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Effects of Organic Matter from Paitan *(Tithonia diversifolia)* on the Growth Performance of Arabica Coffee (*Coffea arabica*) Seedlings in Ultisols

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Abstract: Arabica coffee seedlings grown on Ultisols often experience limited growth due to low levels of organic matter and nutrient deficiencies, presenting a major challenge for nursery productivity in Central Sulawesi. This study aimed to evaluate the effectiveness of organic matter derived from Paitan *(Tithonia diversifolia)* in improving the growth performance of Coffea arabica seedlings. A Completely Randomized Design (CRD) was employed using five compost dosages (0, 5, 10, 15, and 20 tons/ha equivalent) with four replications. Growth parameters—including germination time, plant height, stem girth, leaf number, leaf area, biomass accumulation, and relative growth rate—were observed over 17 weeks. Soil chemical properties were analyzed to assess changes in fertility. Data were processed using ANOVA followed by an HSD test at the 5% significance level. The results showed that compost substantially improved plant height, stem diameter, leaf number, shoot and root dry weight, and relative growth rate, while germination time, leaf area, and root length remained unaffected. Soil analysis indicated increases in organic carbon, nitrogen, potassium, and cation exchange capacity, demonstrating enhanced nutrient availability. The study concludes that Paitan compost, particularly at 13–15 g per polybag, is an effective organic amendment that improves seedling vigor and offers a sustainable alternative to chemical fertilizers for nursery management on Ultisols.

Keywords: Arabica coffee; Organic amendment; Paitan compost; Seedling growth; Ultisols

Introduction

Coffee is one of the world's most significant plantation commodities, valued for its economic (Salma & Muspiah, 2024) and social impact as a major agricultural export that supports the livelihoods of around 25 million farmers and generates employment throughout its supply chain (Mamoun et al., 2025; Salma & Muspiah, 2024; Khasanah et al., 2023). In Indonesia, coffee serves as a flagship commodity, contributing to foreign exchange earnings, industrial raw materials, and job creation, thus playing a vital role in the national economy (Khasanah et al., 2023; Hendrasto et al., 2023; Novida et al., 2025).

Among coffee species, Coffea arabica L. (Arabica coffee) is distinguished by its superior cup quality, distinctive flavor, and higher market price compared to Robusta, accounting for about 65% of global production and dominating specialty and premium markets due to its aromatic profile and lower caffeine content (Deribe,

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2019; Novida et al., 2025; Surendra et al., 2025). The success of Arabica coffee cultivation hinges on the early growth and development of healthy seedlings, which are closely linked to proper seed storage, optimal nursery conditions, timely planting, and the use of high-quality seeds and pre-treatments to enhance germination and seedling vigor (Nasiro et al., 2017).

In Central Sulawesi, especially in Poso Regency, Arabica coffee is increasingly being cultivated as a priority crop in upland rural areas (Borman et al., 2023; www. rainforest-alliance.org). However, the agricultural lands in this region are dominated by Ultisol. Ultisols are characterized as having moderate development with cambic subhorizons, low organic matter, and generally low fertility parameters such as pH, total nitrogen, cation exchange capacity, and available phosphorus. Soil organic matter is essential for maintaining soil fertility and supporting sustainable agricultural production (Asnur, 2025). These characteristics align with the challenges faced in agricultural use of Ultisols in Indonesian upland regions (Suryani et al., 2021; Rahmayuni et al., 2023).

Scientific studies confirm that low organic matter in nursery media hinders coffee seedling growth. It improves the physical, chemical, and biological properties of the soil (Yanqoritha, 2023) and can be used as a planting medium (Dewanti et al., 2023). Research by Bakala et al. (2024) and Berhe (2024) shows that adding organic inputs like vermicompost or manure improves seedling emergence, root development, and stem growth by enhancing soil aeration (Fadilah et al., 2025), nutrient availability, and microbial activity. The application of compost fertilizer is expected to increase productivity in large chili plants (Mappanganro & Linggarweni, 2023). These findings highlight that insufficient organic input limits seedling vigor, especially during early growth stages.

This research is novel in that it is the first to evaluate the effectiveness of Paitan (Tithonia diversifolia) compost as a single-source organic amendment for improving the growth of Arabica coffee seedlings on Ultisol soils, which are typical of Central Sulawesi. Although various organic materials have been shown to enhance coffee seedling vigor, no prior studies have specifically assessed the unique, nutrient-rich characteristics of Paitan, or its impact on soil chemistry and early seedling physiology in highly acidic, nutrient-poor Ultisols. This study is important because low soil fertility in upland regions such as Poso constrains coffee cultivation, and smallholder farmers increasingly require low-cost, eco-friendly, locally available alternatives to chemical fertilizers. Furthermore, the utilization of Paitan biomass promotes circular nutrient management and sustainable agricultural practices. Therefore, this research provides new scientific evidence on the optimal doses of Paitan compost that can improve the quality of nursery media and strengthen the establishment of early coffee seedlings. It also provides new scientific evidence on the optimal doses of Paitan compost that can improve nursery media quality and strengthen the establishment of early coffee seedlings.

Method

Research Location and Design

This research was conducted in a coffee seedling nursery in Lape Village, Poso Regency, Central Sulawesi, an area known for Arabica coffee cultivation on Ultisols. The study used approximately 1-month-old Arabica coffee seedlings grown in Ultisols collected locally, with fresh Tithonia diversifolia leaves as organic material. Polybags (10 × 15 cm) were used as containers, and watering was done regularly. A Completely Randomized Design (CRD) with one factor—the dosage of Tithonia diversifolia organic material at five levels (0, 5, 10, 15, and 20 tons/ha)—was applied, with four replications totaling 20 experimental units. The organic materials were finely chopped and thoroughly mixed with other components to undergo a fermentation process. After fermentation, the mixture was incorporated into the planting medium prior to planting. Growth parameters observed every two weeks for eight weeks included plant height, number of leaves, stem diameter, and fresh and dry weights of shoots and roots.

Composting Method

The preparation of Paitan organic compost began with gathering materials and chopping the paitan finely. Brown sugar was dissolved and mixed with coconut water and decomposer microbes. The chopped paitan was then combined with rice husks, bran, and animal manure using a shovel, followed by spraying with a microbial solution (300 ml per 16 liters of water) to evenly coat all materials. The mixture was flattened, covered with a tarp, and fermented for two weeks, with checks every two days. If the material dried out, it was moistened with a diluted microbial solution (150 ml per 8 liters of water). Well-fermented compost is dark brown and smells like soil, not foul. For the growing medium, topsoil from Watutau Village, Lore Barat Subdistrict, was sieved and mixed with paitan compost, then filled into polybags and saturated with water. The nursery site was cleared of weeds before planting. One week before planting, paitan compost was weighed, mixed thoroughly with soil, and placed in polybags based on treatment doses. Labels were attached to each polybag according to the treatment layout to ease treatment application and observation. Arabica coffee seeds were sourced from Watutau Village, using only ripe, undamaged seeds. Seeds were soaked in water, and floating ones were discarded. Viable seeds were sun-dried for 1–2 days, then sown two per polybag with the seed hilum facing upward before being covered with soil to encourage germination. Maintenance involved watering every two days depending on soil condition and manually removing weeds from in and around the polybags once weed growth appeared.

Observation Variables

Observation parameters in this study included several growth and physiological indicators of Arabica coffee seedlings. Germination time (days) was recorded by counting the number of days from sowing until emergence. Plant height (cm) was measured from the base to the top of the shoot using a ruler, beginning two weeks after germination, and continued at two-week intervals until 17 weeks after planting. Stem girth (cm) was measured 2 cm above the soil surface using thread and a ruler at the same intervals. The number of leaves (leaf count) was recorded from the fourth week after germination by counting fully opened leaves, measured biweekly until 17 weeks after planting. Leaf area (cm^2) was estimated using a labeled first leaf traced on paper, then compared by weight ratio between a paper replica and known paper area, following Winarni et al. (2013): LA = (PA × RW) / PW, where LA = leaf area, PA = paper area, RW = replica weight, and PW = paper weight. Shoot dry weight (g) was determined by oven-drying the aboveground part of the plant at 85°C for approximately 4 hours until fully dry, while root dry weight (g) was measured similarly for the belowground part using samples from the same plant. Root length (cm) was recorded at 19 weeks after planting by measuring from the root base to the tip using a ruler before oven-drying. Relative growth rate (g/day) was assessed through destructive sampling at 60 and 120 days after planting, calculated using the formula $RGR = (\ln W_2 - \ln W_1) / (t_2 - t_1)$, where W_1 and W_2 represent the dry weights at the first and second time points, and t_1 and t_2 are the respective days after planting.

Data Analysis

Data were analyzed using ANOVA, and if significant differences were found, further comparison was performed using the Honestly Significant Difference (HSD) test at a 5% significance level (Gomes & Gomes, 1995).

Result and Discussion

Result

Based on laboratory analysis, the application of various doses of Paitan compost in polybags resulted in notable improvements in soil chemical properties. The soil pH remained within a neutral range (6.2–6.5) across all treatments, indicating that compost addition did not cause significant shifts in soil acidity or alkalinity, which is favorable for most crops. Organic carbon content increased from 2.2% in the control to 2.58% at the highest compost dose (15 grams), reflecting an enhancement in soil organic matter that supports soil fertility and microbial activity (Susilowati et al., 2023). Similarly, total nitrogen content rose from 0.31% to 0.51%, demonstrating that Paitan compost can contribute essential macronutrients necessary for plant growth. The availability of phosphorus (P_2O_5) remained relatively stable, ranging from 22.07 to 23.61 ppm, and stayed within the adequate range for plant uptake, suggesting that compost application does not negatively affect phosphorus availability.

Table 1. Soil Chemical Properties in the Paitan Compost Dosage Treatment

Dos	pH (H2O)	C (%)	N (%)	P (ppm)	K (ppm)	KTK ($cmol^+kg^{-1}$)
0 g	6.50	2.20	0.31	23.61	29.00	28.12
9 g	6.40	2.37	0.39	23.51	32.00	33.05
11 g	6.20	2.48	0.45	22.92	35.00	35.06
13 g	6.40	2.56	0.49	22.07	37.00	37.18
15 g	6.20	2.58	0.51	23.00	38.00	37.78

Note(s): Results of analysis of the soil science laboratory of Tadulako University, Palu.

In contrast, potassium (K_2O) content increased significantly from 29 ppm in the control to 38 ppm at the highest compost dose, highlighting the compost's role in enhancing potassium availability, which is vital for plant physiological processes. Furthermore, cation exchange capacity (CEC) improved from 28.12 cmol(+)/kg to 37.78 cmol(+)/kg, indicating better nutrient retention and soil buffering capacity. Overall, the use of Paitan compost at increasing doses positively influenced soil chemical quality by boosting organic matter, essential nutrients, and the soil's ability to retain and supply nutrients, thereby supporting sustainable plant growth.

The analysis of variance (ANOVA) revealed that the addition of Paitan compost at varying dosages did not significantly influence the germination time of Arabica coffee seeds. Across all treatment groups, the average germination period ranged narrowly between 28.19 and 29.69 days (Table 2), indicating that the timing of seed emergence remained consistent regardless of the amount of organic compost applied. This uniformity in germination timing suggests that factors intrinsic to the seeds, such as seed viability and vigor, were sufficiently high and consistent across treatments. Additionally, the environmental conditions within the nursery—such as temperature, moisture, and light-were likely well-controlled and uniform, providing an optimal setting for seed germination. Consequently, the presence or absence of paitan compost did not create significant variations in the microenvironment affecting seed germination. These findings imply that while paitan compost may influence later stages of seedling growth by improving soil fertility and structure, it does not accelerate or delay the initial germination process, which is primarily governed by seed quality and stable environmental factors.

Table 2. Average Germination Time for Arabica Coffee Seedlings

Doses compost	Average Germination Time (days)
0 g	29.69a
9 g	28.81a
11 g	28.63a
13 g	28.75a
15 g	28.19a

Note: Lowercase letters a, b, c: in the same column indicate a significant difference between the types of compost according to the BNT (Smallest Real Difference) test.

Plant height measurements showed a significant difference only at 17 weeks after planting (WAP), where seedlings treated with *paitan* compost were notably taller than those in the control group. Earlier observations at 7, 9, 11, 13, and 15 WAP revealed no statistically significant differences, suggesting that the compost's effects on growth were not immediate. This delay likely reflects the time required for the organic compost to decompose and release essential nutrients into the soil, making them available for uptake by the seedlings. At 17 WAP, the seedlings receiving the highest compost dosage of 15 g exhibited the greatest average height of 9.74 cm, significantly surpassing the control seedlings, which averaged 6.28 cm. This marked increase in height indicates that the compost enhanced nutrient availability, particularly potassium, a key element known to promote cell elongation and vertical growth in plants. The results imply that while compost amendments may not influence early seedling height, their benefits become apparent as nutrient release progresses, supporting improved growth and vigor in Arabica coffee seedlings over time. This finding underscores the importance of allowing sufficient time for organic amendments to integrate into the soil ecosystem to maximize their positive effects on plant development.

Stem girth measurements showed no significant difference between treatments at 7 WAP, indicating that early stem thickening was similar regardless of compost application. However, starting at 9 WAP, differences became statistically significant, and from 11 to 17 WAP, the effect of paitan compost on stem girth was highly significant. Seedlings treated with the highest compost dose of 15 g consistently exhibited the greatest stem thickness, reaching an average girth of 1.11 cm at 17 WAP, while the control group recorded the smallest girth of 0.79 cm. This increase in stem girth is likely attributed to improved nutrient availability and uptake facilitated by the compost-enriched growing medium.

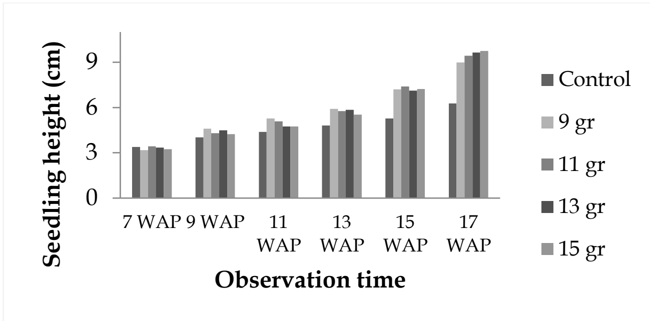

Figure 1. Graph of the increase in height of coffee seedlings treated with different doses of paitan-compost

Enhanced nutrient supply, particularly of macronutrients such as nitrogen and potassium, supports increased cell division and expansion in the stem's vascular tissues, leading to thicker and stronger stems. Additionally, the compost likely stimulated physiological activities such as photosynthesis and hormone production, further promoting stem development. These findings suggest that organic amendments like Tithonia diversifolia compost play a crucial role in strengthening seedling structural growth, which is essential for supporting future plant vigor and resilience.

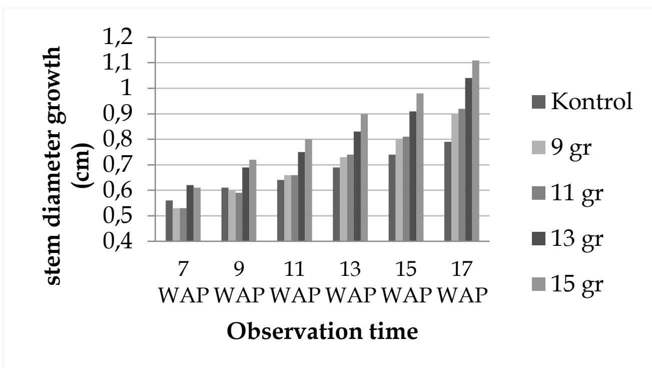

Figure 2. Graph of stem diameter growth (cm) of coffee seedlings treated with different doses of Paitan-compost

The study found that the number of leaves on Arabica coffee seedlings was significantly influenced by the application of Paitan compost, particularly from 11 WAP onward. While no significant differences were observed at 9 WAP, seedlings treated with 13 g and 15 g of compost produced the highest average leaf numbers, reaching up to 8.75 leaves at 17 WAP. This increase in leaf production is closely linked to the enhanced availability of key nutrients such as nitrogen and potassium provided by the compost. Nitrogen is essential for chlorophyll synthesis and overall vegetative growth, while potassium plays a critical role in enzyme activation and water regulation, both of which support robust leaf development.

In contrast, compost application did not significantly affect leaf area throughout the study, despite slight increases observed in higher compost treatments (up to 3.54 cm² in the 13 g treatment). The lack of significant change in leaf size may be due to limited nitrogen availability during the early growth stages or physical constraints on root expansion caused by the relatively small size of the polybags, which could restrict nutrient uptake and limit leaf expansion.

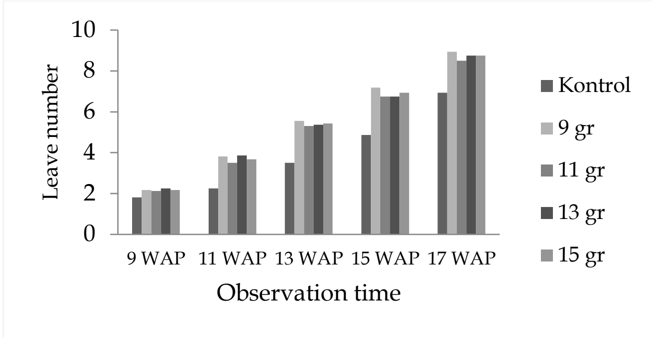

Figure 3. Graph of the increase in leave number of coffee seedlings treated with different doses of Paiton compost

Regarding biomass accumulation, dry shoot weight was significantly higher in compost-treated seedlings at 19 WAP, with the 13 g treatment showing the greatest average shoot dry weight of 1.04 g. Root dry weight also showed significant improvements at 10 and 19 WAP in compost-amended plants compared to controls. These results suggest that the compost enhanced nutrient supply, thereby supporting greater biomass production in both shoots and roots, which is critical for seedling vigor and establishment.

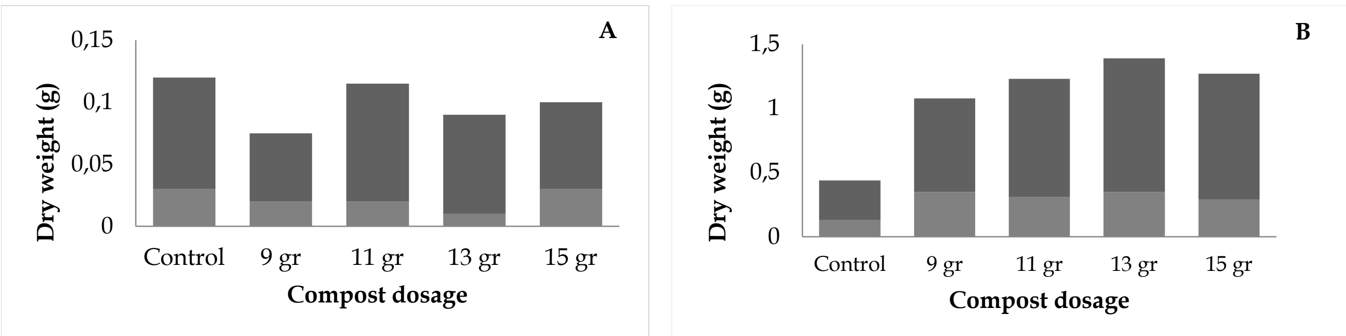

Figure 4. Graph of root and shoot dry weight of coffee seedlings: A) at 9 week after planting (WAP); and, B) 17 WAP

Root length, however, did not differ significantly among treatments. Although the longest average root length (21.77 cm) was recorded in the 15 g compost treatment, the limited volume of the polybags likely restricted full root system development, potentially masking the effects of compost on root elongation.

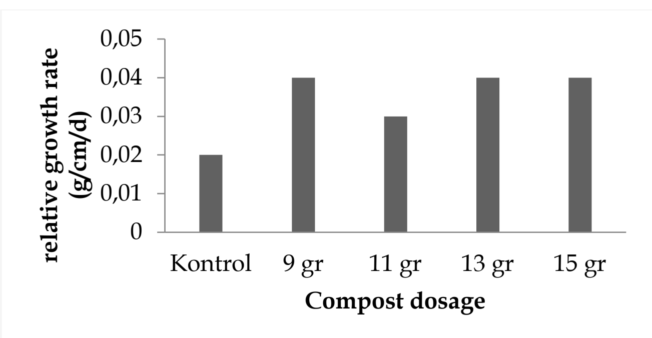

Figure 5. Graph of the relative growth rate of coffee seedlings at various doses of Paitan compost

Finally, relative growth rate (RGR) was significantly improved by compost application. The control group exhibited the lowest RGR at 0.02 g/day, while seedlings receiving 9, 11, 13, and 15 g of compost showed significantly higher rates ranging from 0.03 to 0.04 g/day. This enhancement is attributed to the improved availability of essential nutrients-particularly nitrogen, phosphorus, and potassium-which promote photosynthesis, cell division, and cell expansion, thereby accelerating overall seedling growth.

Discussion

The application of *paitan* compost in Arabica coffee seedling growth has demonstrated a range of physiological responses across different parameters. Although the germination time was not significantly affected by the compost treatments, this aligns with findings from Bewley et al. (2013) and Savage et al. (2006), who emphasize that seed germination is primarily governed by intrinsic seed factors such as maturity, dormancy status, and environmental conditions like moisture and temperature. The similarity in germination times across treatments suggests that the compost did not adversely affect seedbed conditions during the early establishment phase, corroborating reports by Lončarić et al. (2024) that organic amendments generally do not influence germination timing but rather seedling vigor post-emergence.

Significant improvements in plant height were observed at 17 weeks after planting (WAP), with all compost treatments outperforming the control. This delay in response suggests a lag phase in compost decomposition and nutrient mineralization, consistent with findings by Lazcano et al. (2013) and Zhao et al. (2021), who note that organic amendments require microbial activity and favorable environmental conditions to break down complex organic compounds into plant-available forms, particularly nitrogen and potassium—both crucial for vertical growth. The primary function of N is to stimulate cell division, thereby promoting both growth and production (Pane et al., 2023). The slow-release nature of organic fertilizers provides sustained nutrient availability over time, supporting the gradual improvement in seedling height observed in this study.

Stem girth followed a similar trend, with significant differences emerging after 9 WAP and becoming highly significant in later observations. Notably, the 13 g and 15 g compost treatments resulted in the greatest stem diameters. This suggests that increasing compost dosage improved nutrient supply, particularly potassium, which plays a key role in promoting thicker, sturdier stems through enhanced cell division and water regulation (Marschner, 2012; Wang et al., 2013). Potassium is essential for maintaining turgor pressure and facilitating photosynthate transport, which contribute to stronger stem development, as supported by studies on nutrient-mediated stem growth in woody plants (Menge & Kirkby, 2001).

In terms of leaf production, compost-treated seedlings had significantly more leaves than the control, particularly at 11 to 17 WAP. The role of nitrogen in promoting vegetative growth is well established (Fageria & Moreira, 2011), and the improved leaf development observed in this study supports the assumption that *paitan* compost served as an effective nitrogen source. A denser leaf canopy implies higher photosynthetic potential, which can positively influence overall plant biomass accumulation and long-term productivity (Poorter & Nagel, 2000).

Contrary to expectations, the compost treatments did not significantly influence leaf area. This could be attributed to several factors: firstly, the physical constraint of polybag size may have limited root expansion and thus nutrient uptake, a phenomenon documented by Poorter et al. (2012) who highlighted container volume as a limiting factor for root and shoot growth. Secondly, leaf area development may require a more precise balance of nitrogen and water, both of which may fluctuate during compost decomposition (Getachew & Muleta, 2017). These findings suggest that while compost supports overall vegetative expansion, it may not immediately translate to increased individual leaf size.

The results for shoot and root dry weight support the hypothesis that organic amendments enhance biomass accumulation. At 19 WAP, compost-treated seedlings, particularly at the 13 g rate, exhibited significantly greater dry matter in both shoots and roots. This indicates effective nutrient uptake and translocation, contributing to robust seedling structure. These results align with studies by Cruz-Barrera et al. (2025) and Diacono et al. (2010), which demonstrated that compost improves soil physical properties, water-holding capacity, and microbial activity, thereby supporting plant growth and biomass accumulation.

Interestingly, while root biomass improved, root length did not significantly differ across treatments. This may be attributed to spatial limitations within the polybags, which can physically restrict root elongation (Poorter et al., 2012). Similar observations have been reported in confined container environments, where root morphology is often altered by volume constraints rather than nutrient limitations (Lynch et al., 2011). Therefore, future studies should consider larger containers or field trials to better assess root architecture responses to organic amendments.

Relative growth rate (RGR), a key indicator of biomass production efficiency, showed a highly significant increase in compost-treated plants. The consistent enhancement of RGR across all compost treatments highlights the importance of nutrient availability in sustaining physiological processes such as photosynthesis and cell expansion (Lambers & Oliveira, 2019). This is likely due to the balanced nutrient release from the compost, which provided sufficient nitrogen, phosphorus, and potassium during critical growth phases. These macronutrients are essential for metabolic processes and support accelerated biomass accumulation (Fageria & Moreira, 2011).

The overall positive response of Arabica coffee seedlings to Paitan compost application reinforces the role of organic amendments in sustainable nursery practices. In regions like Poso Regency, where access to chemical fertilizers may be limited, the use of local organic resources offers an effective and environmentally friendly alternative. Moreover, integrating such practices supports circular economy principles by utilizing locally available biomass and reducing dependency on external inputs (Smith et al., 2020; Kelly, 2009; Lal, 2020).

In summary, while certain parameters such as germination time, leaf area, and root length were not significantly influenced by compost treatments, most growth indicators—including plant height, stem girth, leaf number, dry weight, and RGR—responded positively to increasing compost dosages. These findings validate the agronomic potential of *paitan* as a compost material and suggest that its integration into nursery management can enhance seedling quality and vigor. Future studies could expand on these findings by assessing long-term field performance and refining compost application rates to optimize growth and yield.

Conclusion

This study demonstrates that organic matter derived from Paitan (Tithonia diversifolia) is an effective amendment for improving the growth performance of Arabica coffee seedlings cultivated on nutrient-poor Ultisol soils. Although compost application did not influence germination time, leaf area, or root length, it significantly enhanced key developmental traits—including plant height, stem girth, leaf number, shoot and root dry biomass, and relative growth rate—indicating substantial improvements in seedling vigor. The optimal responses were obtained at compost doses equivalent to 13–15 g per polybag, suggesting that moderate applications of Paitan compost provide the most efficient nutrient release and uptake. Enhancements in soil organic carbon, nitrogen, potassium, and cation exchange capacity further confirm that Paitan compost improves soil fertility and supports sustainable nursery practices. These findings validate the initial research objective: to identify an eco-friendly, locally sourced organic input capable of strengthening Arabica coffee seedling growth in regions dominated by Ultisols.

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Author Contributions
Conceptualization, RD and FR; methodology, FR. MS and ARS; validation date, BES and; format analysis, RD and ARS; investigation, FR; data curation, RD; writing—original draft preparation, FR; writing—review and editing, BES. All authors have read and agreed to the published version of the manuscript.

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