

EFFECTS OF SOIL AMENDMENTS ON  
EARLY GROWTH OF CACAO  
SEEDLINGS USING ACIDIC RED SOIL  
FROM SITIO KAPATAGAN, GUPITAN,  
KAPALONG

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**ABSTRACT**

Cacao (*Theobroma cacao*) production is often constrained by highly acidic soils that limit nutrient availability and hinder early seedling development. This experimental study aimed to determine the effects of various organic soil amendments on the growth performance of cacao seedlings under acidic soil conditions in Brgy. Gupitan. Five treatments, T1 (Control), T2 (Vermicompost + Chicken dung, T3 (Chicken dung + Carbonized Rice Hull, T4 (Vermicompost + Carbonized Rice Hull), and T5 (Vermicompost + Chicken Dung + Carbonized Rice Hull), were evaluated using a randomized complete block design. Growth parameters, including seedling vigor index, seedling height, number of leaves, stem diameter, leaf length, leaf width, shoot length, and root length, were measured at multiple intervals. Results showed significant improvements across most growth indicators in plants treated with organic amendments. T5 consistently produced the highest seedling height, leaf dimensions, stem diameter, and shoot length, while T4 recorded the highest seedling vigor index and root length. The findings demonstrated that the combined application of vermicompost, chicken dung, and carbonized rice hull markedly enhanced cacao seedlings' growth in acidic soil. These results suggest that organic amendments can serve as effective, sustainable options for improving cacao establishment in marginal soils.

Keywords: ***Acidic Soil; Plant Growth; Soil Amendments; Soil pH; Vermicompost***

## INTRODUCTION

Cacao (*Theobroma cacao* L.) is an economically important tropical crop that supports the livelihoods of millions of smallholder farmers worldwide, primarily due to its central role in chocolate production and the global cocoa industry. Despite its economic significance, cacao productivity is often constrained by environmental factors, particularly soil acidity, which is prevalent in many tropical regions. Acidic soils negatively affect plant growth by reducing the availability of essential nutrients such as phosphorus, calcium, and magnesium, while increasing the solubility of toxic elements like aluminum and manganese. These conditions impair root development, restrict nutrient uptake, and ultimately reduce seedling vigor and overall crop performance (Regasa et al., 2025).

Soil acidity is a widespread problem affecting a significant portion of arable land globally and is considered a major factor contributing to declining agricultural productivity. In acidic soils, phosphorus becomes less available due to fixation by aluminum and iron compounds, making it inaccessible to plants and further limiting growth. According to Chen and Lai (2024), improving soil nutrient availability through organic amendments such as vermicompost can enhance soil quality and nutrient dynamics, thereby supporting better plant growth. Similarly, Toor et al. (2024) reported that vermicompost application improves soil fertility, increases nutrient availability, and enhances plant physiological performance, emphasizing its potential as a sustainable soil amendment.

The issue of soil acidity is further exacerbated by unsustainable land-use practices, including deforestation, continuous cropping, and the excessive or improper use of chemical fertilizers. These practices accelerate soil degradation, leading to declining soil fertility and reduced agricultural productivity. Consequently, farmers, especially those in developing countries, face increasing challenges in maintaining cacao yield and quality, which directly affects their income and food security. In the Philippines, cacao production is recognized as a promising agricultural sector; however, it continues to face several constraints. These include the widespread occurrence of acidic soils, limited financial resources, inadequate access to modern farming technologies, and insufficient agricultural extension services. These challenges are more pronounced in upland and indigenous communities, where farmers often rely on traditional practices and have limited exposure to improved soil management strategies. In Sitio Kapatagan, Barangay Gupitan, a predominantly agricultural area, highly acidic red soils significantly restrict cacao production. Indigenous farmers in this locality are particularly affected, as poor soil conditions hinder plant establishment and growth, thereby limiting productivity and economic opportunities.

While various methods of managing soil acidity have been studied, there remains a gap in research focusing on low-cost, locally available organic amendments suitable for upland indigenous farming systems. Organic materials such as vermicompost, decomposed chicken dung, and carbonized rice hull have shown potential in improving soil physicochemical properties, increasing soil pH, enhancing nutrient availability, and reducing soil acidity (Abu Regasa et al., 2025). However, limited studies have examined their combined effects on cacao plantlet growth in acidic soils, particularly within indigenous farming communities.

This study aims to evaluate the effects of vermicompost, decomposed chicken dung, and carbonized rice hull on the growth performance of cacao plantlets cultivated in acidic soils. By identifying effective, affordable, and sustainable soil management practices, this research seeks to contribute to improved cacao production among smallholder and indigenous farmers. Furthermore, the findings of this study may support community-based agricultural training programs and promote environmentally sustainable farming practices. In a broader context, this research supports the United Nations Sustainable Development Goals (SDGs), particularly SDG 1 (No Poverty) by enhancing farmers' livelihoods, SDG 2 (Zero Hunger) by improving agricultural productivity and food security, SDG 4 (Quality Education) through knowledge transfer and community-based training, and SDG 13 (Climate Action) by promoting sustainable and eco-friendly soil management practices that contribute to environmental conservation.

## **METHODOLOGY**

### **Research Design**

A quantitative experimental design was used to determine the effects of soil amendments on the growth of cacao plantlets in acidic soil. Treatments were arranged in a Completely Randomized Design (CRD) to ensure unbiased results. This approach allowed for the systematic measurement of growth parameters under controlled conditions.

This study employed a quantitative experimental research design to determine the effects of different soil amendments on the germination and growth performance of cacao seedlings grown in acidic soil. According to Creswell and Creswell (2018), experimental research is used to examine the effect of treatments or interventions on specific outcomes under controlled conditions. This design enables researchers to collect numerical data and objectively compare the effects of different treatments. The study was arranged using a Completely Randomized Design (CRD), in which treatments were assigned randomly to the experimental units. Gomez and Gomez (1984) explained that CRD is appropriate when experimental units are relatively uniform, as it helps minimize bias and experimental error through randomization.

This design was considered appropriate for the study because it allowed the researchers to evaluate and compare the effects of different soil amendment combinations on cacao seedlings under controlled nursery conditions. The use of random treatment allocation and quantitative measurements provided reliable data for assessing seedling germination and growth responses.

### **Research Locale and Duration of the Study**

The study was conducted in Purok Lumad Dugayan, a small community within Barangay Gupitan, Kapalong, Davao del Norte. The experimental area consisted of 225 cacao seedlings, which were used to evaluate growth performance under acidic soil conditions with different soil amendments.

## Experimental Design and Treatments

This study was utilized and is laid out in a Completely Randomized Design (CRD). The treatments were as follows:

- T1- Control (Acidic Soil only)
- T2- Vermicompost (5 g) + Decomposed Chicken Dung (5 g)
- T3- Decomposed Chicken Dung (5 g) + Carbonized Rice Hull (5 g)
- T4- Vermicompost (5 g) + Carbonized Rice Hull (5 g)
- T5- Vermicompost (5 g) + Decomposed Chicken Dung (5 g)  
+ Carbonized Rice Hull (5 g)

## Seedling Establishment and Maintenance

### Nursery Installation

The 25-square-meter area is set up specifically for early seedlings or young plants' early growth and development, ensuring controlled conditions for optimal establishment. The structure was constructed using bamboo, twine, net, and nails, with 225 poly bags of a size of 6 x 8.

### Disinfection

Disinfection employs a sprayer to sterilize tools, containers, and the growing environment thoroughly. This critical step prevents the spread of pathogens and diseases, fostering clean conditions necessary for the healthy development of seedlings and young plants.

### Soil Media and Treatment Application

The study utilized acidic soil collected from Sitio Kapatagan, a cacao-growing area within Brgy. Gupitan, Kapalong. The soil was placed in 6 x 8-inch polyethylene bags to serve as individual growth units for the cacao seedlings. Each bag was prepared to provide adequate drainage and sufficient space for root development while maintaining uniform conditions across all samples.

### Seed Preparation, Extraction and Cleaning

Fully ripened pods were selected based on external characteristics, including uniform color, absence of physical damage, and freedom from visible disease symptoms. The pods were manually opened using a clean knife, and the seeds were removed together with the mucilage. All extracted seeds were washed under running clean water to remove the remaining pulp. Damaged, undersized, or discolored seeds were discarded to ensure uniformity and viability of planting materials.

### Pre-Selection and Soaking, and Sowing Procedure

The cleaned seeds were subjected to a pre-selection process using the flotation method: seeds were placed in clean water, and floating seeds were discarded as they typically indicate low viability. The remaining viable seeds were soaked in clean water for 12-24 hours

to promote uniform germination and rehydration. After soaking, seeds were sown directly into individual bags containing the prepared growing medium according to the experimental treatments. Each seed was planted at a depth of 1-2 cm with the embryo side positioned upward.

### **Soil Amendments Application**

The vermicompost was sourced from a nursery in Asuncion, Davao del Norte, while the decomposed chicken dung was obtained from a poultry farm in Brgy. Gupitan. The carbonized rice hull was purchased in Tagum City from a banana chips factory transported in highways. The soil amendments were applied basally at a standard dosage of 5 grams per polyethylene bag before sowing the cacao seeds. Each seed was then planted directly into the amended soil. All seedlings were subjected to the same soil preparation and treatment procedure to maintain consistency, allowing for accurate comparison of growth performance under the different treatment conditions.

### **Nursery Management**

Seedlings were monitored daily, and germination was recorded from emergence until complete germination. Weeding and maintenance were performed manually whenever necessary. No chemical treatments were applied during the germination stage to maintain organic growth conditions. Seedlings were allowed to establish for 4-6 weeks, after which they were considered ready for treatment application and subsequent data collection.

### **Data Gathered**

#### **Germination Percentage**

This was calculated by dividing the number of seeds germinated by the total number of seeds planted, then multiplying the result by 100. The measurement was recorded at the termination of the study.

#### **Germination Rate (GR)**

Germination speed was monitored by counting the number of seeds that germinated and dividing it by the total time (in days) taken. This was done using 10 seedling samples per treatment.

$$\text{Germination Rate} = \frac{\text{Total Germinated Seeds}}{\text{Time (days)}} \times 100$$

#### **Seedling Vigor Index (SVI)**

This index measures the overall health and growth of cacao seedlings. It is calculated by multiplying the germination percentage by the total seedling length (including both shoot and root). SVI reflects the strength and vigor of the seedlings. This was measured at 15, 30, 60, and 90 days after planting using tape measure.

$$\text{SVI} = \text{Germination Percentage} \times \text{Seedling Length (Shoot + Root)}$$

## **Seedling Height**

Seedling height was measured from the plant's base (soil level) to the tip of the highest functional leaf of ten (10) sample experimental plants using tape measure. Measurements were taken at 15, 30, 45, and 60 days after planting using tape measure.

## **Number of Leaves**

Ten randomly selected experimental plants were counted manually, recording only healthy, undamaged leaves. Measurements were taken at 15, 30, 45, and 60 days after planting.

## **Stem Diameter**

Stem diameter was measured using a caliper at a consistent height of 5 cm above the soil level. The caliper was carefully placed around the stem to avoid compression or damage, and the reading was recorded to the nearest centimeter. Measurements were taken at 15, 30, 45, and 60 days after planting.

## **Leaf Length**

The length of the third fully mature leaf from the shoot (the third leaf from the growing tip or apical meristem) to the tip of the leaf was measured using a ruler or measuring tape and recorded in centimeters. Measurements were taken on 10 seedling samples per treatment at 15, 30, 45, and 60 days after planting.

## **Leaf Width**

The widest part of the third fully mature leaf from the shoot, typically across the middle, was measured using a ruler and recorded in centimeters. Measurements were taken on 10 seedling samples per treatment at 15, 30, 45, and 60 days, and at the termination of the study.

## **Shoot and Root Length**

Shoot length was measured from the point of shoot emergence to the tip of the shoot using a ruler or measuring tape and recorded in centimeters. Measurements were taken from ten (10) sample seedlings per treatment at 45 and 60 days after sowing to determine the effect of the soil amendments on shoot growth. The length of the primary root (taproot) was measured from the base of the cacao seed to the root tip. Five (5) seedlings from each treatment group were carefully uprooted to avoid damaging the roots. Root length was recorded in centimeters at the termination of the study.

## **Soil pH and Nutrient Content**

Soil pH was measured initially to assess the effects of soil amendments on soil acidity. Soil nutrient content, including key nutrients such as nitrogen, phosphorus, and potassium, was analyzed to determine soil status.

Environmental Conditions

Temperature and relative humidity (RH) were recorded using a hygrometer. Measurements were taken daily in the morning, afternoon, and evening to capture variations throughout the day.

Statistical Analysis

All quantitative data were subjected to statistical analysis using Analysis of Variance (ANOVA) in a Completely Randomized Design (CRD). Significant differences among treatment means were tested using the Honest Significant Difference (HSD) at a 5% significance level.

Ethical Consideration

This study followed ethical guidelines by using cacao seeds sourced responsibly. It will focus on minimizing plant harm by applying safe, non-invasive methods for soil amendments and growth monitoring. The data was collected honestly and used only for scientific purposes. Environmental impact was considered by managing waste and resources efficiently.

RESULTS

Soil Analysis Result

Table 1  
Baseline Soil pH and Nutrient Levels of Acidic Soil Used for Cacao (*Theobroma cacao*) Seedlings Growth

| Parameter            | Value | Unit                          | Remarks          |
|----------------------|-------|-------------------------------|------------------|
| Soil pH              | 4.00  |                               | Extremely Acidic |
| Nitrogen             | -     | Qualitative                   | Low              |
| Phosphorus           | -     | Qualitative                   | Low              |
| Potassium            | -     | Qualitative                   | Low              |
| Nutrient Requirement | 0.10  | N kg/ha                       | -                |
|                      | 0.12  | P <sub>2</sub> O <sub>5</sub> | -                |
|                      | 0.09  | K <sub>2</sub> O kg/ha        | -                |
| Lime Requirement     | 9.50  | Tons/ha                       | To raise pH      |

The baseline soil analysis revealed that the experimental soil has a pH of 4.00, which is classified as extremely acidic. Such a low pH level is unfavorable for cacao seedling growth, as it significantly limits the availability of essential nutrients while increasing the solubility of toxic elements such as aluminum and manganese. These conditions can adversely affect root development, nutrient uptake, and overall plant vigor.

The qualitative results further indicate that nitrogen, phosphorus, and potassium levels in the soil are low. These macronutrients are essential for plant growth, with nitrogen supporting vegetative development, phosphorus aiding in root formation, and potassium

enhancing overall plant health and stress tolerance. The deficiency of these nutrients suggests that the soil is inherently infertile and unable to support optimal cacao seedling growth without intervention.

The nutrient requirement data (0.10 kg N/ha, 0.12 kg P<sub>2</sub>O<sub>5</sub>, and 0.09 kg K<sub>2</sub>O/ha) emphasize the need for supplementation to meet the nutritional demands of cacao seedlings. Additionally, the lime requirement of 9.50 tons/ha indicates a substantial need to neutralize soil acidity and raise the pH to a more suitable level for crop production.

These findings emphasize that the experimental site is highly constrained for cacao production due to both chemical imbalance and nutrient deficiency. The extremely acidic condition, combined with low macronutrient availability, suggests poor soil fertility and limited biological activity, which can restrict seedling establishment and early growth. Without appropriate soil amendment strategies, such conditions may continue to hinder nutrient cycling and reduce plant productivity. Therefore, the application of organic amendments in this study is essential not only to supply nutrients but also to improve soil buffering capacity, enhance microbial activity, and gradually ameliorate soil acidity, making the environment more conducive for sustainable cacao seedling development.

Germination Percentage, Germination Rate, and Seedling Vigor Index

**Table 2**  
*Effects of Soil Amendments on Germination Percentage, Germination Rate, and Seedling Vigor Index of Cacao Seedlings under Acidic Soil Conditions*

| Treatment          | Germination Percentage (%) | Germination Rate | Seedling Vigor Rate |
|--------------------|----------------------------|------------------|---------------------|
| T1- Control        | 93.00                      | 2.80             | 8.65 <sup>c</sup>   |
| T2- VC + DCD       | 98.00                      | 2.93             | 14.64 <sup>b</sup>  |
| T3- DCD + CRH      | 95.00                      | 2.86             | 10.63 <sup>d</sup>  |
| T4- VC + CRH       | 100.00                     | 3.00             | 16.78 <sup>a</sup>  |
| T5- VC + DCD + CRH | 98.00                      | 2.93             | 11.96 <sup>c</sup>  |
| CV (%)             | 4.58                       | 4.35             | 3.32                |
| F-test             | Ns                         | Ns               | **                  |

Means with the same Letter are not significantly different from each other (HSD 0.05)

The HSD results revealed clear and statistically supported differences in germination performance among the treatments. ANOVA results revealed a significant difference among the treatment means. Treatment 4 (Vermicompost + Carbonized Rice Hull) consistently obtained the highest values across all measured parameters, recording 100% germination, the highest germination rate (3.00), and the greatest seedling vigor index (16.78). These results indicate that Treatment 4 significantly outperformed the other treatments in promoting both germination efficiency and early seedling growth. The superior performance of Treatment 4 may be attributed to the synergistic effects of vermicompost and carbonized rice hull. Vermicompost is known to enhance soil microbial activity, improve nutrient availability, and supply essential plant growth hormones such as auxins and cytokinins, which stimulate faster germination and early root development. Meanwhile, carbonized rice hull improves soil aeration, water retention, and drainage, creating a favorable physical environment for seed imbibition and root emergence.

The combination of these two amendments likely created optimal soil conditions that supported rapid germination and vigorous seedling establishment.

Treatments 2 and 5 also showed relatively high germination performance, indicating that organic amendments, individually or in combination, still improve soil conditions compared to the control. However, their slightly lower performance compared to Treatment 4 suggests that the combined physical and biological benefits of vermicompost and carbonized rice hull together are more effective than single or less balanced amendments. In contrast, Treatment 1 (control) consistently recorded the lowest values in all parameters, highlighting the limitations of the untreated acidic soil. The poor germination performance in the control treatment can be associated with low nutrient availability, poor soil structure, and unfavorable pH conditions (pH 4.00), which collectively hinder seed activation and early seedling development.

The HSD results strongly indicate that organic amendment combinations, particularly vermicompost and carbonized rice hull, significantly enhance germination performance and seedling vigor in cacao under acidic soil conditions. These findings support the effectiveness of integrated organic soil management practices in improving early-stage crop establishment.

Seedling Height

**Table 3**  
*Seedling Height at 15, 30, 45, and 60 Days of Cacao Seedlings after Sowing as Affected by Soil Amendments Grown under Acidic Soil*

| Treatment          | Seedling Height    |                    |                    |                     |
|--------------------|--------------------|--------------------|--------------------|---------------------|
|                    | 15                 | 30                 | 45                 | 60                  |
| T1- Control        | 6.91 <sup>c</sup>  | 15.53 <sup>b</sup> | 16.80 <sup>b</sup> | 17.08 <sup>c</sup>  |
| T2- VC + DCD       | 6.99 <sup>bc</sup> | 17.45 <sup>a</sup> | 19.07 <sup>a</sup> | 20.93 <sup>ab</sup> |
| T3- DCD + CRH      | 6.97 <sup>bc</sup> | 17.96 <sup>a</sup> | 19.16 <sup>a</sup> | 22.21 <sup>a</sup>  |
| T4- VC + CRH       | 7.52 <sup>a</sup>  | 17.59 <sup>a</sup> | 18.87 <sup>a</sup> | 19.68 <sup>a</sup>  |
| T5- VC + DCD + CRH | 7.54 <sup>a</sup>  | 18.44 <sup>a</sup> | 19.81 <sup>a</sup> | 22.26 <sup>a</sup>  |
| CV (%)             | 7.80               | 4.44               | 4.35               | 5.72                |
| F-test             | **                 | **                 | **                 | **                  |

Means with the same Letter are not significantly different from each other (HSD 0.05)

Seedling height showed highly significant differences among treatments across all observation periods (15, 30, 45, and 60 days), indicating that the application of organic amendments had a strong and measurable effect on cacao seedling growth under acidic soil conditions. Treatment 5 consistently recorded the highest average seedling height throughout the study, with values of 7.54 cm at 15 days, 18.44 cm at 30 days, 19.81 cm at 45 days, and 22.26 cm at 60 days. This consistent superiority across all growth stages highlights its effectiveness in promoting sustained seedling development.

Treatment 3 also exhibited strong performance, particularly at 45 and 60 days, with seedling heights of 19.16 cm and 22.21 cm, respectively, which were statistically comparable to Treatment 5 based on the HSD test. This suggests that both treatments significantly enhanced vegetative growth compared to the other treatments. In contrast, Treatment 1

(control) consistently recorded the lowest seedling heights across all observation periods, confirming the detrimental effects of highly acidic and nutrient-deficient soil conditions on plant growth.

The highly significant results indicate that organic amendments play a crucial role in improving cacao seedling growth under acidic soil conditions. The superior performance of Treatment 5 can be attributed to the synergistic effects of vermicompost, decomposed chicken dung, and carbonized rice hull. These amendments collectively enhance soil structure, increase microbial activity, improve moisture retention, and supply essential nutrients needed for continuous plant growth. Such improvements create a more favorable rhizosphere environment, allowing for better root development and more efficient nutrient uptake, which directly contributes to increased seedling height.

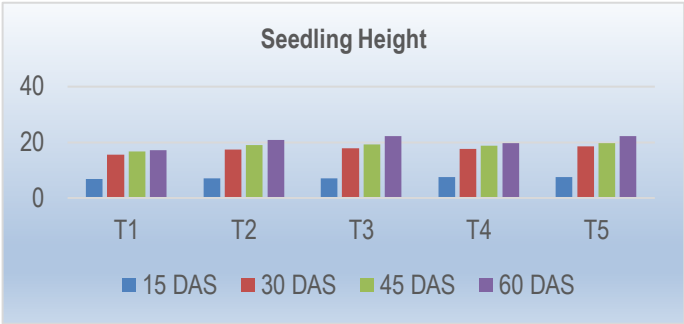


**Figure 1.** Seedling Height of Cacao Seedling at 15, 30, 45, and 60 Days after Sowing as Applied with Soil Amendments under Acidic Soil Conditions

Number of Leaves

**Table 4**  
*Number of Leaves at 15, 30, 45, and 60 Days of Cacao Seedlings after Sowing as Affected by Soil Amendments Grown under Acidic Soil*

| Treatment          | Number of Leaves  |                   |                    |                   |
|--------------------|-------------------|-------------------|--------------------|-------------------|
|                    | 15                | 30                | 45                 | 60                |
| T1- Control        | 1.77 <sup>e</sup> | 4.67 <sup>d</sup> | 6.03 <sup>d</sup>  | 5.98 <sup>c</sup> |
| T2- VC + DCD       | 2.83 <sup>c</sup> | 5.20 <sup>b</sup> | 6.97 <sup>bc</sup> | 9.10 <sup>a</sup> |
| T3- DCD + CRH      | 2.70 <sup>d</sup> | 5.47 <sup>a</sup> | 8.00 <sup>a</sup>  | 9.77 <sup>a</sup> |
| T4- VC + CRH       | 3.50 <sup>a</sup> | 4.93 <sup>c</sup> | 6.43 <sup>cd</sup> | 7.17 <sup>b</sup> |
| T5- VC + DCD + CRH | 3.27 <sup>b</sup> | 5.50 <sup>a</sup> | 7.50 <sup>ab</sup> | 9.77 <sup>a</sup> |
| CV (%)             | 7.38              | 2.57              | 6.43               | 5.88              |
| F-test             | **                | **                | **                 | **                |

Means with the same Letter are not significantly different from each other (HSD 0.05)

The number of leaves of cacao seedlings showed highly significant differences among treatments across all observation periods (15, 30, 45, and 60 days after sowing), as indicated by the F-test ( $p < 0.01$ ). At 15 days after sowing, Treatment 4 (VC + CRH) recorded the highest number of leaves (3.50), followed by Treatment 5 (VC + DCD + CRH) with 3.27 leaves. The control (T1) had the lowest value at 1.77 leaves. At 30 days, Treatments 3 (DCD + CRH) and 5 (VC + DCD + CRH) obtained the highest and statistically comparable values (5.47 and 5.50 leaves, respectively), while the control remained the lowest at 4.67 leaves. At 45 days, Treatment 3 recorded the highest number of leaves (8.00), followed by Treatment 5 (7.50), while the control (T1) had 6.03 leaves. At 60 days, Treatments 2 (VC + DCD), 3 (DCD + CRH), and 5 (VC + DCD + CRH) produced the highest and statistically comparable leaf numbers (9.10, 9.77, and 9.77, respectively). Treatment 1 (control) had the lowest value (5.98), while Treatment 4 recorded 7.17 leaves. Treatments 2, 3, and 5 consistently showed higher leaf production at later growth stages, while the control consistently recorded the lowest values across all sampling periods. This indicates that combined amendments, especially those including CRH and DCD, promoted better leaf development in cacao plantlets grown in acidic soil.

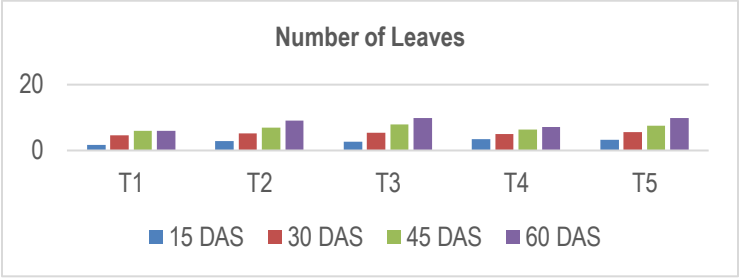


**Figure 2.** Number of Leaves of Cacao Seedling at 15, 30, 45, and 60 Days after Sowing as Applied with Soil Amendments under Acidic Soil Conditions

**Stem Diameter**

**Table 5**  
*Stem Diameter at 15, 30, 45, and 60 Days of Cacao Seedlings after Sowing as Affected by Soil Amendments Grown under Acidic Soil*

| Treatment          | Stem Diameter     |                    |                    |                    |
|--------------------|-------------------|--------------------|--------------------|--------------------|
|                    | 15                | 30                 | 45                 | 60                 |
| T1- Control        | 2.36 <sup>e</sup> | 3.12 <sup>b</sup>  | 3.23 <sup>c</sup>  | 3.49 <sup>bc</sup> |
| T2- VC + DCD       | 2.95 <sup>b</sup> | 3.34 <sup>ab</sup> | 3.40 <sup>bc</sup> | 3.85 <sup>ab</sup> |
| T3- DCD + CRH      | 2.97 <sup>b</sup> | 3.50 <sup>a</sup>  | 3.50 <sup>ab</sup> | 3.30 <sup>c</sup>  |
| T4- VC + CRH       | 2.95 <sup>b</sup> | 3.53 <sup>a</sup>  | 3.53 <sup>a</sup>  | 3.79 <sup>ab</sup> |
| T5- VC + DCD + CRH | 3.09 <sup>a</sup> | 3.51 <sup>a</sup>  | 3.51 <sup>ab</sup> | 4.06 <sup>a</sup>  |
| CV (%)             | 0.94              | 3.84               | 2.99               | 5.30               |
| F-test             | **                | **                 | **                 | **                 |

Means with the same Letter are not significantly different from each other (HSD 0.05)

The HSD results revealed highly significant differences among treatments ( $p < 0.01$ ) across all observation periods (15, 30, 45, and 60 days after sowing), indicating that soil amendments had a strong influence on the stem development of cacao seedlings grown under acidic soil conditions.

At 15 days after sowing, Treatment 5 (VC + DCD + CRH) recorded the highest stem diameter (3.09 mm), indicating an early advantage in seedling structural growth. This was significantly higher than the control (T1), which consistently recorded the lowest value (2.36 mm), reflecting the limiting effects of acidic and nutrient-deficient soil conditions on early stem development. At 30 days, Treatments 3 (DCD + CRH), 4 (VC + CRH), and 5 (VC + DCD + CRH) exhibited statistically comparable and significantly higher stem diameters (3.50 mm, 3.53 mm, and 3.51 mm, respectively). This suggests that combinations of organic amendments were more effective in promoting stem thickening during the early vegetative stage compared to single or no amendment applications. At 45 days, Treatment 4 recorded the highest stem diameter (3.53 mm), closely followed by Treatments 3 (3.50 mm) and 5 (3.51 mm), all of which were statistically similar based on HSD grouping. This indicates that the benefits of organic amendments were sustained over time, likely due to continuous nutrient release and improved soil physical conditions that support stem growth. At 60 days, Treatment 5 produced the highest stem diameter (4.06 mm), significantly outperforming most treatments and indicating its superior long-term effect on structural development. Treatments 2 (3.85 mm) and 4 (3.79 mm) also showed relatively high values, while Treatment 3 (3.30 mm) showed a slight decline compared to earlier growth stages. The control remained the least performing treatment, reinforcing the negative impact of untreated acidic soil conditions.

The results demonstrate that integrated organic amendments, particularly the combination of vermicompost, decomposed chicken dung, and carbonized rice hull, significantly enhance stem diameter growth in cacao seedlings. The observed improvements may be attributed to enhanced nutrient availability (especially nitrogen and potassium), improved soil aggregation, better moisture retention, and increased microbial activity, all of which contribute to stronger stem formation and overall seedling vigor.

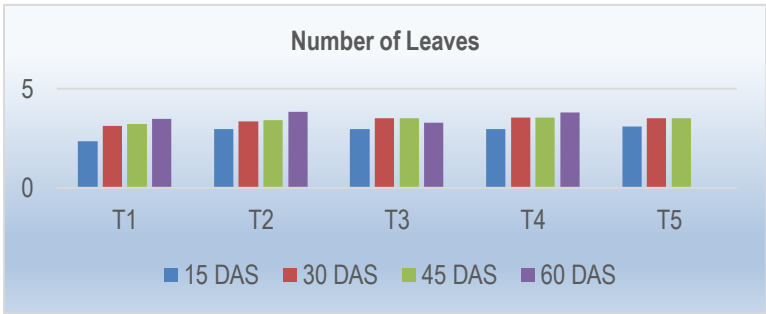


**Figure 3.** Stem Diameter of Cacao Seedling at 15, 30, 45, and 60 Days after Sowing as Applied with Soil Amendments under Acidic Soil Conditions

Leaf Length

**Table 6**  
*Leaf Length at 15, 30, 45, and 60 Days of Cacao Seedlings after Sowing as Affected by Soil Amendments Grown under Acidic Soil*

| Treatment          | Leaf Length       |                    |                      |                      |
|--------------------|-------------------|--------------------|----------------------|----------------------|
|                    | 15                | 30                 | 45                   | 60                   |
| T1- Control        | 0.68 <sup>c</sup> | 8.11 <sup>b</sup>  | 9.81 <sup>c</sup>    | 10.54 <sup>c</sup>   |
| T2- VC + DCD       | 0.49 <sup>d</sup> | 9.79 <sup>a</sup>  | 10.80 <sup>ab</sup>  | 11.34 <sup>ab</sup>  |
| T3- DCD + CRH      | 0.69 <sup>c</sup> | 9.31 <sup>ab</sup> | 10.42 <sup>bc</sup>  | 10.79 <sup>bc</sup>  |
| T4- VC + CRH       | 1.54 <sup>a</sup> | 9.71 <sup>a</sup>  | 10.49 <sup>abc</sup> | 11.22 <sup>abc</sup> |
| T5- VC + DCD + CRH | 1.08 <sup>b</sup> | 10.14 <sup>a</sup> | 11.20 <sup>a</sup>   | 11.89 <sup>a</sup>   |
| CV (%)             | 0.91              | 7.54               | 3.95                 | 3.51                 |
| F-test             | **                | **                 | **                   | **                   |

Means with the same Letter are not significantly different from each other (HSD 0.05)

Table 6 shows that leaf length differed significantly among treatments across all sampling periods, as indicated by the highly significant F-test values ( $p < 0.01$ ). At 15 days after sowing, Treatment 4 (VC + CRH) recorded the longest leaves, followed by Treatment 5 (VC + DCD + CRH), while Treatment 2 produced the shortest leaves among the amended treatments. This indicates an early response of cacao seedlings to organic amendments, particularly those involving vermicompost and carbonized rice hull.

As the seedlings developed, Treatment 5 consistently produced the longest leaves at 30, 45, and 60 days after sowing, with the highest value recorded at 60 days (11.89 cm). This consistent performance suggests that the combined application of vermicompost, decomposed chicken dung, and carbonized rice hull provided a more sustained supply of nutrients and improved soil conditions necessary for continuous leaf elongation.

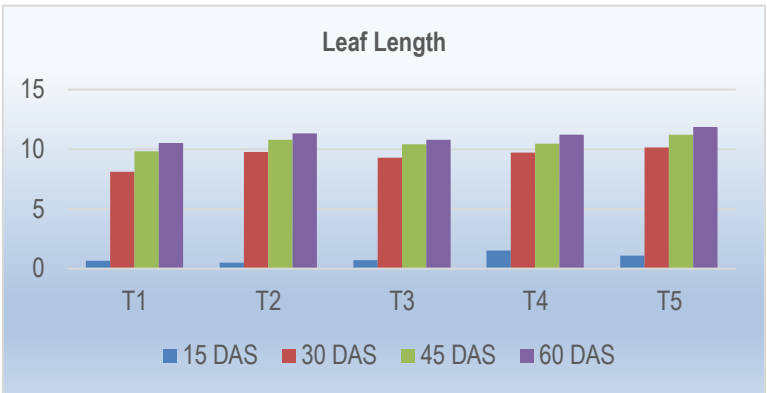


**Figure 4.** Leaf Length of Cacao Seedling at 15, 30, 45, and 60 Days after Sowing, as Applied with Soil Amendments under Acidic Soil Conditions

In contrast, the control treatment (T1) consistently recorded the shortest leaf length across all sampling periods, reflecting the limiting effects of acidic and nutrient-deficient soil conditions on vegetative growth. The consistently lower performance of T1 highlights the importance of soil amendment in improving plant growth under unfavorable soil conditions. The results indicate that the application of organic soil amendments, particularly combinations involving vermicompost, decomposed chicken dung, and carbonized rice hull, significantly enhances leaf elongation and promotes better vegetative growth of cacao plantlets under acidic soil conditions. These improvements may be attributed to enhanced nutrient availability, improved soil structure, and better water retention, which collectively support sustained leaf development.

Leaf Width

**Table 7**  
*Leaf Width at 15, 30, 45, and 60 Days of Cacao Seedlings after Sowing as Affected by Soil Amendments Grown under Acidic Soil*

| Treatment          | Leaf Width        |                   |                   |                   |
|--------------------|-------------------|-------------------|-------------------|-------------------|
|                    | 15                | 30                | 45                | 60                |
| T1- Control        | 0.25 <sup>d</sup> | 3.37 <sup>b</sup> | 3.82 <sup>c</sup> | 4.13 <sup>e</sup> |
| T2- VC + DCD       | 0.35 <sup>c</sup> | 4.01 <sup>a</sup> | 4.42 <sup>b</sup> | 4.40 <sup>d</sup> |
| T3- DCD + CRH      | 0.35 <sup>c</sup> | 4.02 <sup>a</sup> | 4.35 <sup>b</sup> | 4.79 <sup>b</sup> |
| T4- VC + CRH       | 0.56 <sup>a</sup> | 4.05 <sup>a</sup> | 4.44 <sup>b</sup> | 4.67 <sup>c</sup> |
| T5- VC + DCD + CRH | 0.51 <sup>b</sup> | 4.36 <sup>a</sup> | 4.89 <sup>a</sup> | 5.18 <sup>a</sup> |
| CV (%)             | 1.81              | 6.03              | 5.20              | 0.41              |
| F-test             | **                | **                | **                | **                |

Means with the same Letter are not significantly different from each other (HSD 0.05)

The results in Table 7 show that leaf width was significantly affected by all treatments across all sampling periods, as indicated by the highly significant F-test values ( $p < 0.01$ ). At 15 days after sowing, Treatment 4 (VC + CRH) recorded the widest leaves, followed closely by Treatment 5 (VC + DCD + CRH), while the control (T1) consistently had the narrowest leaves. This indicates an early positive response of cacao seedlings to organic amendments, particularly those involving vermicompost and carbonized rice hull.

As the seedlings progressed in growth, Treatment 5 consistently produced the widest leaves at 30, 45, and 60 days after sowing, with the highest value recorded at 60 days (5.18 cm). This consistent superiority suggests that the combined application of vermicompost, decomposed chicken dung, and carbonized rice hull provided a more balanced and sustained nutrient supply, promoting continuous leaf expansion and improved vegetative development. In contrast, the control treatment (T1) consistently recorded the smallest leaf width across all sampling periods, reflecting the limiting effects of highly acidic and nutrient-deficient soil conditions. This reinforces the importance of soil amendments in improving plant growth performance under unfavorable soil environments. Organic soil amendments, particularly combinations involving vermicompost, decomposed chicken dung, and carbonized rice hull, significantly enhance leaf expansion in cacao seedlings. These improvements may be attributed

to enhanced nutrient availability, improved soil physical properties, and better moisture retention, all of which contribute to stronger early vegetative growth under acidic soil conditions.

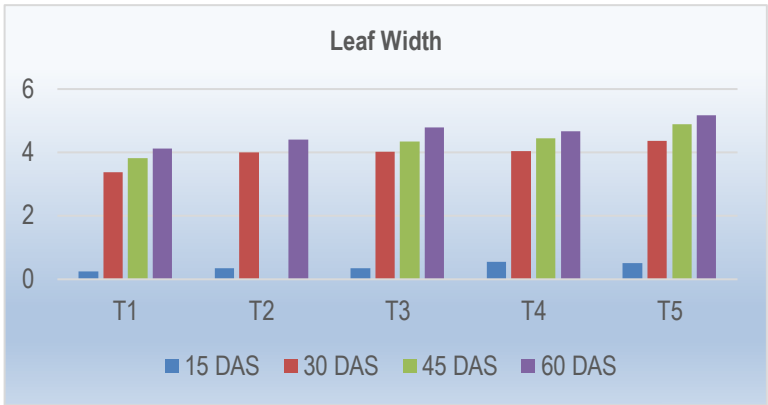


**Figure 5.** Leaf Width of Cacao Seedling at 15, 30, 45, and 60 Days after Sowing as Applied with Soil Amendments under Acidic Soil Conditions

Shoot and Root Length

**Table 8**  
*Shoot Length at 45, and 60 Days after Sowing, and Root Length of Cacao Seedlings at Termination Period as Affected by Soil Amendments Grown under Acidic Soil*

| Treatment          | Shoot Length (cm) |                   | Root Length (cm)   |
|--------------------|-------------------|-------------------|--------------------|
|                    | 45                | 60                | At Termination     |
| T1- Control        | 0.00 <sup>e</sup> | 0.00 <sup>e</sup> | 9.27 <sup>c</sup>  |
| T2- VC + DCD       | 2.38 <sup>a</sup> | 2.57 <sup>a</sup> | 12.53 <sup>b</sup> |
| T3- DCD + CRH      | 1.69 <sup>b</sup> | 1.96 <sup>b</sup> | 9.00 <sup>c</sup>  |
| T4- VC + CRH       | 0.48 <sup>d</sup> | 0.51 <sup>d</sup> | 16.73 <sup>a</sup> |
| T5- VC + DCD + CRH | 0.92 <sup>c</sup> | 0.97 <sup>c</sup> | 11.37 <sup>b</sup> |
| CV (%)             | 4.26              | 1.62              | 6.70               |
| F-test             | **                | **                | **                 |

Means with the same Letter are not significantly different from each other (HSD 0.05)

Root growth and shoot development were significantly influenced by the treatments, as indicated by the highly significant F-test values ( $p < 0.01$ ), demonstrating that soil amendments had a strong effect on the overall early growth performance of cacao seedlings. For shoot length, Treatment 2 (VC + DCD) recorded the greatest growth at both 45 and 60 days after sowing, followed by Treatment 3 (DCD + CRH). In contrast, the control treatment (T1) showed no observable shoot development during the same period, indicating severe limitations in seedling establishment under untreated acidic soil conditions.

At termination, root length was also significantly affected by the treatments. Treatment 2 produced the longest roots (16.73 cm), followed by Treatments 3 and 5, which both recorded 11.37 cm. The control treatment consistently exhibited the shortest root length (9.27 cm), reflecting restricted root expansion due to low nutrient availability and highly acidic soil conditions. Soil amendments, particularly the combination of vermicompost and decomposed chicken dung (VC + DCD), significantly enhanced both shoot and root development of cacao plantlets under acidic soil conditions. These improvements suggest better nutrient availability, enhanced microbial activity, and improved soil structure, which collectively promote stronger root establishment and more vigorous early vegetative growth.

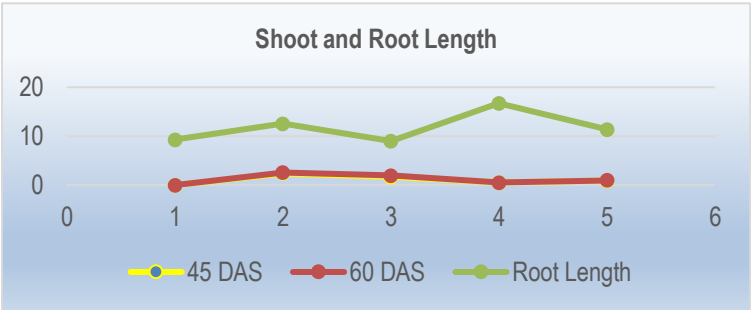


**Figure 6.** Shoot Length at 45, and 60 Days after Sowing, and Root Length of Cacao Seedling at Termination Period as Applied with Soil Amendments under Acidic Soil Condition

### Temperature and Relative Humidity

**Table 9**

*Environmental Conditions (Temperature and Relative Humidity) in the Cacao Seedling Nursery*

| Number of Weeks | Temperature |       |         | Relative Humidity |       |         |
|-----------------|-------------|-------|---------|-------------------|-------|---------|
|                 | Morning     | Noon  | Evening | Morning           | Noon  | Evening |
| 1               | 28.80       | 32.70 | 28.90   | 77.20             | 83.10 | 75.10   |
| 2               | 27.60       | 30.60 | 27.60   | 82.40             | 74.40 | 79.50   |
| 3               | 26.80       | 31.20 | 28.20   | 82.40             | 73.00 | 77.40   |
| 4               | 26.02       | 29.80 | 28.20   | 80.80             | 72.00 | 75.80   |
| 5               | 26.10       | 32.40 | 27.60   | 84.50             | 76.80 | 80.10   |
| 6               | 26.40       | 31.96 | 29.70   | 81.00             | 67.20 | 72.40   |
| 7               | 27.10       | 32.60 | 30.20   | 78.00             | 70.70 | 71.10   |
| 8               | 27.30       | 30.60 | 29.01   | 79.50             | 73.80 | 75.10   |
| 9               | 29.10       | 37.30 | 30.60   | 78.00             | 65.50 | 70.20   |

Table 9 presents the weekly environmental conditions in the cacao seedling nursery in terms of temperature and relative humidity. Temperature values showed noticeable daily variation across the observation period. Morning temperatures ranged from 26.02°C to 29.10°C, while noon temperatures recorded the highest values, ranging from 29.80°C to 37.30°C. Evening temperatures were relatively more stable, ranging from 27.60°C to 30.60°C. The highest recorded temperature (37.30°C) occurred at noon during Week 9, indicating periods of potential heat stress for cacao seedlings. Relative humidity also fluctuated throughout the study period. Morning humidity levels ranged from 77.20% to 84.50%, while noon values showed a noticeable decline, ranging from 65.50% to 83.10%. Evening relative humidity ranged from 70.20% to 80.10%. The lowest relative humidity (65.50%) was recorded at noon during Week 9, coinciding with the highest temperature observed.

The data indicate that the nursery environment experienced consistently higher temperatures and lower relative humidity during midday periods, conditions that may contribute to moisture loss and physiological stress in cacao seedlings. However, morning and evening periods generally maintained more favorable conditions for seedling growth. These environmental fluctuations are important in interpreting seedling performance, as cacao is highly sensitive to heat and water stress. The use of organic soil amendments such as vermicompost, decomposed chicken dung, and carbonized rice hull likely helped buffer these environmental stresses by improving soil moisture retention, enhancing soil structure, and increasing nutrient availability. These improvements may have supported better seedling resilience despite periods of high temperature and low humidity.

Furthermore, in acidic soil conditions, organic amendments play a dual role by not only improving nutrient availability but also enhancing the soil's water-holding capacity, which helps reduce the impact of environmental stressors such as heat and dryness. This interaction between soil amendments and environmental conditions likely contributed to the overall growth performance observed in the study.

## DISCUSSION

### Germination Percentage, Germination Rate, and Seedling Vigor Index

ANOVA results showed no significant differences among treatments, although Treatment 4 recorded slightly higher mean values across germination parameters. This suggests that while the treatments did not differ statistically, organic amendments still contributed positively to early seedling performance under acidic soil conditions. Carbonized rice hull (CRH) may have enhanced germination by improving soil aeration, moisture retention, and structure, which are critical for seed activation in acidic soils (Argüello et al., 2023). In addition, vermicompost likely supported germination through improved microbial activity and nutrient availability (Hammed et al., 2023), while decomposed chicken dung becomes more effective when combined with other organic materials such as vermicompost or CRH (Argüello et al., 2022).

Environmental monitoring further explains these trends, as the nursery experienced high noon temperatures (up to 37.3°C) and reduced relative humidity, conditions that may

induce moisture stress and slow germination. However, treatments containing organic amendments, particularly T5 (VC + DCD + CRH), likely improved soil moisture retention and buffered heat stress due to their ability to enhance soil structure and water-holding capacity. Although not statistically significant, the consistent improvement in germination-related parameters in amended treatments suggests that integrated organic amendments enhance early cacao seedling establishment by improving soil physical conditions and reducing environmental stress effects.

### **Seedling Height (cm)**

Seedling height showed highly significant differences among treatments, with Treatment 5 consistently producing the tallest seedlings, while the control (T1) recorded the shortest. Treatments 4 and 5 both exhibited superior height growth compared to the control, indicating the effectiveness of organic amendments in improving cacao growth under acidic soil conditions. The strong performance of Treatment 5 can be attributed to the synergistic effects of vermicompost, decomposed chicken dung, and carbonized rice hull. CRH improves soil aeration and structure (Hougni, 2023), while vermicompost enhances nutrient availability and microbial activity, especially when combined with chicken dung (Nonthakaew et al., 2022). This combination likely supported sustained nutrient release and better root development, resulting in improved seedling height.

Treatment 3 showed moderate improvement, suggesting that chicken dung and CRH contribute to growth but are more effective when integrated with vermicompost. These findings are consistent with previous studies reporting that organic amendment integration improves soil properties, nutrient availability, and overall seedling vigor in acidic conditions (Lobo et al., 2022; Dogbatse et al., 2020; Arévalo-Hernández et al., 2022; Oyege & Bhaskar, 2023; Mateus-Rodríguez et al., 2023).

### **Number of Leaves**

The F-test indicated highly significant differences among treatments across all observation periods. Treatment 4 recorded the highest mean at 15 days, while Treatment 5 consistently produced the greatest number of leaves at 30, 45, and 60 days. The control (T1) consistently had the lowest values, confirming the beneficial effects of organic amendments on leaf development under acidic soil conditions. These results are supported by previous studies showing that vermicompost, decomposed chicken dung, and carbonized rice hull improve soil fertility, microbial activity, and nutrient availability, thereby enhancing leaf production (Aracelly-López et al., 2020). The synergistic effect of chicken dung and carbonized rice hull has also been reported, where chicken dung supplies essential macronutrients while carbonized rice hull improves aeration and moisture retention (Coulis et al., 2023), which aligns with the improved performance of Treatment 3.

Furthermore, studies have consistently shown that combined organic amendments enhance vegetative growth, particularly in acidic or nutrient-deficient soils (Bouskout et al., 2022; Ali et al., 2021; Dogbatse et al., 2021). Carbonized rice hull (biochar) also improves soil physical properties and nutrient retention, contributing to increased leaf production (Mon et al., 2024; Loguercio et al., 2023).

## Stem Diameter

ANOVA revealed a highly significant difference among treatments in stem diameter. Treatment 5 recorded the largest diameters at 15 and 60 days, while Treatment 4 showed the best performance at 30 and 45 days. Overall, Treatment 5 was significantly superior to the control, indicating the strong effect of organic amendments on stem development under acidic soil conditions. These results align with studies showing that organic fertilizers improve soil structure, moisture retention, and nutrient uptake, resulting in better stem growth (Aggangan, 2019). Stem diameter is also an important indicator of plant vigor, particularly in acidic soils where organic inputs enhance structural development (Basulgan et al., 2022). Similar findings were reported by Dogbatse et al. (2021), where biochar and organic fertilizers increased stem girth.

The combined application of vermicompost, chicken dung, and carbonized rice hull improves aeration and nutrient availability, especially nitrogen and potassium, which support vascular development (Choudhary & Machavaram, 2023). Additionally, organic amendments reduce aluminum toxicity and improve nutrient mobility in acidic soils (Aristide et al., 2021; Puyongan, 2022). Recent studies further confirm that balanced organic inputs enhance stem strength and stress tolerance (Santos et al., 2024; Suganthi et al., 2024), while sustained nutrient release from vermicompost and chicken dung promotes continuous growth. Biochar integration also improves overall soil fertility and plant performance (Sánchez-Reinoso, 2020).

## Leaf Length

Leaf length showed highly significant differences among treatments, with Treatment 5 consistently producing the longest leaves at 30, 45, and 60 days. Its consistent superiority over the control demonstrates the strong effect of integrated organic amendments in promoting vegetative growth under acidic soil conditions. These results are supported by studies showing that carbonized rice hull improves soil aeration and moisture balance (Kumar et al., 2022), while vermicompost enhances nutrient uptake, microbial activity, and growth hormone production, leading to improved leaf development (Carmona et al., 2022). Chicken dung alone (T2) showed moderate performance, likely due to its limited structural benefits compared to CRH (Marrocos et al., 2020).

Further evidence indicates that CRH improves root respiration and enhances phosphorus and potassium availability, which are essential for leaf elongation (Daniel et al., 2025; Francisco-Santiago et al., 2023). Vermicompost also supplies enzymes and nutrients that stimulate plant growth and vigor, especially when combined with soil conditioners (Weinstein et al., 2024; Mwafuliwa et al., 2024). In addition, organic amendments improve soil structure and provide slow, steady nutrient release, supporting continuous leaf development (Quintino et al., 2020; Sauvadet et al., 2020; Scaccabarozzi et al., 2020). The superior performance of Treatment 5 confirms that integrating nutrient-rich organic fertilizers with soil-improving materials optimizes cacao seedling growth in acidic soil conditions.

## Leaf Width

Leaf width showed highly significant differences among treatments, with Treatment 5 consistently producing the widest leaves at 30, 45, and 60 days. This was significantly superior

to the control, indicating the strong effect of integrated organic amendments on leaf expansion under acidic soil conditions. Treatments containing carbonized rice hull (T3, T4, and T5) consistently performed better than T1, emphasizing its role as a structural amendment that improves soil porosity, aeration, and water retention, thereby enhancing nutrient uptake and leaf expansion (Yao et al., 2021; Quintino et al., 2020). Leaf width is also a reliable indicator of plant vigor (Visscher et al., 2024; Eduah et al., 2025), and results show that chicken dung improves growth more effectively when combined with structural amendments, as observed in Treatments 2 and 3.

Vermicompost further enhances vegetative growth through microbial activity and growth hormone production, and its synergy with carbonized rice hull supports improved leaf development (Ayamba et al., 2021). Studies also show that combining vermicompost with soil conditioners improves moisture balance, nutrient retention, and microbial activity, contributing to larger leaf size (Villason & Olguera, 2020). Additionally, integrating chicken dung with biochar-like materials enhances canopy development and soil fertility (Daniel et al., 2025; Baja et al., 2021). The superior leaf width in Treatment 5 confirms that multi-component organic amendments provide the most favorable conditions for optimal cacao seedling development in acidic soils.

### **Shoot and Root Length**

Shoot length showed highly significant differences among treatments at 45 and 60 days after sowing, indicating that organic amendments strongly influenced early vegetative development of cacao seedlings under acidic soil conditions. Treatment 2 (VC + DCD) recorded the highest shoot length at both observation periods, followed by Treatment 3 (DCD + CRH), while the control (T1) showed no observable shoot growth (0.00 mm), confirming the severe restriction of acidic and nutrient-deficient soil on early seedling establishment. The superior performance of Treatment 2 suggests that vermicompost combined with decomposed chicken dung provides readily available nutrients that stimulate early shoot elongation. This is supported by Lazcano et al. (2009), who reported that vermicompost significantly enhances plant growth and shoot development by improving nutrient availability, microbial activity, and plant growth-promoting substances. In contrast, Treatment 4 (VC + CRH) showed stronger root development but lower shoot growth, indicating a possible shift in biomass allocation toward root establishment. Treatment 5 (VC + DCD + CRH) showed moderate shoot growth, suggesting that multi-component amendments improve overall soil conditions but may influence growth distribution between shoot and root systems.

On the other hand, ANOVA revealed a highly significant difference in root length at termination, with Treatment 4 recording the highest root length among all treatments. This indicates that organic amendments significantly influenced the root development of cacao seedlings under acidic soil conditions. Studies have shown that vermicompost and carbonized rice hull enhance root elongation by improving soil aeration, microbial activity, and overall soil structure (Ferry et al., 2022; Florida et al., 2020). These improvements create a favorable rhizosphere environment that supports deeper and more extensive root growth.

Chicken dung also contributes to root development by supplying essential nutrients; however, its effectiveness increases when combined with structural amendments such as

carbonized rice hull, as observed in Treatment 5 (Bai et al., 2022). Overall, vermicompost strongly supports shoot growth, while its combination with carbonized rice hull (T4) resulted in the best root performance. These findings emphasize that balanced combinations of organic amendments are essential for optimizing both root and shoot development of cacao seedlings in acidic soil conditions.

## Conclusion

This study evaluated the effects of vermicompost, chicken dung, and carbonized rice hull on the growth of cacao plantlets in acidic soil conditions. Results indicated that organic amendments significantly enhanced vegetative growth, particularly in parameters such as leaf length, leaf width, shoot length, and root length. Among the treatments, vermicompost combined with carbonized rice hull (T4) produced the most consistent improvement across growth parameters, emphasizing their synergistic effect on nutrient availability and soil structure. While chicken dung alone had moderate effects, its inclusion in combination treatments contributed to additional growth benefits. Overall, the findings confirm that organic soil amendments offer a sustainable and cost-efficient alternative to synthetic fertilizers, especially for nutrient-deficient and acidic soils. These results support previous studies promoting organic inputs as viable solutions for improving soil fertility and enhancing cacao seedling performance. However, long-term studies are recommended to assess the continued effects of these amendments on field performance, yield, and soil health over time.

The application of organic soil amendments affected the germination and growth performance of cacao seedlings cultivated in acidic soil, according to the study. The treatments did not significantly alter the germination rate or percentage; however, they did considerably alter the seedling vigor index. The highest seedling vigor index was obtained when vermicompost and carbonized rice hull (T4) were combined, suggesting better seedling establishment and vigor. The growth parameters of cacao seedlings, such as seedling height, number of leaves, stem diameter, leaf length, leaf width, shoot length, and root length, also showed notable variations. In general, seedlings grown in untreated acidic soil did not perform as well as those treated with organic amendments. By enhancing the availability of nutrients and the soil conditions required for plant development, the amendments improved seedling growth. Vermicompost and carbonized rice hull (T4) were shown to be the most effective combination of treatments for enhancing seedling vigor and root development, but other amendment combinations also demonstrated positive impacts on a variety of growth metrics. In order to produce cacao seedlings on acidic soils, it is advised to employ carbonized rice hull and vermicompost as a sustainable and useful soil management technique.

## Recommendations

Based on the results of the study, the application of vermicompost and carbonized rice hull (T4) is recommended for improving the growth performance of cacao seedlings grown in acidic soil. This treatment consistently enhanced seedling vigor and root development and showed favorable effects on several growth parameters compared with the control treatment. The findings suggest that the use of these organic amendments can serve as a sustainable and environmentally friendly approach to improving cacao seedling production in acidic soils. For future research, it is recommended to evaluate the long-term effects of vermicompost,

decomposed chicken dung, and carbonized rice hull on the growth, yield, and disease resistance of cacao under field conditions. Further studies may also investigate different application rates and combinations of these amendments, assess their effectiveness on different cacao varieties, and conduct detailed soil and plant nutrient analyses to better understand their effects on soil fertility and plant development. Studies involving larger sample sizes and longer observation periods are likewise encouraged to validate and expand the findings of the present study.

For farmers and agricultural practitioners, proper training on the preparation and application of organic soil amendments is encouraged to improve cacao productivity in acidic soils. Agricultural extension workers and policymakers may also promote the adoption of cost-effective organic amendments as part of sustainable soil management and cacao production programs.

Based on the results of the study, the application of vermicompost, decomposed chicken dung, and carbonized rice hull (T5) produced the most favorable growth performance of cacao plantlets in acidic red soil from Sitio Kapatagan. The amendments significantly improved plant height and overall vigor compared to the control, which showed the weakest growth, indicating that organic soil amendments are beneficial for cacao cultivation in acidic conditions. Future studies on large scale that include larger sample sizes, analyze soil and plant nutrients, and test different cacao varieties to deepen understanding of amendment effects. For practitioners and farmers, proper training on the preparation and application of organic amendments is necessary to improve cacao productivity in acidic soils. Policymakers and agricultural extension workers may also consider promoting the use of cost-effective organic amendments as part of sustainable soil management strategies.

### **Limitations of the Study**

This study was conducted in a single location in Purok Lumad, Sitio Dugayan, Barangay Gupitan, Kapalong, Davao del Norte, under nursery conditions. The findings are limited to the specific soil characteristics, environmental conditions, and cacao planting materials used during the study period. Only three soil amendments-vermicompost, decomposed chicken dung, and carbonized rice hull, and their combinations at a fixed application rate of 5 g per polyethylene bag were evaluated. Therefore, the results may not be directly applicable to other soil types, amendment rates, cacao varieties, or field conditions. Furthermore, the study focused on the germination and early growth performance of cacao seedlings and did not assess the long-term effects of the soil amendments on field establishment, yield, or disease resistance.

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