
**Asian Journal of Agriculture and Rural Development**
Volume 15, Issue 4 (2025): 650-662

# Transforming serayu sediment into compost-amended medium for soybean cultivation

**Aman Suyadi**[a] †
**Didit Agustinus Suratman**[b]
**Teguh Pribadi**[c]

[a,b,c] *Universitas Muhammadiyah Purwokerto, Indonesia.*

† ✉ amansuyadi.ump@gmail.com (*Corresponding author*)

## Article History

**Received:** 28 August 2025
**Revised:** 15 October 2025
**Accepted:** 30 October 2025
**Published:** 24 November 2025

## Keywords

Compost
Growing media
River sediment
Sediment valorization
Soil amendments
Soybean.

## ABSTRACT

River sediment accumulation poses both environmental and management challenges in tropical watersheds; however, these sediments possess physicochemical properties that can be valorized for agricultural use through appropriate amelioration. This study evaluated the potential of Serayu River sediment from three sites: Somagede, Banyumas, Kebasen (Indonesia) as a growing medium for soybean (*Glycine max* L. Merril) cultivation. Twelve sediment-based media were formulated by combining sediment with compost, zeolite, and biochar in different ratios and tested in a completely randomized design with three replications. The sediments exhibited sandy clay loam to clay loam textures, neutral pH (7.60–7.66), but low organic matter (1.69–2.40%) and nutrient contents. Compost amendment substantially improved media fertility and crop performance, whereas zeolite and biochar treatments produced moderate responses. The best results were obtained from compost-amended treatments M3 (sediment: compost = 3:1) and M6 (1:1), which increased plant height by 17–19%, stem diameter by 61–74%, and filled pod number by 51–61% compared with the control. Principal component analysis confirmed that compost treatments consistently clustered within the high-performance quadrant, demonstrating synergistic effects on vegetative and reproductive traits. These findings indicate that compost-enhanced sediment can serve as a sustainable alternative growing medium, addressing sediment disposal issues and improving soil fertility for legume production. The study highlights a viable pathway for circular agriculture and sustainable sediment management in tropical river basins, with future research recommended to include heavy metal assessment, multi-season field validation, and biological inoculation for optimizing nitrogen fixation.

**Contribution/Originality:** This study provides the first systematic evaluation of Serayu River sediment as a soybean growing medium, employing multi-location characterization and multivariate analysis to demonstrate that compost amelioration (sediment:compost 3:1) achieves 68% yield enhancement with economic viability (benefit-cost ratio 4.25), establishing a novel framework for transforming river sediment waste into productive agricultural resources in tropical watersheds.

DOI: 10.55493/5005.v15i4.5746
ISSN(P): 2304-1455/ ISSN(E): 2224-4433

**How to cite:** Suyadi, A., Suratman, D. A., & Pribadi, T. (2025). Transforming serayu sediment into compost-amended medium for soybean cultivation. *Asian Journal of Agriculture and Rural Development, 15*(4), 650–662. 10.55493/5005.v15i4.5746



# 1. INTRODUCTION

River sediment accumulation is a critical environmental challenge in tropical watersheds, where intensive erosion, anthropogenic activity, and land-use change contribute to accelerating sedimentation rates that threaten the integrity of aquatic ecosystems and the sustainability of water resources (Liu, Walling, & He, 2018; Owens, 2020; Reid et al., 2019). The Serayu River System in Central Java, Indonesia, illustrates this challenge, experiencing severe sedimentation that reduces reservoir capacity, increases the risk of flooding, and requires high-cost dredging operations (Barneveld et al., 2025; Thapa et al., 2024). Traditional sediment management approaches including in-area disposal or discharge into the sea are increasingly unsustainable due to environmental regulations, space constraints, and ever-increasing costs (Barneveld et al., 2025; Safhi, 2022; Thapa et al., 2024). This paradigm encourages researchers to explore innovative sediment valorization strategies that transform waste materials into productive agricultural resources, in line with circular economy principles and sustainable development goals.

Recent advances in sediment characterization have revealed promising physico-chemical properties to support plant cultivation when appropriately modified (Kiani, Raave, Simojoki, Tammeorg, & Tammeorg, 2021; Szara-Bąk, Baran, & Klimkowicz-Pawlas, 2023). River sediments generally exhibit a favorable textural composition (sandy clay to clayey silt), adequate porosity for root penetration, and neutral pH conditions conducive to nutrient availability (Kiani, Arzani, & Maibody, 2021; Szara-Bąk et al., 2023). However, critical limitations include deficient organic matter content, suboptimal concentrations of macronutrients (especially nitrogen, phosphorus, and potassium), and varying microelement profiles that require a targeted soil amelioration strategy (Douglas et al., 2018; Liu et al., 2017; Mao et al., 2016). Although previous studies have demonstrated the potential of sediments for horticultural applications with the cultivation of chili peppers (Braga et al., 2017), with sunflower production comprehensive evaluation of the cultivation of legumes in sediment-based media is still limited, particularly regarding the optimization of organic ameliorant combinations for nitrogen-fixing plant systems. The selection of appropriate soil ameliorants is a critical determinant of the performance of sediment-based planting media, with organic ameliorants showing superior efficacy in overcoming multiple fertility constraints simultaneously (Braga et al., 2024; Mupambwa & Mnkeni, 2018; Singh et al., 2024). Compost provides a comprehensive nutrient profile, increases cation exchange capacity, improves soil structure, and stimulates beneficial microbial activity that is essential for nutrient cycling and plant health (Braga et al., 2024; Mupambwa & Mnkeni, 2018; Singh et al., 2024). Biochar offers long-term carbon sequestration, enhanced nutrient retention through surface adsorption mechanisms, and improvement of soil physical properties, although the effects may require an extended establishment period to fully manifest (Ding et al., 2016; Kapoor, Sharma, Kumar, & Sepehya, 2022). Zeolite contributes to nutrient retention and water-holding capacity through its unique crystalline structure and high surface area, particularly beneficial on coarse-textured substrates (Ding et al., 2016; Kapoor et al., 2022). However, systematic comparative evaluation of these ameliorants in sediment-based systems, especially their interactive effects on legume performance, is still insufficient to guide practical implementation strategies.

Soybeans (Glycine max L. Merrill) are an ideal model crop for sediment-based cultivation systems due to their moderate environmental tolerances, significant nutritional and economic value, and unique nitrogen fixation capabilities through symbiotic relationships with Rhizobium bacteria (Ding et al., 2016; Kapoor et al., 2022). The species' capacity to thrive in suboptimal soil conditions while contributing to soil fertility through biological nitrogen fixation makes it particularly suitable for marginal land rehabilitation initiatives (Karimuna, Rahni, & Boer, 2016; Mutammimah, Minardi, & Suryono, 2020). Despite this potential, there have been no comprehensive studies that have systematically evaluated the Serayu River sediment as a planting medium for soybean cultivation, nor have researchers optimized ameliorant combinations specifically for legume production in sediment-based systems. This knowledge gap limits the practical application of sediment valorization strategies and hinders the development of evidence-based guidelines for sustainable sediment management in agricultural contexts. Therefore, this study aims to: (1) comprehensively characterize the physicochemical properties of Serayu River sediments from multiple representative locations, and (2) systematically evaluate the efficacy of various organic and inorganic ameliorants in optimizing the growth performance and yield of soybeans in sediment-based planting media. In turn, this study addresses the research gap through an integrated evaluation: (1) physicochemical characterization of Serayu sediment from three locations, and (2) comparative testing of 12 media formulations (sediment ± compost, zeolite, biochar) on soybean growth and yield. Special attention is given to commonly practiced compost ratios (3:1, 1:1, 1:3) to examine dosage effects on plant responses.

# 2. METHODS

## *2.1. Time and Place*

The research was conducted at the Experimental Garden of the Faculty of Agriculture and Fisheries, University of Muhammadiyah Purwokerto (UMP), located in Karangsari Village, Banyumas, Central Java, with coordinates 7° 23'

56" S and 109° 16' 53" E, at an altitude of 85 meters above sea level. The annual rainfall is 3,612 mm. The research was carried out from January to April 2025.

### 2.2. Research Design

This study used a one-factor Complete Random Design (CRD) to evaluate the influence of the composition of the planting medium with the addition of various ameliorants on the growth and yield of soybean crops (Table 1). Each treatment was repeated three times, with each test consisting of five test units (polybags), so that the total number of polybags was 12 treatments × 3 replications × 5 test units = 180 polybags. The dimensions of the polybag used are 40 cm × 40 cm.

**Table 1.** Treatments tried in planting media research.

| Code | Description | Code | Description |
|---|---|---|---|
| M0 | Planting media from FPP-UMP experimental garden (Andosol) | M6 | M1 composite planting medium: Compost (1:1) |
| M1 | Planting medium derived from Serayu River sediment (Soil type is alluvial) | M7 | M1 composite planting medium: Zeolite (1:1) |
| M2 | Composite planting medium M0: M1 (1:1) | M8 | M1 composite planting medium: Biochar (1:1) |
| M3 | M1 composite planting medium: Compost (3:1) | M9 | M1 composite planting medium: Compost (1:3) |
| M4 | M1 composite planting medium: Zeolite (3:1) | M10 | M1 composite planting medium: Zeolite (1:3) |
| M5 | M1 composite planting medium: Biochar (3:1) | M11 | M1 composite planting medium: Biochar (1:3) |

**Note:** The amendment ratios (3:1, 1:1, and 1:3) were selected to represent low, medium, and high levels commonly applied in pot trials. These proportions were chosen based on previous studies, practical field experience, and relevant literature on growing media formulation.

#### 2.2.1. Research Stages

Collection and preparation of planting media. Serayu River sediments were collected from three different location points in the Banyumas region, namely: Somagede, Kebasen, and Banyumas (Figure 1). A total of 750 kg of sediment was taken at a depth of 2–5 cm at each point. The sediment was dried in the sun for 7 days. Each sediment sample was then taken as 1 kg to analyze the physical and chemical properties of the soil at the Soil Science Laboratory, UGM. Preparation of planting media involved mixing the dried sediment with compost, zeolite, and biochar according to the treatment applied (Table 1). The soil or sediment used is fine soil that passes through a 0.25 cm2 sieve. The ready planting medium was then placed in a polybag as a soybean planting medium. Sowing and planting procedures included soaking soybean seeds of the Demas I variety in water for 15 minutes to select quality seeds; floating seeds were discarded. Each polybag was planted with 2–3 seeds manually using tugal in the prepared planting hole. The hole was covered with soil and watered as needed. Insertion was done 1–2 days after planting (HST) to replace dead or abnormal plants with reserve seeds. Plant maintenance. Maintenance includes watering twice a day (07:00–09:00 and 16:00–18:00 WIB) using local water, except when the soil is saturated due to rain. Weeds in polybags are pulled out manually, while weeds around polybags are hoed every two days. Pest control is carried out by removing pests directly or applying synthetic pesticides if the attack intensity exceeds 50%. Fertilization is performed according to the following doses: Urea (0.125 g per polybag at 0 HST and 30 HST), KCl (0.50 g per polybag at 0 HST), and SP36 (0.75 g per polybag at 0 HST). Harvesting occurs at 86 HST when 95% of the pods are brownish-yellow. The harvest is dried in the sun and stored in plastic bags labeled according to the treatment.

#### 2.2.2. Observation Variables

The observation variables collected in this study consisted of four components (Table 2). The first component is the physical properties of the soil, which include soil texture, porosity, soil bulk density, and soil specific gravity. The chemical properties of the soil include pH, organic matter, nitrogen content, phosphorus content, potassium content, calcium content, sodium content, salinity (measured as electrical conductivity), cation exchange capacity (CEC), and magnesium content. The second component is vegetative growth, which comprises plant height, stem diameter, number of leaves, and leaf area. The third component involves root characteristics and chlorophyll content, including the number of root nodules, root length, weight of wet roots, weight of dry roots, and chlorophyll content of leaves. The final component pertains to seed yield and quality, which encompasses the total number of pods, the number of filled pods, and the weight of seeds per 100 seeds.

**Table 2.** Variables observed in the planting media research.

| Variable (Initial) | Measurement method | Observation time (HST) | Unit |
|---|---|---|---|
| Soil texture (Text) | Triangle of soil texture | - | |
| Total dust (TDE) | Hydrometer method (Bouyoucus, 1939) | - | % |
| Total clay (TLE) | Hydrometer method | - | % |
| Total sand (TPA) | Hydrometer method | - | % |
| Soil volume weight (BVT)/bulk density | Sample Ring | - | g cm-3 |
| Soil specific gravity (BJT) | Picnometer | - | g cm-3 |
| Porosity (by) | Comparison of BVT and BJT | - | % |
| pH (pH) | - | - | - |
| Organic matter (BO) | Wet oxidation | - | % |

| Variable (Initial) | Measurement method | Observation time (HST) | Unit |
|---|---|---|---|
| Total nitrogen content (KNT) | Sulfuric acid destruction (Kjedahl) | - | % |
| Total phosphorus content (KFT) | Strong Acid ($HClO_4/H_2SO_4$) | - | % |
| Available phosphorus content (FTS) | Olsen ($NaHCO_3$ 0.5 N pH 8.5) | - | Ppm |
| Total potassium content (KKT) | $HNO_3$ + $HClO_4$ (Flame Photometer) | - | % |
| Available potassium content (KTS) | Ammonium Acetate 1 N (pH 7) (Flame photometer) | - | and% |
| Cation exchange capacity (CEC) | Number of base conversions (SB) + $Al^{3+}$ Conversion | - | and% |
| Potassium interchangeable (CADD) | Ammonium acetate 1 N (pH 7) (Flame photometer) | - | and% |
| Sodium interchangeable (NADD) | Ammonium acetate 1 N (pH 7) (Flame photometer) | - | and% |
| Total magnesium (MGT) | AAS (Atomic absorption spectrophotometer) | - | % |
| Magnesium available (MGTS) | AAS (Atomic Absorption Spectrophotometer) | - | and% |
| Electrical transmission power (DHL) | Conducttometer (EC meter) | - | Ms |
| Plant height (TTA) | Measurements with rulers | 14, 28, 42 & 56 | Cm |
| Rod diameter (DBA) | Measurements with rulers | 14, 28, 42 & 56 | Cm |
| Leaf area (LDA) | Correction & gravimetric factors | 14, 28, 42 & 56 | cm2 |
| Number of leaves (JDA) | Visual | 14, 28, 42 & 56 | - |
| Total root nodules (JBA) | Visual | 86 | - |
| Root length (PJA) | Measurements with rulers | 86 | Cm |
| Weight of wet roots (BAB) | Digital scales | 86 | g |
| Dry root weight (BAK) | Digital scales | 86 | g |
| Chlorophyll (KKL) | UV-VIS spectrophotometry (Susanti, Nasrudin, & Septyrophysia, 2024) | 42 | mg L-1 |
| Total number of pods (JPT) | Visual | 86 | - |
| Number of Fill Pods (JPI) | Visual | 86 | - |
| Number of seeds (JBI) | Visual | 86 | - |
| Weight of seeds per 100 grains (B100) | Digital scales | 86 | g |

#### *2.2.3. Data Analysis*

The physical and chemical properties of the soil are analyzed descriptively (without repetition). One-way ANOVA analysis at a significance level of 5% was used to assess the significant influence of the treatment on the observed variables (vegetative growth, root characteristics, chlorophyll content, seed yield, and quality). Parametric assumptions were checked using the Shapiro-Wilk normality test and the Levene homogeneity test at a significance level of 5%, respectively.

Data that do not meet the normality assumption are transformed (logarithm of Y or √Y), while variance homogeneity is considered met if the p-value exceeds 0.05. If ANOVA indicates significant differences ($p < 0.05$), a follow-up test of honest significant difference (HSD) or Tukey's test is performed at a 5% significance level to compare the mean values between treatments. Results are presented as mean ± standard deviation (SD), with different groups labeled with letters (a, b, c, etc.) based on the BNJ follow-up test. Statistical analysis was conducted using Past 5.2.2 software (Hammer, Harper, & Ryan, 2016)

#### *2.2.4. Data Transparency*

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

## 3. FINDINGS

### *3.1. Physicochemical Characteristics of Serayu River Sediment as a Potential Planting Media*

An in-depth understanding of the physicochemical properties of sediments is a fundamental prerequisite for developing effective amelioration strategies for material transformation waste to become a productive planting medium. A comprehensive characterization of Serayu River sediments from three representative locations Somagede, Banyumas, and Kebasen was conducted to evaluate the potential baseline and identify nutritional constraints that require amelioration interventions.

Spatial variations in sediment composition reflect deposition dynamics influenced by hydrogeomorphological characteristics, land use in catchment areas, and anthropogenic activity along river flows (Buscaroli, Zannoni, & Dinelli, 2021; Hammer, Harper, & Ryan, 2001; Zorzal-Almeida et al., 2018).

**Table 3.** The physical and chemical properties of the composite sedimentary soil from three different locations were used in the planting medium experiment.

| Parameters | Unit | Somagede | São Paulo | Kebasen |
|---|---|---|---|---|
| Text | - | Sand clay sand dunes | Sand clay sand dunes | Clay Squirt |
| EFT | % | 20.23 | 20.32 | 34.76 |
| TLE | % | 20.11 | 20.11 | 33.99 |
| LANDFILL | % | 50.82 | 50.94 | 24.94 |
| BVT | g cm-3 | 1.25 | 1.13 | 1.10 |
| BJT | g cm-3 | 2.26 | 1.96 | 1.92 |
| Por | % | 44.80 | 42.62 | 42.87 |
| pH (H2O) | - | 7.66 | 7.66 | 7.60 |
| **BO** | **%** | **1.83 (r)** | **1.69 (r)** | **2.40 (s)** |
| KNT | % | 0.07 | 0.08 | 0.07 |
| KFT | % | 0.07 | 0.07 | 0.07 |
| **FTS** | **Ppm** | **7.63 (SR)** | **8.53 (SR)** | **7.01 (sr)** |
| KKT | % | 0.07 | 0.07 | 0.07 |
| **KTS** | **and%** | **0.87 (SR)** | **1.08 (r)** | **1.07 (r)** |
| CADD | and% | 5.17 | 5.29 | 5.01 |
| NADD | and% | 0.51 | 0.64 | 0.65 |
| **CEC** | **and%** | **23.41 (s)** | **27.81 (s)** | **22.16 (s)** |
| MGT | % | 0.52 | 0.65 | 0.47 |
| MGTS | and% | 2.37 (s) | 2.56 (s) | 2.45 (s) |
| DHL | Ms | 0.10 | 0.15 | 0.21 |
| Fertility status | - | Low | Low | Low |

Remarks: The parameter codes used in this table are described in Table 3. The letters in parentheses indicate the fertility status of the soil based on PPT (1995), where sr (Very low), r (Low), s (Moderate), t (High), and st (Very high).

Based on the data in Table 3, it can be seen that Compost-amended media, particularly M3 (Sediment: compost 3:1) and M6 (1:1), consistently enhanced soybean vegetative growth and yield components compared to other treatments (Table 3). These improvements are attributable to the increased supply of organic matter and nutrients, as well as better soil structure, which are well-documented effects of compost application (Azad, Hossain, Islam, Rahman, & Kabir, 2021; Iliyasu & Etikan, 2021). In contrast, zeolite and biochar treatments produced only moderate improvements, likely due to their slower nutrient release and long-term effects that are less visible in a single-season pot trial (Lehmann et al., 2025). Overall, the findings confirm that compost integration is the most immediate and effective amendment strategy for valorizing river sediment into a productive growing medium for soybean.

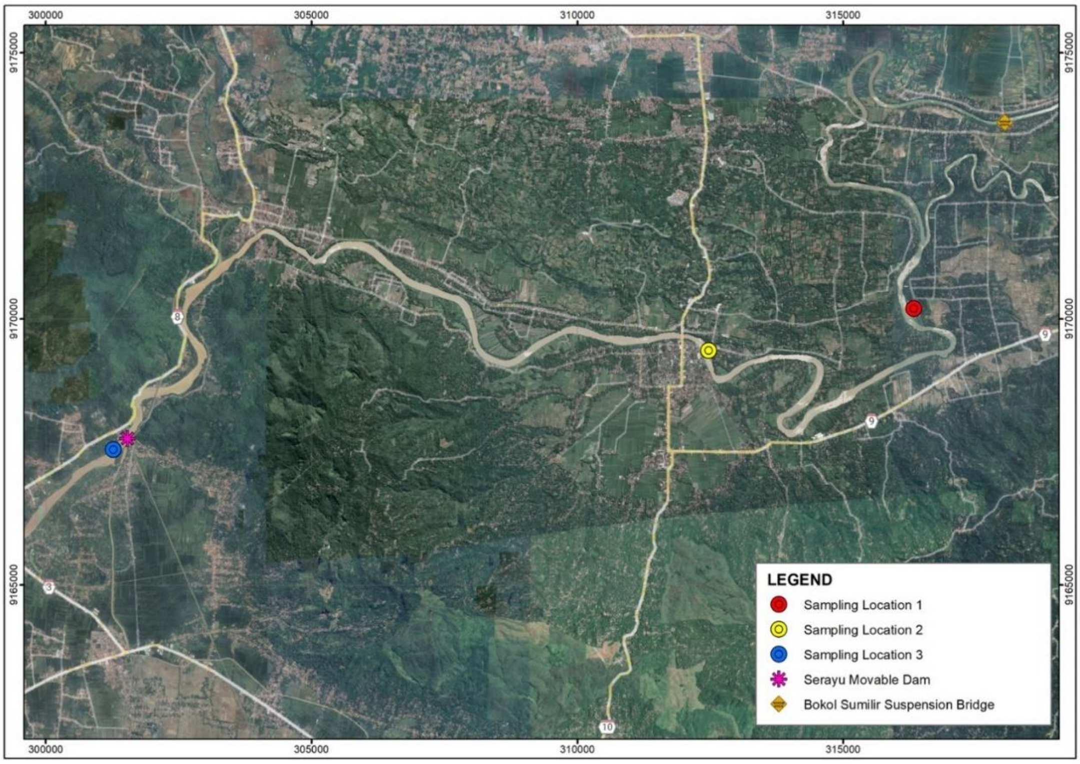


**Figure 1.** The location of the Serayu River sediment sampling point used in the planting media research.

The spatial distribution of sampling points (Figure 1) represents the variability of sediment characteristics along the longitudinal gradient of the Serayu River, from the erosional zone in Somagede to the depositional zone in Kebasen. The Somagede site, located in the upstream segment, receives sediment inputs from intensive agricultural areas with coarse-textured and nutrient-depleted characteristics. Banyumas, as a transitional point, shows intermediate characteristics with slight enrichment in available phosphorus. Kebasen, influenced by the existence of weir infrastructure, experienced preferential accumulation of fine particles carrying absorbed nutrients, reflected in a marginal increase in organic matter (2.40%) and improved cation retention capacity.

Comparison with river sediments from other fluvial systems reveals a consistent pattern of nutrient deficiencies. Braga, Domene, and Gandara (2019) reported similar characteristics in Amazon River sediments, with a content of 3% organic matter, total nitrogen <4.6 g $kg^{-1}$, and phosphorus available 0.5-0.8 g $kg^{-1}$, albeit with slight superiority in nutrient content. This similarity indicates that tropical river sediments generally require substantial amelioration before they can function as productive growing media. The low electrical conductivity (0.10-0.21 mS) confirms the absence of salinity issues, providing flexibility in the selection of ameliorants without concern for salt accumulation.

The synthesis of physicochemical characteristics indicates that the Serayu River sediment has adequate foundational properties appropriate texture, neutral pH, absence of salinity, but requires targeted amelioration to overcome acute nutritional deficiencies, especially in terms of organic matter, nitrogen, and phosphorus. Amelioration strategies should focus on: (1) increasing the content of organic matter to improve soil structure and nutrient cycling, (2) macronutrient supplementation to overcome immediate deficiencies, and (3) enhancing cation exchange capacity to increase long-term nutrient retention (Massawe, Mtei, Munishi, & Ndakidemi, 2016; Stewart, Pierzynski, Middendorf, & Prasad, 2020; Verma, Singh, Pathania, & Aggarwal, 2019). The understanding of these baseline characteristics is the foundation for evaluating the effectiveness of various ameliorant combinations in transforming sediment into a productive planting medium for soybean cultivation. (Di Carlo, Chen, Haynes, Phillips, & Courtney, 2019; Gathagu, Mourad, & Sang, 2018; Reichert-Nguyen, French, & Slacum, 2016; Ruiz-Compean et al., 2017). The response of vegetative growth of plants to various media formulations provides an early indication of the success of amelioration strategies in addressing the nutritional deficiencies that have been identified.

### *3.2. Vegetative Growth Response to Sediment-Based Media Amelioration*

Evaluation of the vegetative growth of soybean plants on various sediment-based planting media formulations revealed complex temporal dynamics, reflecting the interaction between nutrient availability, physical characteristics of the medium, and the adaptability of plants to sub-optimal conditions. Intensive monitoring of morphological parameters during the 56-day vegetative period provides comprehensive insights into the effectiveness of various amelioration strategies in overcoming growth constraints inherent in sediment-based media. The differential response of plants to various ameliorant combinations indicates that optimization of media composition requires holistic consideration of multiple growth-limiting factors, rather than simple nutrient supplementation (Adebayo, Kiani, Ruotsalainen, Pirttilä, & Lehosmaa, 2023). For this, Table 4 presents the dynamics of plant height growth during the 56 days of observation, revealing distinct temporal response patterns between treatments.

**Table 4.** Plant height at different growth phases.

| Planting media | TTA14 | TTA28 | TTA42 | TTA56 |
|---|---|---|---|---|
| M0 | 10.90 ± 1.15 AB | 15.19 ± 1.72 | 25.51 ± 4.05 | 27.23 ± 4.09 abc |
| M1 | **11.27 ± 0.96 A** | 14.21 ± 2.41 | 24.13 ± 4.00 | 24.90 ± 4.31 ABC |
| M2 | 9.67 ± 0.72 ABC | 14.23 ± 2.20 | 23.80 ± 4.52 | 25.57 ± 1.86 ABC |
| M3 | 8.67 ± 1.35 ABC | 14.06 ± 5.22 | 28.68 ± 6.25 | 31.83 ± 7.20 AB |
| M4 | 8.70 ± 0.26 ABC | 11.41 ± 1.23 | 8.47 ± 3.20 | 21.70 ± 3.50 BC |
| M5 | 8.53 ± 0.64 ABC | 11.15 ± 0.61 | 19.37 ± 0.57 | 20.27 ± 1.82 c |
| M6 | 7.77 ± 1.91 c | 14.62 ± 1.71 | 26.67 ± 4.84 | 32.34 ± 3.32 A |
| M7 | 9.53 ± 0.65 ABC | 13.05 ± 3.77 | 25.40 ± 3.92 | 28.43 ± 3.06 abc |
| M8 | 8.07 ± 0.76 BC | 12.07 ± 1.25 | 19.90 ± 5.98 | 20.20 ± 3.29 c |
| M9 | 7.23 ± 0.64 c | 13.85 ± 0.68 | 22.87 ± 2.97 | 26.73 ± 2.14 abc |
| M10 | 8.00 ± 1.11 BC | 11.64 ± 1.64 | 7.37 ± 3.29 | 22.23 ± 1.74 ABC |
| M11 | 8.37 ± 0.81 ABC | 11.25 ± 1.26 | 17.53 ± 1.27 | 19.40 ± 2.80 c |

**Note:** Different letters within the same column indicate significant differences among treatments according to Duncan's Multiple Range Test (DMRT) at $p < 0.05$.

Temporal analysis of plant height growth reveals a dynamic response pattern to the composition of the planting medium. In the initial establishment phase (14 HST), the soil control Andosol (M0) showed superiority with a height of 10.90±1.15 cm, while the compost-based treatments (M3, M6, M9) exhibited an initial growth depression, with values ranging from 7.23 to 8.67 cm. This phenomenon can be attributed to temporary nitrogen immobilization during the initial decomposition phase of organic matter, a characteristic common in fresh compost applications (Fan et al., 2019; Lehrsch, Brown, Lentz, Johnson-Maynard, & Leytem, 2016). However, a dramatic reversal occurred as the vegetative phase progressed, where at 56 HSTs, the M6 treatment (sediment: compost 1:1) reached a maximum height of 32.34±3.32 cm, representing a 19% increase over the control, followed by M3 (sediment: compost 3:1) with 31.83±7.20 cm. This transformation of the growth trajectory indicates that after the initial stabilization phase, the mineralization of organic matter from the compost provides sustained nutrient release that supports exponential growth. Table 5 presents the corresponding variation in stem diameter observed across the same growth stages. This parameter serves as a complementary indicator of vegetative vigor and structural development of the soybean stem under different media compositions. A consistent trend is observed where compost-amended treatments, particularly M3 and M6, exhibit thicker stems compared with the control, confirming the positive effect of compost on overall plant robustness. These results collectively reinforce that compost not only enhances vertical growth but also contributes to improved stem biomass and mechanical strength during vegetative development.

**Table 5.** Stem diameters at different growth phases.

| Planting media | DBA14 | DBA28 | DBA42 | DBA56 |
|---|---|---|---|---|
| M0 | 1.67 ± 0.06 | 1.99 ± 0.07 cd | 3.96 ± 1.28 | 4.85 ± 0.66 AB |
| M1 | 1.80 ± 0.04 | 2.09 ± 0.14 bcd | 4.21 ± 1.63 | 4.63 ± 0.85 ab |
| M2 | 1.69 ± 0.23 | 2.04 ± 0.31 cd | 4.57 ± 2.26 | 4.82 ± 0.23 AB |
| M3 | 1.94 ± 0.35 | 2.53 ± 0.55 A | 6.95 ± 0.76 | 7.81 ± 1.18 A |
| M4 | 1.68 ± 0.16 | 1.80 ± 0.07 d | 3.53 ± 0.89 | 4.43 ± 0.39 AB |
| M5 | 1.61 ± 0.20 | 1.79 ± 0.12 d | 5.40 ± 3.61 | 4.45 ± 0.42 AB |
| M6 | 1.72 ± 0.53 | 2.89 ± 0.57 AB | 5.58 ± 0.99 | 8.42 ± 1.52 A |
| M7 | 1.82 ± 0.46 | 2.51 ± 0.88 abcd | 3.57 ± 0.24 | 5.32 ± 0.90 ABC |
| M8 | 1.64 ± 0.13 | 1.78 ± 0.27 d | 3.03 ± 0.45 | 4.25 ± 0.86 c |
| M9 | 1.59 ± 0.06 | 2.56 ± 0.36 ABC | 4.55 ± 0.74 | 6.71 ± 1.22 BC |
| M10 | 1.48 ± 0.11 | 1.94 ± 0.15 cd | 4.89 ± 2.76 | 4.49 ± 0.22 ab |
| M11 | 1.57 ± 0.06 | 1.61 ± 0.02 d | 2.90 ± 0.25 | 3.94 ± 0.26 c |

**Note:** Means followed by different letters in the same column are significantly different according to Tukey's HSD test ($p < 0.05$).

*Information:* The development of rod diameter, as an indicator of structural strength and vascular capacity, showed a more pronounced response pattern to media amelioration. The M6 treatment achieved a maximum diameter of 8.42±1.52 mm at 56 HSTs, representing a remarkable 73% increase over controls (4.85±0.66 mm), while M3 showed a 61% increase with a diameter of 7.81±1.18 mm. The consistent superiority of compost-based treatment was observed since 28 HST, where M6 (2.89±0.57 mm) and M3 (2.53±0.55 mm) were significantly higher than biochar (M5: 1.79±0.12 mm) and zeolite (M4: 1.80±0.07 mm) treatments. Enhanced stem diameter in compost treatment can be attributed to improved hydraulic conductivity and enhanced cambial activity facilitated by the availability of balanced nutrients and improved soil water relations (Carmo, Lima, & Silva, 2016; Qasim et al., 2024; Simiele et al., 2022). Table 6 summarizes the temporal variation in leaf number and leaf area index across the sediment-based treatments. These parameters complement the growth assessment by illustrating the canopy expansion potential that influences photosynthetic performance and biomass accumulation.

**Table 6.** Number of leaves at different phases of growth.

| Planting media | JDA14 | JDA28 | JD42 | JDA56 |
|---|---|---|---|---|
| M0 | 4.07 ± 0.83 | 12.60 ± 2.27 abcd | 22.93 ± 3.74 abc | 43.33 ± 6.58 abc |
| M1 | 4.40 ± 0.00 | 10.40 ± 1.44 bcde | 9.00 ± 2.80 c | 43.47 ± 12.94 abc |
| M2 | 3.40 ± 1.11 | 10.93 ± 1.81 abcde | 10.40 ± 4.92 bc | 41.27 ± 5.37 abc |
| M3 | 3.40 ± 0.60 | 13.47 ± 4.59 a | 37.80 ± 14.08 a | 63.87 ± 8.77 a |
| M4 | 3.60 ± 0.87 | 9.67 ± 1.86 bcde | 7.27 ± 1.50 c | 33.33 ± 5.60 bc |
| M5 | 2.93 ± 0.81 | 7.87 ± 2.47 f | 15.20 ± 3.93 c | 29.33 ± 4.01 c |
| M6 | 3.60 ± 1.22 | 15.13 ± 4.93 abc | 36.67 ± 14.66 a | 60.60 ± 17.48 ab |
| M7 | 4.67 ± 1.30 | 11.53 ± 1.29 abcde | 24.80 ± 4.91 abc | 42.27 ± 5.64 abc |
| M8 | 3.20 ± 1.22 | 9.00 ± 0.35 cde | 16.60 ± 2.69 ab | 35.67 ± 8.16 abc |
| M9 | 3.27 ± 0.92 | 14.20 ± 1.56 ab | 30.00 ± 5.89 bc | 60.07 ± 18.05 ab |
| M10 | 2.93 ± 0.31 | 7.13 ± 0.61 e | 17.73 ± 4.69 ab | 32.33 ± 5.72 bc |
| M11 | 3.07 ± 0.31 | 8.33 ± 1.03 f | 15.93 ± 1.33 ab | 31.33 ± 3.24 c |

**Note:** Values followed by different lowercase letters within the same column indicate significant differences among treatments according to Tukey's HSD test ($p < 0.05$).

Remarks: The treatment code refers to Table 6, while the variable name corresponds to the definition in Table 2. The average score in the same column with the same lowercase letter did not differ significantly based on Tukey's follow-up test (BNJ) at a significance level of 0.05. The number of repetitions in the experiment was n = 3. Some data have been transformed before statistical analysis: inverse square root ($1/y^2$) for variable JDA14, inverse square root transformation ($1/y^2$) for variables JDA28, JDA42.

The production of leaves as primary photosynthetic organs shows a very sensitive response to nutrient availability in the planting medium. The M3 treatment yielded the highest number of leaves (63.87±8.77 leaves) at 56 HSTs, representing a 47% increase over controls (43.33±6.58 leaves), followed by M6 with 60.60±17.48 leaves. A striking contrast was seen in the treatment of high biochar (M5: 29.33±4.01 leaves) and high zeolite (M4: 33.33±5.60 leaves), which underwent severe leaf production suppression. This pattern indicates that excessive application of non-organic ameliorants can induce nutrient imbalances or physical constraints that inhibit leaf primordia development. An interesting pattern can be seen in M9 (sediment: 1:3 compost), which, despite having the highest compost, produces only 60.07±18.05 leaves, suggesting potential negative effects of excessive organic matter on physical properties of the medium or prolonged nitrogen immobilization. The temporal dynamics of leaf production reveal critical phases where ameliorant effects become most pronounced, with the acceleration phase between 28-42 HST serving as a key discriminator between successful and unsuccessful treatments. The high variability observed in some high-performing treatments (M6: ±17.48, M9: ±18.05) suggests that while these media formulations can support exceptional leaf production, they may also create conditions where individual plant responses become more heterogeneous due to localized nutrient hotspots or microenvironmental variations within the growing medium.

**Table 7.** Leaf area in different growth phases.

| Planting media | LDA14 | LDA28 | LD42 | LDA56 |
|---|---|---|---|---|
| M0 | 5.63 ± 1.59 | 32.50 ± 14.72 bcd | 133.63 ± 27.51 bc | 374.33 ± 288.70 abc |
| M1 | 6.76 ± 1.25 | 24.91 ± 5.32 bcd | 95.13 ± 33.45 c | 268.16 ± 129.76 abc |
| M2 | 4.23 ± 1.75 | 27.93 ± 11.45 bcd | 126.46 ± 54.19 bc | 273.29 ± 62.60 abc |
| M3 | 5.77 ± 2.44 | 71.18 ± 34.21 ab | 346.35 ± 146.70 ab | 591.00 ± 176.60 ab |
| M4 | 4.71 ± 1.39 | 17.99 ± 7.55 d | 88.55 ± 13.04 c | 189.95 ± 82.97 c |
| M5 | 4.87 ± 1.79 | 14.95 ± 4.22 d | 58.76 ± 13.82 c | 139.83 ± 32.19 c |
| M6 | 6.94 ± 3.13 | 92.31 ± 18.09 a | 378.77 ± 63.49 a | 640.67 ± 146.68 a |
| M7 | 6.19 ± 1.98 | 25.88 ± 7.31 bcd | 123.88 ± 33.33 bc | 333.67 ± 133.43 abc |
| M8 | 4.07 ± 1.93 | 20.74 ± 4.98 cd | 77.67 ± 35.25 c | 190.41 ± 49.18 bc |
| M9 | 4.64 ± 0.95 | 51.64 ± 8.25 abc | 290.85 ± 33.16 ab | 717.76 ± 287.63 a |
| M10 | 3.90 ± 1.36 | 12.61 ± 1.29 d | 62.51 ± 20.73 c | 158.87 ± 39.61 c |
| M11 | 3.21 ± 0.51 | 12.71 ± 3.85 d | 51.91 ± 23.73 c | 147.00 ± 29.90 c |

**Note:** Different lowercase letters (a, b, c, d) within the same column indicate significant differences among treatments according to Tukey's Honest Significant Difference (HSD) test at $p < 0.05$.

The expansion of total leaf area, an integrative proxy for canopy photosynthetic capacity, was greatest under compost-amended media, with M9 reaching 717.76 ± 287.63 $cm^2$ at 56 HST, followed by M6 (640.67 ± 146.68 $cm^2$) and M3 (591.00 ± 176.60 $cm^2$). High-biochar treatments (M5, M11) produced markedly smaller canopies (139–147 $cm^2$), indicating stunted leaf expansion (Table 7). This pattern indicates that compost fosters both higher leaf number and greater individual leaf expansion through improved water status, cell extensibility, and sustained nutrient supply (Seehausen et al., 2017; Sharma, Saha, Arora, Shah, & Nain, 2017; Wang et al., 2025), whereas excessive biochar or certain mineral amendments may induce pH shifts, micronutrient imbalances, or hydrophobic effects that limit water uptake and leaf growth. Integrated with other vegetative metrics, these results confirm the clear advantage of sediment:compost ratios 3:1 (M3) and 1:1 (M6) in rapidly restoring productivity in nutrient-poor sediments via multiple synergistic mechanisms—immediate nutrient availability, enhanced water retention and aggregate stability, and stimulation of beneficial soil microbiota—whereas biochar and zeolite appear to act primarily as longer-term conditioners whose benefits may require aging or field conditioning to materialize (Sánchez-Monedero et al., 2019; Sánchez-Monedero, Sánchez-García, Alburquerque, & Cayuela, 2019).

### *3.3. Root System Dynamics and Physiological Status of Plants*

A comprehensive characterization of root systems and physiological parameters provides critical insights into the adaptation mechanisms of soybean plants to various sediment-based media formulations, revealing hidden dynamics that are not always reflected in above-ground growth. The root architecture and symbiotic efficiency of Rhizobium are fundamental determinants of legume productivity, especially in sub-optimal media conditions where strategic root deployment and biological nitrogen fixation can compensate for nutrient limitations (Concha & Doerner, 2020; De Lara-Del Rey & Pérez-Fernández, 2023). The evaluation of integrated below-ground parameters and physiological indicators provides a holistic understanding of the plant-soil interactions that underlie differential growth responses observed in the vegetative phase.

**Table 8.** Root system parameters and physiological status.

| Planting media | PJA | CHAPTER | CONTAINER | JBA | KKT |
|---|---|---|---|---|---|
| M0 | 32.60 ± 11.98 AB | 4.371 ± 2.28 AB | 1.19 ± 0.48 abcd | 18.53 ± 15.99 | 14.06 ± 5.24 |
| M1 | 28.83 ± 6.76 AB | 3.30 ± 2.33 AB | 1.13 ± 0.44 abcd | 8.07 ± 7.43 | 11.79 ± 5.43 |
| M2 | 24.37 ± 2.52 AB | 2.97 ± 1.75 ab | 1.22 ± 0.21 abcd | 9.60 ± 1.59 | 11.84 ± 1.52 |
| M3 | 33.60 ± 1.28 A | 6.81 ± 5.40 b | 2.12 ± 0.50 ab | 13.13 ± 5.71 | 11.84 ± 2.62 |
| M4 | 16.13 ± 6.99 b | 1.23 ± 0.20 c | 0.53 ± 0.16 d | 2.53 ± 1.67 | 13.45 ± 0.67 |
| M5 | 18.33 ± 3.055 AB | 1.74 ± 0.53 ab | 0.68 ± 0.14 cd | 7,000 ± 5.01 | 9.19 ± 3.08 |
| M6 | 34.47 ± 21.39 AB | 7.57 ± 5.57 A | 2.53 ± 1.60 A | 6.07 ± 3.43 | 10.26 ± 4.10 |
| M7 | 15.97 ± 2.85 b | 1.85 ± 0.45 ab | 0.91 ± 0.130 abcd | 2.80 ± 1.31 | 8.61 ± 5.59 |
| M8 | 22.70 ± 3.61 AB | 2.95 ± 1.55 AB | 1.15 ± 0.39 abcd | 12.87 ± 5.63 | 10.02 ± 2.60 |
| M9 | 24.87 ± 8.86 AB | 7.61 ± 3.57 A | 1.67 ± 0.15 ABC | 6.87 ± 2.69 | 10.20 ± 0.74 |
| M10 | 35.50 ± 29.72 AB | 1.97 ± 0.47 ab | 0.82 ± 0.18 bcd | 3.87 ± 2.70 | 12.09 ± 2.86 |
| M11 | 20.50 ± 2.51 AB | 2.33 ± 1.28 AB | 0.96 ± 0.40 abcd | 10.27 ± 6.27 | 9.887 ± 2.43 |

**Note:** Different lowercase letters (a, b, c, d) within the same column indicate significant differences among treatments according to Tukey's Honest Significant Difference (HSD) test at $p < 0.05$.

Comprehensive root and physiological measurements indicate that compost-amended media (notably M3 and M6) promoted balanced root–shoot development and the greatest root biomass, whereas some mineral-rich treatments produced either excessive root elongation without corresponding shoot growth (e.g., M10, high variability) or strong root suppression (M4, M5), suggesting nutrient stress or toxicity (Junaidi, Kallenbach, Byrne, & Fonte, 2018; Kiani et al., 2021). Although control plants sometimes exhibited more nodules numerically, nodulation did not directly translate into productivity consistent with the distinction between nodule number and nodule effectiveness, while compost treatments appeared to support fewer but potentially more effective nodules through improved micronutrient and microbial conditions (Concha & Doerner, 2020; De Lara-Del Rey & Pérez-Fernández, 2023). Leaf chlorophyll varied little across treatments, implying maintained basic photosynthetic capacity despite large differences in leaf area and total photosynthetic surface (Braga et al., 2024), a pattern compatible with the "dilution" effect during rapid canopy expansion. Overall, these results suggest that compost delivers immediate, multifaceted benefits enhancing nutrient availability, rhizosphere health, and efficient resource allocation whereas high rates of biochar or zeolite may induce imbalances (pH, micronutrient availability, or cation competition) that compromise physiological performance; therefore, successful sediment amelioration must optimize both nutrient supply and biological conditions to translate below-ground improvements into durable yield gains (Junaidi et al., 2018; Kelly et al., 2022).

### *3.4. Translation of Vegetative Growth to Productivity: An Analysis of Yield Components*

Evaluation of yield components is the definitive parameter to assess the effectiveness of sediment-based media amelioration in supporting soybean crop productivity. The transition from vegetative vigor to reproductive output involves a complex allocation of resources that is strongly influenced by nutrient availability and planting media conditions during the critical phases of pod formation and seed filling (Junaidi et al., 2018; Kelly et al., 2022).

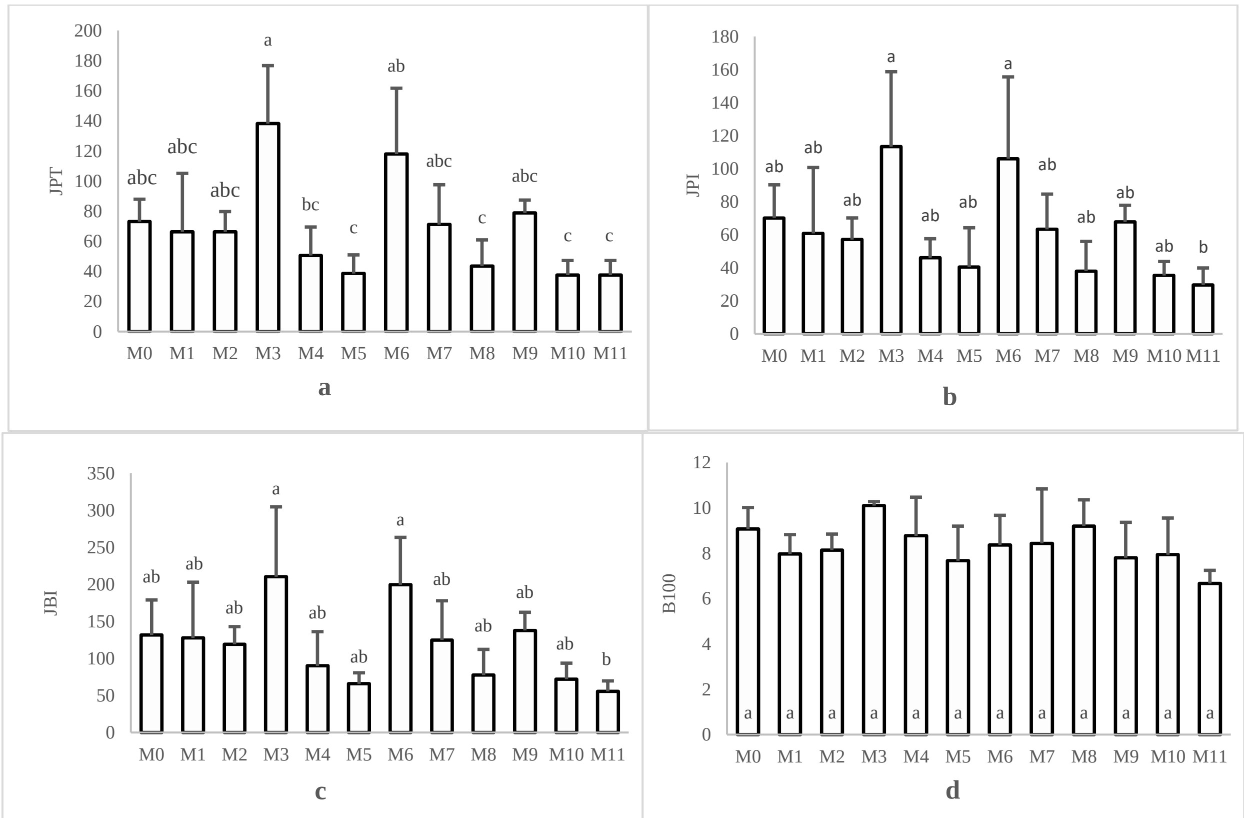


**Figure 2.** Components of soybean crop yield.

**Note:** Caption of Figure 2. The mean (± standard deviation) of a. The total number of pods; b. Number of filling pods; c. The number of seeds, and d. The weight of 100 soybean seeds in various planting media treatments.

The treatment code refers to Table 1, while the variable name corresponds to the definition in Table 2. The values followed by the same letter did not differ significantly based on Tukey's post hoc test (BNJ) at a significance level of 0.05. Number of repetitions: n = 3. The original data had previously undergone a logarithmic transformation [log(y)] to meet the normality assumptions in statistical analysis (applicable to JPT, JPI, and JBI variables).

Compost-amended media, particularly M3 (3:1) and M6 (1:1), translated vegetative vigor into markedly superior reproductive performance, with pod filling rates above 89% and seed numbers 51–60% higher than the control, while biochar-dominated treatments (M5, M11) suffered severe reproductive failure with reductions exceeding 50% (Junaidi et al., 2018; Kelly et al., 2022). Importantly, M3 maintained seed size despite increased seed number, resulting in a 68% yield advantage (2.65 t $ha^{-1}$) over the control, highlighting balanced source–sink relationships. This agronomic gain corresponds to substantial economic benefits estimated at Rp 10.7 million $ha^{-1}$ additional revenue and a benefit–cost ratio of 4.25, demonstrating that compost-based amelioration is not only technically effective but also economically viable (Bremaghani, 2024; Sánchez-Monedero et al., 2019). These findings underscore the capacity of compost to optimize nutrient availability, water retention, and soil structure in tandem, thereby transforming river sediments into sustainable, productive media for soybean cultivation.

### *3.5. Integrated Multivariate Analysis: Uncovering Holistic Response Patterns*

The complexity of the interactions between growth, physiological, and productivity parameters in sediment-based media systems requires a multidimensional analytical approach to uncover response patterns that are not detected through conventional univariate analysis. Principal Component Analysis (PCA) provides a robust statistical framework to reduce data dimensionality while maintaining maximum information about variability between treatments, allowing for the identification of key gradients that determine the success of amelioration (Duforet-Frebourg, Luu, Laval, Bazin, & Blum, 2016; Gewers et al., 2021; Jolliffe & Cadima, 2016; Kiani et al., 2021). Simultaneous evaluation of 10 key growth and yield parameters revealed the underlying structure that explains the differential response of soybean plants to various sediment amelioration strategies.

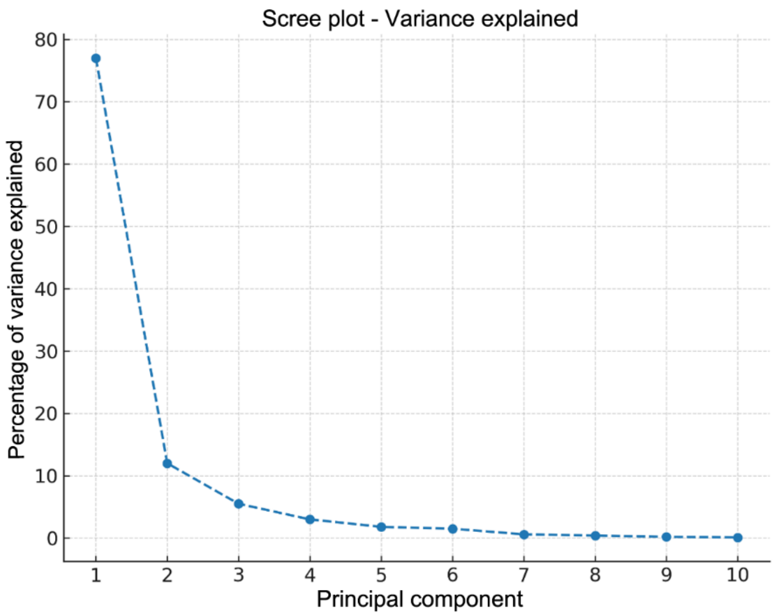


**Figure 3.** PCA scree plot.

Dimensionality reduction of the integrated dataset produced a clear and interpretable ordination: PC1 accounted for 76.8% of the total variance, and PC2 accounted for an additional 12.3% (cumulative 89.1%), indicating that two components capture the overwhelming majority of treatment-driven variability (Figure 3). Loadings on PC1 were dominated by yield and growth variables (Seed number 0.38; filled pods 0.36; leaf area 0.34; height 0.32; root dry weight 0.30), justifying the interpretation of PC1 as an integrated "productivity" axis, whereas PC2 contrasted root development against reproductive output, reflecting alternative allocation strategies among treatments. Treatment scores cluster consistently in PCA space: compost-amended media (notably M3, M6, M9) occupy high positive PC1 values, forming a distinct high-performance group, while biochar- and high-zeolite treatments cluster on the negative side of PC1; controls and sediment-only occupy intermediate positions. Multivariate hypothesis testing (PERMANOVA; pseudo-F = 12.4, $p < 0.001$) and pairwise contrasts (compost vs. mineral clusters, $t = 4.82$, $p < 0.001$) statistically validate these separations. Collectively, the PCA results indicate that the primary effect of amelioration treatments is coherent and unidirectional compost creates a suite of synergistic improvements across physiological, growth, and yield traits, whereas some mineral amendments induce fragmented or adverse responses and thus provide a robust, multivariate basis for recommending compost-based strategies for sediment valorization (Bertolini, Royer, & Pastres, 2021; Brown, Butler, Radford‐Smith, & Dwyer, 2022; Miller, Carlile, Phillips, McDuie, & Congdon, 2018).

## 4. CONCLUSION

This study demonstrates that Serayu River sediment, when appropriately amended, particularly with compost at 3:1 and 1:1 ratios, can be transformed into a productive growing medium for soybean, yielding substantial improvements in growth, root function, and reproductive output. Beyond the experimental results, the findings have broader implications: valorizing river sediment through organic amendments aligns with principles of sustainable agriculture and circular economy by converting a waste stream into a valuable input, reducing pressure on arable land, and closing local nutrient loops. Such practices can contribute to enhanced smallholder productivity and food security in areas affected by sedimentation or land degradation. However, translation to practice requires caution: before widescale adoption, field trials across seasons, monitoring of metal (Loid) contaminants, life-cycle and cost–benefit assessments, and guidelines for safe sediment sourcing and amendment rates are essential. Policymakers and land managers could incorporate sediment valorization strategies into integrated watershed and agricultural planning, pairing sediment reuse with composting programs, farmer training, and targeted subsidies or incentives that promote circular-economy approaches. Overall, the results support a pragmatic pathway for transforming a sediment management challenge into an opportunity for sustainable intensification and resilient food systems.

**Funding:** This research is funded by LPPM-UMP through the 2024 Professor Acceleration Program (Grant number: 98765432).
**Institutional Review Board Statement:** Not applicable.
**Transparency:** The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
**Competing Interests:** The authors declare that they have no competing interests.
**Authors' Contributions:** All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
**Disclosure of AI Use:** The author(s) used OpenAI's ChatGPT to edit and refine the wording of the Introduction. All outputs were reviewed and verified by the authors.

## REFERENCES

Adebayo, A., Kiani, S., Ruotsalainen, A. L., Pirttilä, A. M., & Lehosmaa, K. (2023). Growth of floating hook-moss (Warnstorfia fluitans) differs with nutrient and water flow adjustments in greenhouse and cold room conditions. *Heliyon*, *9*(1), e12821. https://doi.org/10.1016/j.heliyon.2023.e12821

Azad, K. M. S., Hossain, N., Islam, M. J., Rahman, A., & Kabir, S. (2021). *Preventive determination and avoidance of ddos attack with sdn over the iot networks.* Paper presented at the 2021 International Conference on Automation, Control and Mechatronics for Industry 4.0 (ACMI).

Barneveld, H. J., Frings, R. M., Mosselman, E., Venditti, J. G., Kleinhans, M. G., Blom, A., . . . Hoitink, A. J. F. (2025). Extreme river flood exposes latent erosion risk. *Nature*, *644*, 391–397. https://doi.org/10.1038/s41586-025-09305-3

Bertolini, C., Royer, E., & Pastres, R. (2021). Multiple evidence for climate patterns influencing ecosystem productivity across spatial gradients in the Venice Lagoon. *Journal of Marine Science and Engineering*, *9*(4), 363. https://doi.org/10.3390/jmse9040363

Braga, B. B., Costa, C. A. G., Lima, G. D., De Lacerda, C. F., Foerster, S., Brosinsky, A., & Medeiros, P. H. A. (2024). Reuse of sediment as a soil conditioner in a semiarid region dominated by subsistence farming: Sediment characterization at the regional scale and effects on maize crop. *Journal of Soils and Sediments*, *24*(2), 1039-1055. https://doi.org/10.1007/s11368-023-03679-5

Braga, B. B., Junior, F. H. N., Barbosa, R. M., Brito, P. O, B, d., Martins, K., Medeiros, P. H. A., & Gondim, F. A. (2017). Biomass production and antioxidative enzyme activities of sunflower plants growing in substrates containing sediment from a tropical reservoir. *Journal of Agricultural Science*, *9*(5), 1-12. https://doi.org/10.5539/jas.v9n5p95

Braga, D. P. P., Domene, F., & Gandara, F. B. (2019). Shade trees composition and diversity in cacao agroforestry systems of Southern Pará, Brazilian Amazon. *Agroforestry Systems*, *93*(4), 1409-1421. https://doi.org/10.1007/s10457-018-0250-6

Bremaghani, A. (2024). Utilization of organic waste in compost fertilizer production: Implications for sustainable agriculture and nutrient management. *Law and Economics*, *18*(2), 86-98.

Brown, A., Butler, D. W., Radford-Smith, J., & Dwyer, J. M. (2022). Changes in trait covariance along an orographic moisture gradient reveal the relative importance of light-and moisture-driven trade-offs in subtropical rainforest communities. *New Phytologist*, *236*(3), 839-851. https://doi.org/10.1111/nph.18418

Buscaroli, A., Zannoni, D., & Dinelli, E. (2021). Spatial distribution of elements in near surface sediments as a consequence of sediment origin and anthropogenic activities in a coastal area in Northern Italy. *Catena*, *196*, 104842. https://doi.org/10.1016/j.catena.2020.104842

Carmo, D. L. D., Lima, L. B. d., & Silva, C. A. (2016). Soil fertility and electrical conductivity affected by organic waste rates and nutrient inputs. *Revista Brasileira de Ciência do Solo*, *40*, e0150152. https://doi.org/10.1590/18069657rbcs20150152

Concha, C., & Doerner, P. (2020). The impact of the rhizobia–legume symbiosis on host root system architecture. *Journal of Experimental Botany*, *71*(13), 3902-3921. https://doi.org/10.1093/jxb/eraa198

De Lara-Del Rey, I. A., & Pérez-Fernández, M. A. (2023). Regulatory effect of light and rhizobial inoculation on the root architecture and plant performance of pasture legumes. *Agronomy*, *13*(8), 2058. https://doi.org/10.3390/agronomy13082058

Di Carlo, E., Chen, C. R., Haynes, R. J., Phillips, I. R., & Courtney, R. (2019). Soil quality and vegetation performance indicators for sustainable rehabilitation of bauxite residue disposal areas: A review. *Soil Research*, *57*(5), 419-446. https://doi.org/10.1071/SR18348

Ding, Y., Liu, Y., Liu, S., Li, Z., Tan, X., Huang, X., . . . Zheng, B. (2016). Biochar to improve soil fertility. A review. *Agronomy for Sustainable Development*, *36*(2), 36. https://doi.org/10.1007/s13593-016-0372-z

Douglas, E. J., Pilditch, C. A., Lohrer, A. M., Savage, C., Schipper, L. A., & Thrush, S. F. (2018). Sedimentary environment influences ecosystem response to nutrient enrichment. *Estuaries and Coasts*, *41*(7), 1994-2008. https://doi.org/10.1007/s12237-018-0416-5

Duforet-Frebourg, N., Luu, K., Laval, G., Bazin, E., & Blum, M. G. B. (2016). Detecting genomic signatures of natural selection with principal component analysis: Application to the 1000 genomes data. *Molecular Biology and Evolution*, *33*(4), 1082-1093. https://doi.org/10.1093/molbev/msv334

Fan, H., Liao, J., Abass, O. K., Liu, L., Huang, X., Wei, L., . . . Liu, C. (2019). Effects of compost characteristics on nutrient retention and simultaneous pollutant immobilization and degradation during co-composting process. *Bioresource Technology*, *275*, 61-69. https://doi.org/10.1016/j.biortech.2018.12.049

Gathagu, J. N., Mourad, K. A., & Sang, J. (2018). Effectiveness of contour farming and filter strips on ecosystem services. *Water*, *10*(10), 1312. https://doi.org/10.3390/w10101312

Gewers, F. L., Ferreira, G. R., Arruda, H. F. D., Silva, F. N., Comin, C. H., Amancio, D. R., & Costa, L. D. F. (2021). Principal component analysis: A natural approach to data exploration. *ACM Computing Surveys (CSUR)*, *54*(4), 1-34. https://doi.org/10.1145/3447755

Hammer, Ø., Harper, D. A. T., & Ryan, P. D. (2001). Past: paleontological statistics software package for education and data analysis. *Palaeontologia electronica, 4*(1), 1-9.
Hammer, Ø., Harper, D. A. T., & Ryan, P. D. (2016). *Paleontological statistics, version 3.13*. Oslo, Norway: Natural History Museum, University of Oslo.
Iliyasu, R., & Etikan, I. (2021). Comparison of quota sampling and stratified random sampling. *Biometrics & Biostatistics International Journal, 10*(1), 24-27. https://doi.org/10.15406/bbij.2021.10.00326
Jolliffe, I. T., & Cadima, J. (2016). Principal component analysis: A review and recent developments. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 374*(2065), 20150202. https://doi.org/10.1098/rsta.2015.0202
Junaidi, J., Kallenbach, C. M., Byrne, P. F., & Fonte, S. J. (2018). Root traits and root biomass allocation impact how wheat genotypes respond to organic amendments and earthworms. *PLoS One, 13*(7), e0200646. https://doi.org/10.1371/journal.pone.0200646
Kapoor, A., Sharma, R., Kumar, A., & Sepehya, S. (2022). Biochar as a means to improve soil fertility and crop productivity: A review. *Journal of Plant Nutrition, 45*(15), 2380-2388. https://doi.org/10.1080/01904167.2022.2027980
Karimuna, L., Rahni, N. M., & Boer, D. (2016). The use of Bokashi to enhance agricultural productivity of marginal soils in Southeast Sulawesi, Indonesia. *Journal of Tropical Crop Science, 3*(1), 1–6. https://doi.org/10.29244/jtcs.3.1.1-6
Kelly, C., Haddix, M. L., Byrne, P. F., Cotrufo, M. F., Schipanski, M. E., Kallenbach, C. M., . . . Fonte, S. J. (2022). Long-term compost amendment modulates wheat genotype differences in belowground carbon allocation, microbial rhizosphere recruitment and nitrogen acquisition. *Soil Biology and Biochemistry, 172*, 108768. https://doi.org/10.1016/j.soilbio.2022.108768
Kiani, M., Raave, H., Simojoki, A., Tammeorg, O., & Tammeorg, P. (2021). Recycling lake sediment to agriculture: Effects on plant growth, nutrient availability, and leaching. *Science of the Total Environment, 753*, 141984. https://doi.org/10.1016/j.scitotenv.2020.141984
Kiani, R., Arzani, A. M., & Maibody, S. (2021). Polyphenols, flavonoids, and antioxidant activity involved in salt tolerance in wheat, aegilops cylindrica and their amphidiploids. *Frontiers in Plant Science, 12*, 646221. https://doi.org/10.3389/fpls.2021.646221
Lehmann, L., Giacomoni, M., Maso, F., Colard, J., Margaritis, I., & Duche, P. (2025). Energy availability and macronutrient intake over a 7-day training period in adolescent rugby players. *The Journal of Sports Medicine and Physical Fitness, 65*(5), 641-649. https://doi.org/10.23736/s0022-4707.24.16183-x
Lehrsch, G. A., Brown, B., Lentz, R. D., Johnson-Maynard, J., & Leytem, A. B. (2016). Winter and growing season nitrogen mineralization from fall-applied composted or stockpiled solid dairy manure. *Nutrient Cycling in Agroecosystems, 104*(2), 125-142. https://doi.org/10.1007/s10705-015-9755-9
Liu, C., Walling, D. E., & He, Y. (2018). The international sediment initiative case studies of sediment problems in river basins and their management. *International Journal of Sediment Research, 33*(2), 216-219.
Liu, X., Tao, Y., Zhou, K., Zhang, Q., Chen, G., & Zhang, X. (2017). Effect of water quality improvement on the remediation of river sediment due to the addition of calcium nitrate. *Science of the Total Environment, 575*, 887-894. https://doi.org/10.1016/j.scitotenv.2016.09.149
Mao, W., Kang, S., Wan, Y., Sun, Y., Li, X., & Wang, Y. (2016). Yellow River sediment as a soil amendment for amelioration of saline land in the Yellow River Delta. *Land Degradation & Development, 27*(6), 1595-1602. https://doi.org/10.1002/ldr.2323
Massawe, P. I., Mtei, K. M., Munishi, L. K., & Ndakidemi, P. A. (2016). Improving soil fertility and crops yield through maize-legumes (common bean and Dolichos lablab) intercropping systems. *Journal of Agricultural Science, 8*(12), 148-163. https://doi.org/10.5539/jas.v8n12p148
Miller, M. G. R., Carlile, N., Phillips, J. S., McDuie, F., & Congdon, B. C. (2018). Importance of tropical tuna for seabird foraging over a marine productivity gradient. *Marine Ecology Progress Series, 586*, 233-249. https://doi.org/10.3354/meps12376
Mupambwa, H. A., & Mnkeni, P. N. S. (2018). Optimizing the vermicomposting of organic wastes amended with inorganic materials for production of nutrient-rich organic fertilizers: A review. *Environmental Science and Pollution Research, 25*(11), 10577-10595. https://doi.org/10.1007/s11356-018-1328-4
Mutammimah, U., Minardi, S., & Suryono, S. (2020). Organic amendments effect on the soil chemical properties of marginal land and soybean yield. *Journal of Degraded and Mining Lands Management, 7*(4), 2263–2268.
Owens, P. N. (2020). Soil erosion and sediment dynamics in the Anthropocene: A review of human impacts during a period of rapid global environmental change. *Journal of Soils and Sediments, 20*(12), 4115-4143. https://doi.org/10.1007/s11368-020-02815-9
PPT. (1995). *Procedures for the physical and chemical analysis of soils*. Accra, Ghana: Soil Research Institute, Ministry of Agriculture.
Qasim, S., Gul, S., Ziad, T., Yunus, A. W., Khan, R. U., Akbar, A., & Buriro, A. H. (2024). Influence of composted manures and co-composted biochar on growth performance of saffron and soil nutrients under varying electrical conductivity soil conditions: A two-year field study. *Journal of Agriculture and Food Research, 18*, 101467. https://doi.org/10.1016/j.jafr.2024.101467
Reichert-Nguyen, J., French, E., & Slacum, W. (2016). Panel recommendations on the Oyster BMP nutrient and suspended sediment reduction effectiveness determination decision framework and nitrogen and phosphorus assimilation in oyster tissue reduction effectiveness for oyster aquaculture practices. *Oyster BMP Expert Panel First Incremental Report, 1*, 1–197.
Reid, A. J., Carlson, A. K., Creed, I. F., Eliason, E. J., Gell, P. A., Johnson, P. T. J., . . . Ormerod, S. J. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews, 94*(3), 849-873.
Ruiz-Compean, P., Ellis, J., Cúrdia, J., Payumo, R., Langner, U., Jones, B., & Carvalho, S. (2017). Baseline evaluation of sediment contamination in the shallow coastal areas of Saudi Arabian Red Sea. *Marine Pollution Bulletin, 123*(1-2), 205-218. https://doi.org/10.1016/j.marpolbul.2017.08.059
Safhi, A. E. M. (2022). *Valorization of dredged sediments as sustainable construction resources*. Boca Raton, FL: CRC Press.
Sánchez-Monedero, M. A., Cayuela, M. L., Sánchez-García, M., Vandecasteele, B., D'Hose, T., López, G., . . . Mondini, C. (2019). Agronomic evaluation of biochar, compost and biochar-blended compost across different cropping systems: Perspective from the European project FERTIPLUS. *Agronomy, 9*(5), 225. https://doi.org/10.3390/agronomy9050225

Sánchez-Monedero, M. A., Sánchez-García, M., Alburquerque, J. A., & Cayuela, M. L. (2019). Biochar reduces volatile organic compounds generated during chicken manure composting. *Bioresource Technology*, *288*, 121584. https://doi.org/10.1016/j.biortech.2019.121584

Seehausen, M. L., Gale, N. V., Dranga, S., Hudson, V., Liu, N., Michener, J., . . . Thomas, S. C. (2017). Is there a positive synergistic effect of biochar and compost soil amendments on plant growth and physiological performance? *Agronomy*, *7*(1), 13. https://doi.org/10.3390/agronomy7010013

Sharma, A., Saha, T. N., Arora, A., Shah, R., & Nain, L. (2017). Efficient microorganism compost benefits plant growth and improves soil health in calendula and marigold. *Horticultural Plant Journal*, *3*(2), 67-72. https://doi.org/10.1016/j.hpj.2017.07.003

Simiele, M., De Zio, E., Montagnoli, A., Terzaghi, M., Chiatante, D., Scippa, G. S., & Trupiano, D. (2022). Biochar and/or compost to enhance nursery-produced seedling performance: A potential tool for forest restoration programs. *Forests*, *13*(4), 550. https://doi.org/10.3390/f13040550

Singh, N. K., Sachan, K., Ranjitha, G., Chandana, S., Manoj, B. P., Panotra, N., & Katiyar, D. (2024). Building soil health and fertility through organic amendments and practices: A review. *Asian Journal of Soil Science and Plant Nutrition*, *10*(1), 175-197. https://doi.org/10.9734/ajsspn/2024/v10i1224

Stewart, Z. P., Pierzynski, G. M., Middendorf, B. J., & Prasad, P. V. V. (2020). Approaches to improve soil fertility in Sub-Saharan Africa. *Journal of experimental botany*, *71*(2), 632-641. https://doi.org/10.1093/jxb/erz446

Szara-Bąk, M., Baran, A., & Klimkowicz-Pawlas, A. (2023). Recycling of bottom sediment to agriculture: Effects on plant growth and soil properties. *Journal of Soils and Sediments*, *23*(1), 539-551. https://doi.org/10.1007/s11368-022-03363-0

Thapa, S., Sinclair, H. D., Creed, M. J., Borthwick, A. G. L., Watson, C. S., & Muthusamy, M. (2024). Sediment transport and flood risk: Impact of newly constructed embankments on river morphology and flood dynamics in Kathmandu, Nepal. *Water Resources Research*, *60*(10), e2024WR037742. https://doi.org/10.1029/2024WR037742

Verma, P., Singh, D., Pathania, I. P., & Aggarwal, K. (2019). Strategies to improve agriculture sustainability, soil fertility and enhancement of farmers income for the economic development. In Soil fertility management for sustainable development. In (pp. 43-70). Singapore: Springer.

Wang, X., Sale, P., Hunt, J., Clark, G., Wood, J. L., Franks, A. E., . . . Tang, C. (2025). Enhancing growth and transpiration efficiency of corn plants with compost addition and potential beneficial microbes under well-watered and water-stressed conditions. *Plant and Soil*, *514*, 2475–2493. https://doi.org/10.1007/s11104-025-07527-y

Zorzal-Almeida, S., Salim, A., Andrade, M. R. M., de Novaes Nascimento, M., Bini, L. M., & Bicudo, D. C. (2018). Effects of land use and spatial processes in water and surface sediment of tropical reservoirs at local and regional scales. *Science of the Total Environment*, *644*, 237-246. https://doi.org/10.1016/j.scitotenv.2018.06.361