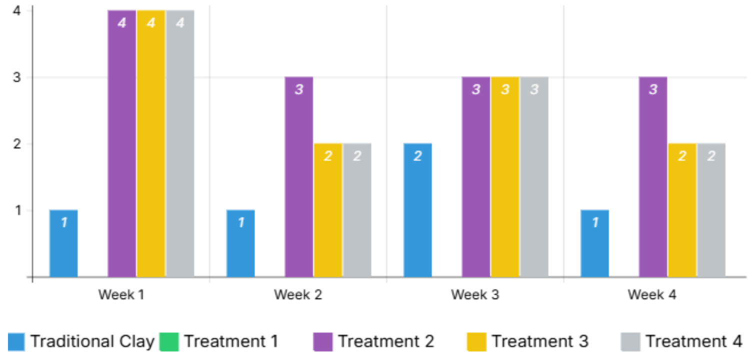

Figure 6. Weekly comparison of soil moisture retention under different treatments.

3.3. Temperature Observations

Temperature remained uniform across all treatments because the experiment was conducted in the same greenhouse environment. Table 3 confirms that temperature did not contribute to differences in plant growth performance.

Table 3. Soil pH levels across four weeks.

Treatment	Week 1	Week 2	Week 3	Week 4
All Treatments	33°C	36°C	37°C	37.5°C

Figure 7 illustrates the weekly temperature measurements recorded throughout the experimental period for all treatments. These data provide an overview of temperature variations over time and ensure that environmental conditions remained comparable during the study.

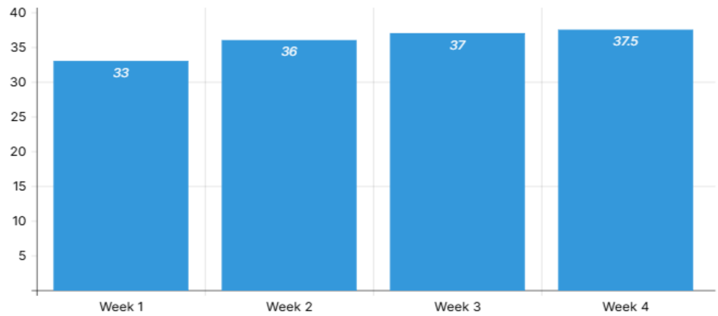

Figure 7. Weekly temperature measurements.

3.4. Plant Height

Treatment 2 produced the tallest plants, with a final average height of 20 cm. Table 4 summarizes the height differences among all treatments, showing Treatment 4 as the lowest performer.

Table 4. Final plant height.

Treatment	Height (cm)
Traditional clay	15
Treatment 1	
Treatment 2	20
Treatment 3	16
Treatment 4	14

Figure 8 presents the final height of plants measured at the end of the experimental period across all treatments. These results provide a comparative overview of plant growth performance and reflect the overall effect of the different charcoal-clay formulations on vegetative development.

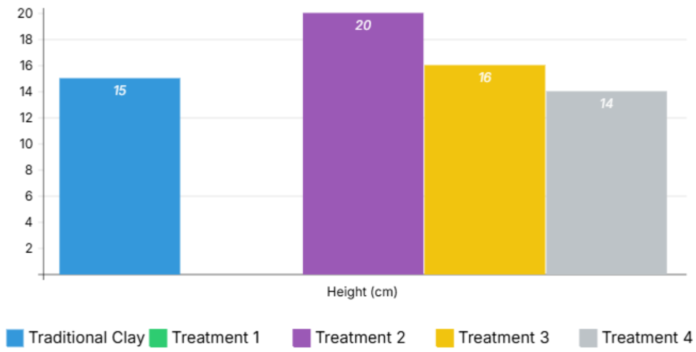

Figure 8. Height of plants at the end of the experiment.

3.5. Plant Weight

Treatment 2 also produced the highest plant weight at 4.0 g, followed by Treatment 3 (3.5 g) and Treatment 1. Treatment 4 recorded the lowest value. At the same time, figure 9 demonstrates visual data on weight of plants at the end of the experiment.

Table 4. Final plant weight.

Treatment	Weight (g)
Traditional Clay	3.2
Treatment 1	
Treatment 2	4.0
Treatment 3	3.5
Treatment 4	3.0

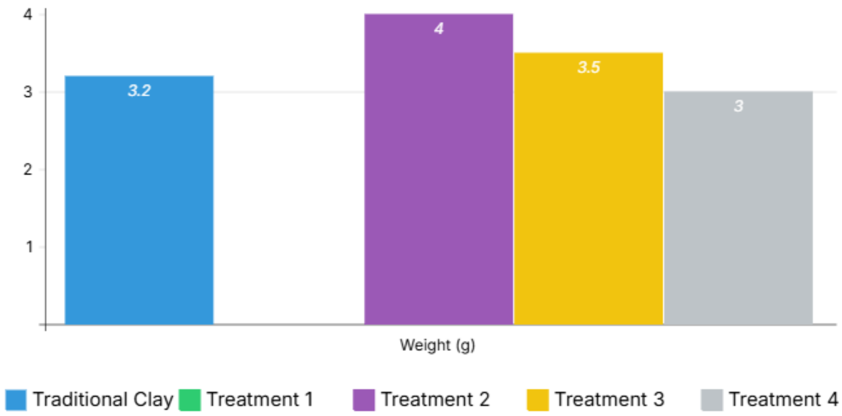

Figure 9. Weight of plants at the end of the experiment.

Therefore, the results demonstrate that Treatment 2 provided the most favorable growing conditions among all formulations. It maintained a stable and optimal soil pH range (6.0-7.0), consistently retained higher moisture levels, and produced the greatest plant height (20 cm) and weight (4.0 g) at the end of the experiment. In contrast, Treatments 3 and 4 showed greater pH fluctuations and inconsistent moisture retention, while traditional clay pots dried more rapidly and demonstrated variable performance. Since temperature conditions remained uniform across all treatments, differences in plant growth can be attributed primarily to the effects of the charcoal-clay compositions.

4. Discussion

This study evaluated the effectiveness of charcoal-based plant pots formulated with rice husk biochar as a sustainable alternative to traditional terracotta pots, focusing on soil moisture retention, pH stability, temperature effects, plant growth performance, material durability, and optimal formulation ratios. The discussion is structured according to the research questions outlined in the study.

The results indicate that Treatment 2 outperformed traditional terracotta pots in maintaining soil moisture and stabilizing soil pH throughout the experimental period. Traditional terracotta pots frequently reached “Dry” or “Dry+” conditions, consistent with previous reports that unmodified clay pots exhibit high evaporative loss due to their porous matrix (Anikwe & Nwobodo, 2018). In contrast, pots incorporating rice husk biochar retained moisture at "Wet" or "Wet+" levels, supporting literature that highlights biochar's high surface area and porosity as mechanisms for enhanced water-holding capacity in soil amendments (Kang et al., 2022). These hydrological benefits of biochar have been demonstrated across multiple soil types and plant systems, indicating its potential to improve water availability under water-limited conditions (Agegnehu et al., 2021).

Soil pH measurements showed that Treatment 2 maintained an optimal range of 6.0-7.0, which aligns with the pH levels associated with improved nutrient availability and plant uptake reported in agronomic biochar studies (Mukherjee & Lal, 2013). Higher charcoal concentrations tended to increase alkalinity, while pots with greater clay proportions exhibited more acidic conditions, suggesting that the buffering capacity of biochar can moderate soil pH but is sensitive to the amendment ratio. Traditional terracotta pots displayed inconsistent pH fluctuations, indicating limited intrinsic capacity to stabilize soil chemistry compared to biochar-enhanced media. These results corroborate findings that biochar amendments can improve soil pH homeostasis, particularly in acidic soils, through increased cation exchange capacity and alkaline surface functional groups (Yao et al., 2025).

Temperature measurements remained uniform across all treatments due to the controlled greenhouse environment, confirming that temperature did not significantly contribute to the observed differences in plant growth. This reinforces previous assertions that moisture and chemical soil properties, rather than thermal variation, are the primary drivers of plant performance in controlled environments (González-García et al., 2023).

Plant growth performance metrics demonstrated that Treatment 2 produced the tallest and heaviest plants, with mean height (20 cm) and weight (4.0 g) exceeding those of plants grown in traditional terracotta pots. These improvements can be attributed to the synergistic effects of consistent moisture availability and stable soil pH, which are critical factors for efficient nutrient uptake and root development (Feng et al., 2025; Jamil et al., 2022). Comparable studies have shown that biochar amendments can promote vegetative growth and biomass accumulation, especially when incorporated at optimal rates that enhance soil physical and chemical properties (Lv et al., 2023).

In contrast, treatments with either excessive charcoal or excessive clay exhibited reduced growth performance. High charcoal content may have altered nutrient balance or adsorbed critical ions, while high clay content could increase soil compaction and acidity, both of which may impede root penetration and nutrient mobility. These observations are consistent with reports that biochar benefits are dose-dependent and that overly high proportions can lead to nutrient immobilization or physical constraints on roots (Jeffery et al., 2017; Kammann et al., 2017).

Durability under varying environmental conditions such as prolonged moisture exposure and sunlight was included within the scope of this study; however, the four-week observation period was insufficient to evaluate long-term structural performance. While short-term assessments provided insights into soil conditions and early plant growth, they did not capture potential cracking, deformation, or material degradation that may occur under extended outdoor exposure. Long-term durability testing is recommended for future research, consistent with calls in the literature for multi-season and field-based evaluations of biochar composites to assess structural resilience under environmental stressors (Joseph et al., 2020).

Among the four formulations tested, Treatment 2 (150 g charcoal, 40% terracotta clay, 50 g natural adhesive, and 60 mL water) emerged as the most effective. This ratio balanced porosity for moisture retention with sufficient strength and shape stability. Formulations with higher charcoal content lacked structural firmness, while higher clay content diminished biochar's functional advantages. These findings underscore the importance of optimizing amendment ratios to achieve synergistic performance, echoing recommendations from other studies that appropriate biochar-clay proportions are critical to maximizing both physical and agronomic benefits (Beusch, 2021).

Future research should extend durability evaluations to outdoor conditions, including prolonged rainfall and solar exposure, to better simulate real-world usage. Testing alternative natural adhesives and diverse biochar sources may further enhance material strength and performance. Expanding the study to include multiple plant species and longer growth periods would improve the generalizability of these findings. Additionally, exploring variations in pot thickness and design could optimize water retention and structural stability, as suggested by recent innovations in biochar-based ceramics (Yao et al., 2025).

To sum up, the findings of this study demonstrate that charcoal-based plant pots, particularly those formulated with a balanced ratio of rice husk biochar and terracotta clay, offer significant advantages over traditional terracotta pots. They provide improved soil moisture retention, stable pH conditions, and enhanced plant growth performance, without being influenced by temperature variations in a controlled environment. Optimizing the charcoal-to-clay ratio is essential to achieve both functional and structural benefits, while treatments with excessive charcoal or clay compromise either strength or soil functionality. This means that these results highlight the potential of biochar-based pots as a sustainable and effective alternative for horticultural applications, with promising implications for future material innovation and plant cultivation practices.

5. Conclusions

This study evaluated charcoal-based plant pots formulated with rice husk biochar and terracotta clay as sustainable alternatives to traditional pots. Among the three formulations tested, Treatment 2 consisting of 150 g charcoal, 40% terracotta clay, and 50 g natural adhesive consistently produced the best outcomes across all measured variables. This treatment maintained optimal soil pH stability, demonstrated superior moisture retention, and yielded the tallest plants and highest weight at the end of the four-week growing period.

The use of biochar improved the physical environment of the soil by enhancing aeration and water-holding capacity, which contributed to healthier plant development. Compared to traditional terracotta pots, charcoal-based pots reduced nutrient loss, maintained more consistent moisture levels, and increased plant growth performance. These results indicate that biochar-integrated plant pots are not only effective for plant cultivation but also align with sustainable agricultural practices by reusing agricultural waste and reducing reliance on non-biodegradable materials.

Overall, this study demonstrates that the integration of rice husk biochar into plant pot production has strong potential for horticultural and agricultural applications. Further research is recommended to explore long-term durability, biodegradation behavior, and performance across multiple plant species and outdoor environments

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