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# Oil palm seedling growth in media amended with fifty percent dairy farm effluent compost under reduced fertiliser input

**MOHD. RASHID MOHD. RAKIB[1,♥], NUR AAINAA HASBULLAH[1], CLAMENT FUI SEUNG CHIN[1], BORHAN ABDUL HAYA[1], N. J. MAYZAITUL-AZWA[1], SITI SULIZA SALAMAT[1], NOR JAWAHIR ABU[1], KHIM PHIN CHONG[2], S. SYAMSIA[3]**
[1]Faculty of Sustainable Agriculture, Universiti Malaysia Sabah. 90000 Sandakan, Sabah, Malaysia. Tel. +60-89-634000, ♥email: rakibmrm@ums.edu.my
[2]Biophysics Research Group, Faculty of Science and Technology, Universiti Malaysia Sabah. Jl. UMS, 88400 Kinabalu, Sabah, Malaysia
[3]Department of Agrotechnology, Faculty of Agriculture, Universitas Muhammadiyah Makassar. Jl. Sultan Alauddin No. 259, Makassar 90221, South Sulawesi, Indonesia

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**Abstract.** *Rakib MRM, Hasbullah NA, Chin CFS, Haya BA, Mayzaitul-Azwa NJ, Salamat SS, Abu NJ, Chong KP, Syamsia S. 2026. Oil palm seedling growth in media amended with fifty percent dairy farm effluent compost under reduced fertiliser input. Asian J Agric 10 (1): g100174. https://doi.org/10.13057/asianjagric/g100174.* Conventional oil palm nursery practices rely heavily on mineral fertilisers, which promote short-term growth but cause adverse environmental impacts. Organic amendments in planting media have the potential to sustain seedling development while reducing dependence on mineral fertilisers. This study evaluated the growth and biomass accumulation of oil palm seedlings at the main nursery stage by amending Dairy Farm Effluent Compost (DFEC) to planting media under reduced mineral fertiliser input. Three-month-old seedlings were transplanted into either 100% mineral soil or a 1:1 mixture of mineral soil and DFEC, with varying mineral fertiliser rates. Treatments were arranged in a Completely Randomized Design (CRD). Ten replications (n = 10) were used for non-destructive measurements, while five randomly selected seedlings per treatment (n = 5) were used for destructive biomass and root assessments at nine months after transplanting. Data were analysed using Analysis of Variance (ANOVA) followed by Tukey's test. Seedlings grown in DFEC-amended media exhibited significantly greater height and bole circumference compared to those in 100% mineral soil with full-rate fertiliser application. Frond production (14-16 fronds) and root numbers (15-24 primary roots) did not differ significantly among treatments. However, dry matter accumulation in fronds and stems was markedly higher in DFEC-amended seedlings, irrespective of fertiliser application, suggesting that DFEC amendment alone was able to sustain seedling growth under the conditions tested. Notably, addition of 50% DFEC to the mineral soil, either with half-rate mineral fertiliser or without fertiliser performed as well as or better than the 100% mineral soil with full-rate fertiliser, in terms of plant height, bole circumference, and fronds, stem and total dry biomass. The findings indicate that dairy farm effluent compost can potentially serve as a sustainable amendment in oil palm nursery systems, providing agronomic benefits while supporting nutrient recycling and reducing the environmental footprint of early-stage cultivation.

**Keywords:** Compost, fertiliser, nursery, oil palm, organic amendment

**Abbreviations:** ANOVA: Analysis of Variance, CRD: Completely Randomised Design, DFEC: Dairy Farm Effluent Compost, EC: Electrical Conductivity, MAT: Months after transplanting, MPOB: Malaysian Palm Oil Board, SAS: Statistical Analysis System, USDA: United States Department of Agriculture

## INTRODUCTION

The African oil palm (*Elaeis guineensis* Jacq.) is an important plantation crop, valued for its remarkably high oil yield per hectare as compared to other major vegetable oil-producing crops, contributing to 40% of the global vegetable oil supplies (United States Department of Agriculture 2025). In Malaysia, oil palm cultivation occupies more than 5.65 million hectares, producing over 18 million tonnes of crude palm oil annually and serving as a critical contributor to national income and global food security (Malaysian Palm Oil Board (MPOB) 2025). The crop's production cycle begins in the nursery, where germinated seeds are established in polybags and maintained for 12-14 months before being transplanted to the field, where they remain productive for 20-25 years (Malaysian Palm Oil Board (MPOB) 2016). The quality of seedlings produced during this stage is critical, as early growth performance directly influences subsequent field establishment, uniformity, and yield potential (Corley and Tinker 2015). While planting material's genetic background contributes to the crop's performance, nursery management practices, particularly growing media composition and nutrient management, play a vital role in producing vigorous and resilient seedlings that ensure optimal field establishment and long-term productivity (Adip et al. 2022).

Conventional oil palm nursery practices rely heavily on mineral fertilisers to sustain seedling growth. However, such inputs are associated with environmental issues, including nutrient leaching, greenhouse gas emissions, and soil acidification (Dikr 2023; Sham et al. 2024). Therefore, there is urgent demand for more sustainable alternatives, such as application of organic amendments as partial or full substitutes for mineral fertilisers that reduce fertiliser dependency while maintaining or enhancing seedling quality. Recent studies have demonstrated the potential of organic amendments such as compost derived from palm oil mill residues in improving soil properties, enhancing nutrient retention, and supporting seedling development under reduced fertiliser regimes (Lau et al. 2024). For example, compost-based media improved soil health, root growth, and nutrient assimilation compared to mineral fertiliser alone (Ayompe et al. 2025). Compost amendments have also been shown to foster beneficial microbial diversity in nursery substrates which support nutrient cycling and seedling vigour (Salamat et al. 2024). Unlike mineral fertilisers, which dissolve rapidly and may transiently exceed short-term plant nutrient demand, compost-derived nutrients are released more gradually through microbial mineralisation, thereby promoting improved synchronisation between nutrient supply and seedling uptake (Oueld et al. 2025). This dynamic enhances nutrient-use efficiency and mitigates leaching losses, a common concern in polybag nursery systems (Sham et al. 2024).

Despite these benefits, data regarding the performance of seedling media amended with dairy farm effluent compost (DFEC) remains limited. DFEC is an organic amendment derived from the aerobic composting of slurry, manure, and bedding materials generated in dairy production systems. Dairy effluent typically contains a mixture of urine, feces, wash water, spilled feed, and bedding residues such as sawdust or straw (Petersen et al. 2007; Palese et al. 2020). Through composting, these effluents undergo microbial decomposition and stabilization, producing a nutrient-rich resource that could support oil palm seedling growth while reducing reliance on mineral fertilisers and support circular economy principles.

Although DFEC is rich in macronutrients and organic matter, it may contain elevated soluble salts, reflected in high Electrical Conductivity (EC), which can induce osmotic stress, impair ion balance, and restrict root elongation in young oil palm seedlings (Gondek et al. 2020). The 50% (v/v) DFEC rate was selected based on previous studies and nursery considerations, as 1:1 soil-compost mixtures can improve physical structure, aeration, moisture retention, and nutrient buffering (Radin et al. 2018; Lau et al. 2024). Lower rates may provide insufficient nutrient contribution, whereas higher rates may increase EC and alter bulk density unfavourably. Therefore, we hypothesised that 50% DFEC would sustain oil palm seedling growth under reduced mineral fertiliser input without observable salinity-related effects during the nursery stage.

Evaluating the performance of DFEC-amended media under reduced mineral fertiliser input is therefore essential to determine whether such integration can sustain seedling growth without compromising vigour. Accordingly, this study evaluated the growth and biomass accumulation of oil palm seedlings in nursery media amended with 50% DFEC (v/v) under reduced fertiliser regimes, focusing specifically on seedling performance at the end of the nursery cycle (12-month-old stage).

## MATERIALS AND METHODS

### Planting materials and media

Three-month-old *Tenera* originated from Deli *dura* × AVROS *pisifera* (*D* × *P*) oil palm seedlings of uniform size were obtained from Ulu Dusun Agricultural Research Centre, Sabah, Malaysia (5°47'11.24"N, 117°46'5.42"E). The planting media consisted of mineral soil (Silabukan series) and Dairy Farm Effluent Compost (DFEC) supplied by the Faculty of Sustainable Agriculture, Universiti Malaysia Sabah (5°55.87′ N, 118°0.38′ E). The DFEC used in this study had a C:N ratio of approximately 13, a characteristic commonly associated with compost suitable for agricultural application. Soil was air-dried, ground, and stored prior to use. The physicochemical properties of both materials are presented in Table 1. It should be noted that the nutrient values for the mineral soil represent exchangeable forms, except for nitrogen, which is reported as total nitrogen, whereas all nutrient values for DFEC represent total concentrations. Consequently, these values are intended to characterise the respective planting media and should not be interpreted as directly comparable analytical fractions. A commercial compound fertiliser (12:12:17:2 N P K Mg) was applied accordingly following the recommended timings and rates by MPOB (2016) (Table 2). Applications were conducted monthly from one to nine months after transplanting (MAT), as a single application per month. At each scheduled MAT, the full- or half-rate (depending on treatment) was applied per seedling. Fertiliser was applied uniformly on the soil surface by circular broadcasting method around the seedling. Approximately 5-8 cm away from the bole during early stages (1-4 MAT) to avoid direct contact with the stem and prevent fertiliser burn. As seedlings increased in size (5-9 MAT), the placement radius was progressively adjusted outward (approximately 8-12 cm from the bole) to align with expanding root distribution. Fertiliser was lightly incorporated into the upper 1-2 cm of the planting media to minimise volatilisation and runoff losses.

**Table 1.** Physicochemical properties of soil and Dairy Farm Effluent Compost (DFEC) used as planting media in nursery (Mean ±standard error)

| Variable | Soil | DFEC |
|---|---|---|
| Nitrogen (%) | 0.35±0.01 | 1.72±0.05 |
| Phosphorus (g kg$^{-1}$) | 0.042±0.001 | 1.30±0.08 |
| Potassium (g kg$^{-1}$) | 1.85±0.16 | 50.37±4.59 |
| Calcium (g kg$^{-1}$) | 3.56±0.03 | 40.02±3.62 |
| Magnesium (g kg$^{-1}$) | 4.89±1.36 | 8.63±0.72 |
| Copper (mg kg$^{-1}$) | <0.01 | 56.95±9.45 |
| Zinc (mg kg$^{-1}$) | 17.55±6.65 | 91.55±9.45 |
| pH | 4.8±0.5 | 8.5±0.5 |
| Electrical conductivity (dS m$^{-1}$) | 0.089±0.005 | 4.30±0.10 |
| C:N ratio | 10±0.90 | 13.05±1.05 |

Note: For the mineral soil, nutrient values represent exchangeable forms, except for nitrogen, which is reported as total nitrogen. For DFEC, all nutrient values are reported as total concentrations

**Table 2.** Fertiliser programme in main nursery

| Age of seedlings (month after transplanting) | *Full-rate (g seedling$^{-1}$) | Half-rate (g seedling$^{-1}$) |
|---|---|---|
| 1 | 10 | 5 |
| 2 | 10 | 5 |
| 3 | 15 | 7.5 |
| 4 | 15 | 7.5 |
| 5 | 20 | 10 |
| 6 | 20 | 10 |
| 7 | 20 | 10 |
| 8 | 30 | 15 |
| 9 | 30 | 15 |

Note: *: Application of compound mineral fertiliser with a ratio of 12:12:17:2 in nitrogen, phosphorus, potassium, and magnesium, according to the rate and timing recommended by Malaysian Palm Oil Board (2016)

**Table 3.** Summary of treatments on oil palm seedlings

| Treatment code | Planting media | Fertiliser application |
|---|---|---|
| T1 | Negative control, 100% mineral soil | None |
| T2 | Positive control, 100% mineral soil (conventional practice) | Full-rate of mineral fertiliser |
| T3 | Mixture of 50% mineral soil and 50% DFEC | None |
| T4 | Mixture of 50% mineral soil and 50% DFEC | Half-rate of mineral fertiliser |

Note: T1: Negative control of 100% mineral soil (Silabukan series) as planting medium, without application of mineral fertiliser, T2: Positive control of 100% mineral soil (Silabukan series) as planting medium, with full rate of mineral fertiliser, T3: Mixture of 50% mineral soil (Silabukan series) and 50% dairy farm effluent compost as planting medium, without application of mineral fertiliser, T4: Mixture of 50% mineral soil (Silabukan series) and 50% dairy farm effluent compost as planting medium, with application of half-rate mineral fertiliser

## Nursery experiment

The experiment comprised four treatments (Table 3) and was conducted following standard nursery management practices (MPOB 2016; Laksono et al. 2019). Seedlings were transplanted into black polyethylene bags (38 × 45 cm), each containing either 100% mineral soil weigh approximately 16 kg or a 1:1 mixture of mineral soil and DFEC (v/v) weigh approximately 8.5 kg. All polybags were filled to a consistent volume (38 × 45 cm), ensuring comparable rooting space across treatments. Differences in substrate mass reflected inherent differences in bulk density between mineral soil and DFEC-amended media. The transplanted seedlings were applied with either full-rate, half-rate, or no mineral fertiliser. The full-rate of mineral fertiliser was based on the recommended rates (Table 2), where each seedling was applied with 10 g fertiliser per seedling (1-2 MAT), 15 g (3-4 MAT), 20 g (5-7 MAT), and 30 g (8-9 MAT). Each treatment consisted of 10 independent experimental units (n = 10), with one seedling per polybag serving as the experimental unit for non-destructive measurements (plant height, bole circumference, and frond number). For destructive assessments, five seedlings per treatment were randomly selected from these experimental units at the end of the experiment (n = 5) to determine primary root number and dry biomass components (fronds, stem, and roots). Seedlings were arranged in equal triangular spacing (0.9 m) within a rain-sheltered facility at Universiti Malaysia Sabah (5° 55.87'N, 118°0.38'E), and assigned according to a Completely Randomised Design (CRD). The rain-shelter provided natural light conditions (approximately 50% of full sunlight during daytime). The average temperature ranged between 25-32°C, with relative humidity between 70-85% throughout the experimental period. These conditions are typical of tropical nursery environments and were considered suitable for oil palm seedling growth. Watering was conducted twice daily, and manual weeding was performed whenever necessary.

## Data collection

Data was recorded monthly, for a period of 9 MAT. However, this study was designed as an endpoint evaluation, therefore, statistical analyses were conducted using data at 9 MAT, representing seedling performance at the end of the nursery cycle (12-month-old seedlings). Monthly growth (plant height, bole circumference, and frond number) trajectories are presented in Figure 3 to support the consistency of treatment effects. The plant's height from the soil base to the tip of a seedling was measured using a ruler, the bole's circumference measured using a measuring tape, and the number of fronds were counted. A destructive sampling was performed at the end of the experiment, where five seedlings per treatment (n = 5) were randomly selected to determine primary root number and dry biomass. Seedlings were separated into fronds, stems, and roots, oven-dried at 60°C for one week, and weighed to obtain dry mass.

## Statistical analysis

Data were subjected to Analysis of Variance (ANOVA), and treatment means were separated using the Tukey's test at $p \leq 0.05$. Prior to ANOVA, the assumptions of normality and homogeneity of variance were verified, and all variables satisfied these assumptions without requiring data transformation. Pearson's correlation analysis was performed to examine relationships among growth variables. Statistical analyses were conducted using SAS software (Version 9.4; SAS Institute Inc., Cary, NC, USA), following the guidelines of Zar (2014).

# RESULTS AND DISCUSSION

Amendment of planting media with Dairy Farm Effluent Compost (DFEC), either with or without mineral fertiliser, significantly influenced oil palm seedling growth and biomass accumulation at 9 months after transplanting (MAT) (Figures 1, 2, and Table 5). Seedlings grown in 100% mineral soil without fertiliser (T1, negative control) exhibited the lowest performance across most parameters, where the plant height, bole circumference, and primary roots number achieved were 70.30 cm, 8.83 cm, and 15, respectively. Meanwhile, conventional nursery practice, represented by seedlings in 100% mineral soil with full-rate fertiliser (T2), markedly improved growth compared to T1, increasing plant height, bole circumference, and primary root number by 20%, 30%, and 63%, respectively.

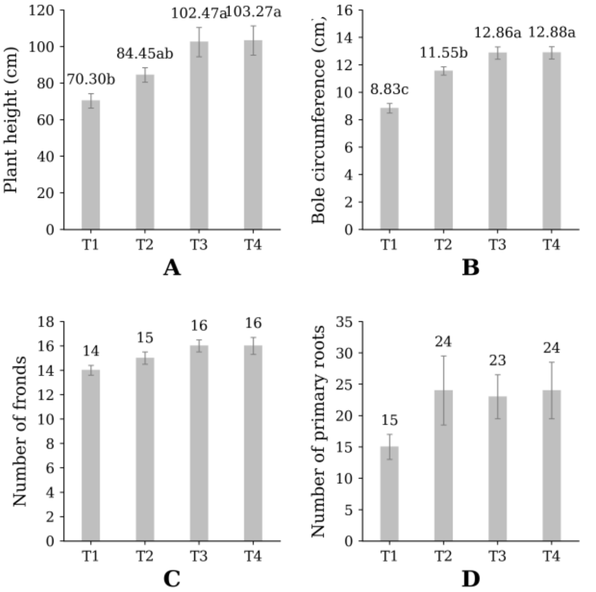

**Figure 1.** Growth of oil palm seedlings at 9 months after transplanting. A. Plant height, B. Bole circumference, C. Number of fronds, D. Number of primary roots. Means ± standard error. Different letters indicate significant differences at $p \leq 0.05$ (Tukey's test). T1: 100% mineral soil, no fertiliser; T2: 100% mineral soil + full-rate fertiliser; T3: 50% mineral soil + 50% DFEC, no fertiliser; T4: 50% mineral soil + 50% DFEC + half-rate fertiliser

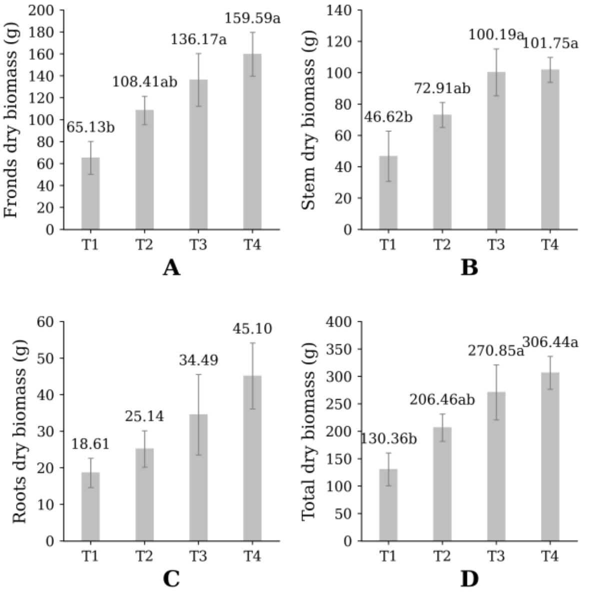

**Figure 2.** Dry biomass of oil palm seedlings at 9 months after transplanting. A. Fronds dry biomass, B. Stem dry biomass, C. Roots dry biomass, D. Total dry biomass. Means ± standard error. Different letters indicate significant differences at $p \leq 0.05$ (Tukey's test). T1: 100% mineral soil, no fertiliser, T2: 100% mineral soil + full-rate fertiliser, T3: 50% mineral soil + 50% DFEC, no fertiliser, T4: 50% mineral soil + 50% DFEC + half-rate fertiliser

The incorporation of 50% DFEC into the mineral soil without fertiliser (T3) further enhanced seedling vigor. Relative to T2, T3 seedlings achieved a 21% increase in plant height (102.47 cm) and an 11% increase in bole circumference (12.86 cm). The number of primary roots, however, showed no significant difference between T2 and T3, with both producing 23-24 roots. Supplementing the DFEC-amended medium with half-rate fertiliser (T4) did not confer significant additional improvements in growth parameters compared to T3, although seedlings in both treatments attained the highest plant height (102.47-103.27 cm) and bole circumference (12.86-12.88 cm). Frond number remained consistent across treatments (14-16), however, the the dry biomass of fronds was significantly higher in oil palm seedlings grown in DFEC-amended media (T3 and T4) compared to the conventional treatment (T2), indicating vigorous growth.

Biomass accumulation closely mirrored the observed vegetative growth responses, further demonstrating the positive effect of DFEC incorporation into the planting media. Seedlings grown in 100% mineral soil without fertiliser (T1) produced the lowest dry biomass, with 65.13 g in fronds, 46.62 g in stems, 18.61 g in roots, and 130.36 g in total biomass. Conventional nursery practice (T2) increased total biomass to 206.46 g, whereas DFEC amendment without mineral fertiliser (T3) further enhanced total biomass to 270.85 g. The greatest biomass accumulation was recorded in T4, with frond, stem, and root dry weights of 159.59 g, 101.75 g, and 45.10 g, respectively, resulting in a total dry biomass of 306.44 g. However, despite these numerical increases, no significant differences were detected between the DFEC-amended treatments with (T4) and without (T3) mineral fertiliser application (Figure 2), indicating that DFEC alone was sufficient to sustain biomass production comparable to that achieved with supplementary mineral fertiliser under the conditions tested.

Pearson's correlation analysis revealed predominantly positive relationships among growth and biomass variables of oil palm seedlings (Table 4). Plant height showed strong and significant correlations with most variables, particularly bole circumference ($r = 0.66$), frond dry weight ($r = 0.90$), stem dry weight ($r = 0.86$), root dry weight ($r = 0.79$), and total dry weight ($r = 0.92$), indicating that taller seedlings were generally associated with greater biomass accumulation. Plant height was also significantly correlated with frond number ($r = 0.74$), but its association with the number of primary roots was weak and not significant ($r = 0.35$). Bole circumference exhibited moderate to strong positive correlations with biomass components, including frond dry weight ($r = 0.59$), stem dry weight ($r = 0.56$), and total dry weight ($r = 0.58$), although its relationships with frond number and primary roots were not significant. Similarly, frond number was significantly correlated with primary roots ($r = 0.50$) and all biomass parameters, especially stem dry weight ($r = 0.79$) and total dry weight ($r = 0.78$). Among belowground traits, the number of primary roots showed weak to moderate correlations with biomass variables, being significant only with frond dry weight ($r = 0.47$), stem dry weight ($r = 0.54$), and total dry weight ($r = 0.47$), but not with root dry weight (r = 0.18). The weak association between primary root number and root dry weight indicates that primary root count alone may not adequately capture the complexity of belowground development. Root architectural traits, including root length, root surface area, root volume, and fine root density, are likely to exert substantial influence on root biomass accumulation and resource acquisition efficiency. Strong interrelationships were observed among biomass components. Frond dry weight was highly correlated with stem dry weight (*r* = 0.91), root dry weight (*r* = 0.77), and total dry weight (*r* = 0.99). Likewise, stem dry weight showed strong correlations with root dry weight (*r* = 0.66) and total dry weight (*r* = 0.95), while root dry weight was also strongly associated with total dry weight (*r* = 0.82). Overall, plant height and bole circumference showed strong positive associations with biomass components, and significant positive correlations were observed among frond, stem, root, and total dry weights.

The Pearson correlation analysis was performed using pooled observations across treatments (n = 20) and was intended to describe associations among growth and biomass traits within the experimental dataset. Because treatment effects may contribute to the observed relationships, these correlations should be interpreted as associative rather than as evidence of direct mechanistic or causal relationships among the measured variables. Nevertheless, the strong positive associations between aboveground growth traits and biomass components support their potential utility as integrated indicators of seedling performance under the conditions evaluated.

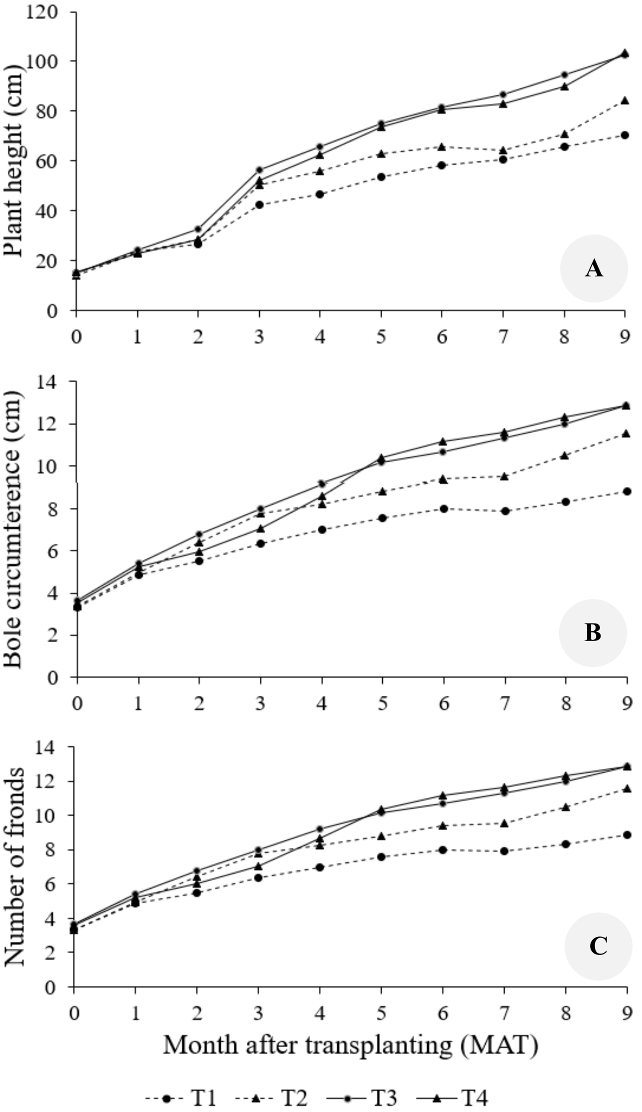

**Figure 3.** Monthly growth of oil palm seedlings. A. Plant height, B. Bole circumference, C. Number of fronds. Means ± standard error (n = 10). Different letters indicate significant differences at p ≤ 0.05 (Tukey's test). T1: 100% mineral soil, no fertiliser, T2: 100% mineral soil + full-rate fertiliser, T3: 50% mineral soil + 50% DFEC, no fertiliser, T4: 50% mineral soil + 50% DFEC + half-rate fertiliser

**Table 4.** Pearson's correlation coefficient (*r*) between variables evaluated for the growth of oil palm seedlings (*n* = 20)

| **Variable** | **Bole circumference** | **Number of fronds** | **Number of primary roots** | **Fronds dry weight** | **Stem dry weight** | **Roots dry weight** | **Total dry weight** |
|---|---|---|---|---|---|---|---|
| Plants' height | 0.66** | 0.74** | 0.35ns | 0.90** | 0.86** | 0.79** | 0.92** |
| Bole circumference | | 0.38ns | 0.29ns | 0.59** | 0.56* | 0.39ns | 0.58** |
| Number of fronds | | | 0.50* | 0.75** | 0.79** | 0.58** | 0.78** |
| Number of primary roots | | | | 0.47* | 0.54* | 0.18ns | 0.47* |
| Fronds dry weight | | | | | 0.91** | 0.77** | 0.99** |
| Stem dry weight | | | | | | 0.66** | 0.95** |
| Roots dry weight | | | | | | | 0.82** |

Note: *: Significantly correlated at $p \leq 0.05$, **: Significantly correlated at $p \leq 0.01$, and ns: Not significant

**Table 5.** Growth and dry biomass of oil palm seedlings at 9 months after transplanting

| Treatment | Plant height (cm) | Bole circumference (cm) | Number of fronds | Number of primary roots | Frond dry biomass (g) | Stem dry biomass (g) | Roots dry biomass (g) | Total dry biomass (g) |
|---|---|---|---|---|---|---|---|---|
| T1 | 70.30 ±3.79b | 8.83 ±0.30c | 14 ±1 | 15 ±2 | 65.13 ±15.84b | 46.62 ±15.64b | 18.61 ±4.18 | 130.36 ±33.43b |
| T2 | 84.45 ±4.68ab | 11.55 ±0.32b | 15 ±1 | 24 ±6 | 108.41 ±14.61ab | 72.91 ±7.94ab | 25.14 ±4.25 | 206.46 ±24.82ab |
| T3 | 102.47 ±8.03a | 12.86 ±0.56a | 16 ±1 | 23 ±4 | 136.17 ±23.94a | 100.19 ±15.64a | 34.49 ±10.43 | 270.85 ±48.31a |
| T4 | 103.27 ±8.24a | 12.88 ±0.55a | 16 ±1 | 24 ±5 | 159.59 ±21.43a | 101.75 ±9.06a | 45.10 ±9.07 | 306.44 ±33.55a |
| Rep. (n) | 10 | 10 | 10 | 5 | 5 | 5 | 5 | 5 |
| F value | 5.93 | 17.92 | 2.94 | 1.16 | 4.41 | 4.30 | 2.35 | 4.62 |
| p value | 0.0021 | <0.0001 | 0.0510 | 0.3543 | 0.0193 | 0.0210 | 0.1112 | 0.0164 |

Note: Means ± standard error. Different letters indicate significant differences at $p \leq 0.05$ (Tukey's test). T1: 100% mineral soil, no fertiliser, T2: 100% mineral soil + full-rate fertiliser, T3: 50% mineral soil + 50% DFEC, no fertiliser, T4: 50% mineral soil + 50% DFEC + half-rate fertiliser

## Discussion

The findings in this study were aligned with other recent studies showing that amendment of organic matters or composts in oil palm nursery planting media were able to match or outperform conventional practice by improving media fertility, including soil physical, chemical, and biological properties. Compost derived from palm oil mill residues increased seedling growth and nutrient availability while reducing reliance on mineral fertilisers, particularly when used as a 1:1 soil mixture, closely mirroring the DFEC ratio used in this study (Lau et al. 2024).

Oil palm seedlings are physiologically mature for field planting at 12 months after sowing of germinated seeds, exhibiting vigorous vegetative growth, a well-developed root system, active nutrient uptake, and sufficient carbohydrate reserves to withstand transplant shock (Murdi et al. 2019). Oil palm seedlings typically attain a height of 90-120 cm and develop 12-16 fully expanded pinnate fronds, depending on their genotype and nursery management practices (Corley and Tinker 2015). The bole undergoes substantial thickening, providing structural support and facilitating water and nutrient transport, and bole circumference is widely recognised as a reliable indicator of seedling vigour (Akpo et al. 2014; Ramachandrudu et al. 2023). Root systems generally comprise 20-25 primary roots, which enhance nutrient and water acquisition while improving anchorage (Rosenani et al. 2016). Dry matter is predominantly allocated to the fronds (40-50%), followed by the stem (25-30%) and roots (20-30%), reflecting the high demand for N, P, K, and Mg required for leaf expansion, chlorophyll synthesis, and biomass accumulation (Cheah et al. 2022).

The insignificant growth response following the application of half-rate mineral fertiliser to the 50% DFEC-amended media (T4), relative to the unfertilised DFEC treatment (T3), is most plausibly explained by a masking effect exerted by the compost amendment (Radin et al. 2018). DFEC contains substantial concentrations of essential macronutrients, particularly K, Ca, Mg, and N (Table 1), and its incorporation at 50% (v/v) likely established nutrient-sufficient conditions at the end of the nursery period. Under such conditions, oil palm seedling growth becomes increasingly regulated by intrinsic physiological capacity rather than by external nutrient supply, thereby diminishing the observable contribution of additional mineral fertiliser inputs. These findings are similar to Salamat et al. (2019) and Purwanto et al. (2025).

The favourable growth response observed in DFEC-amended media may be attributed to integrated improvements in nutrient supply and substrate properties reported in previous studies. Compost incorporation has been shown to increase soil organic matter and cation exchange capacity, thereby enhancing nutrient retention and synchronisation with plant uptake. Likewise, improved moisture buffering, aeration, and microbial activity may promote root proliferation and nutrient cycling, collectively supporting shoot and root biomass accumulation (Oueld et al. 2025). These plausible mechanisms are consistent with previous reports demonstrating that organic amendments improve soil quality, enhance seedling performance, and enable partial substitution of mineral fertilisers in oil palm nursery systems (Rosenani et al. 2016; Radin et al. 2018; Salamat et al. 2019). However, these soil physicochemical and biological properties were not directly measured in the present study; therefore, the proposed mechanisms should be regarded as literature-supported interpretations rather than experimentally verified processes. This mechanistic synergy explains why DFEC-amended treatments achieved comparable or superior biomass relative to conventional fertiliser-based practice. It should be noted that nutrient availability was inferred from total nutrient composition rather than directly measured plant-available forms over time. Therefore, the observed growth responses may reflect a combination of nutrient supply and improved physical properties (e.g., aeration, moisture retention), and mechanistic interpretations should be considered indicative rather than definitive under the conditions tested. Despite the elevated EC and trace element concentrations in DFEC, seedlings grown in DFEC-amended media exhibited growth comparable to that under conventional nursery practice (T2). Plant height (102.47 cm), frond number (14-16), and primary root number (23-24) were within the nursery-stage ranges reported for field-ready oil palm seedlings (Corley and Tinker 2015; Rosenani et al. 2016). These observations indicate consistency with published growth benchmarks but do not constitute comprehensive validation of commercial seedling quality standards.

Beyond the nursery stage, repeated application of DFEC may contribute to long-term improvements in soil quality through the gradual accumulation of organic matter, enhanced cation exchange capacity, improved soil structure, and stimulation of beneficial microbial communities, all of which can increase nutrient retention and nutrient-use efficiency. Such changes have the potential to promote more synchronised nutrient release and reduce nutrient losses associated with rapidly soluble mineral fertilisers. However, these potential benefits were not directly evaluated in the present study. Long-term field experiments are therefore required to quantify the effects of DFEC on soil physicochemical properties, nutrient cycling, rhizosphere microbial dynamics, nutrient uptake efficiency, and fresh fruit bunch productivity under commercial oil palm cultivation. These investigations will provide a more comprehensive understanding of the sustainability of DFEC as a strategy for reducing mineral fertiliser dependence while maintaining soil health and crop productivity over successive production cycles.

Despite the promising outcomes observed, several limitations should be acknowledged. The experimental design did not include a treatment combining 50% DFEC with full-rate mineral fertiliser; therefore, the study does not provide a complete factorial assessment of the interaction between DFEC amendment and fertiliser rate. Consequently, it cannot determine whether the observed growth response reflects a plateau in nutrient availability or identify the optimal level of mineral fertiliser substitution within DFEC-amended media. Future studies should incorporate a full fertiliser gradient within DFEC-based media to determine optimal nutrient management strategies. Although the EC of the DFEC was determined prior to use, the EC of the final soil-DFEC mixture was not measured; therefore, the favourable seedling growth observed should not be interpreted as direct evidence of salinity safety under the tested amendment rate. In addition, the DFEC used in this study originated from a single dairy production system, and compost characteristics may vary substantially depending on feedstock composition, manure management practices, composting duration, and environmental conditions (Bernal et al. 2009; Palese et al. 2020). Such variability may influence nutrient availability, electrical conductivity (EC), and trace element concentrations, thereby affecting reproducibility across batches and locations (Hargreaves et al. 2008). Furthermore, the experiment was conducted at a single nursery site under controlled management conditions; therefore, extrapolation to other climatic regions or operational settings should be approached cautiously. Only one incorporation ratio (50% v/v) was evaluated, and the optimal proportion may differ depending on compost maturity, substrate texture, irrigation regime, and baseline soil fertility (Radin et al. 2018). Finally, although growth and biomass responses were quantified, temporal changes in substrate physicochemical properties and plant nutrient uptake dynamics were not monitored throughout the nursery cycle, limiting mechanistic interpretation of nutrient synchronisation effects (Oueld et al. 2025).

From a practical perspective, safe implementation of DFEC in nursery systems should prioritise the use of well-matured compost, characterised by a stabilised organic matter fraction, reduced C:N ratio (<20), low phytotoxicity, and adequate thermophilic sanitisation to minimise pathogen risks (Bernal et al. 2009; Palese et al. 2020). Monitoring of EC is particularly critical, as excessive salinity may induce osmotic stress and restrict root development in young oil palm seedlings (Gondek et al. 2020). In addition, attention should be given to trace element concentrations, particularly Cu and Zn derived from livestock feed supplements, to ensure levels remain within agronomic safety thresholds (Hargreaves et al. 2008). Future research should evaluate multiple DFEC incorporation rates, quantify nutrient uptake efficiency and soil chemical dynamics over time, and validate nursery findings under field conditions to strengthen the agronomic recommendations derived from this study.

In conclusion, amendment of planting media with DFEC significantly improved oil palm seedling growth and biomass accumulation at 9 MAT, demonstrating the potential of DFEC to reduce mineral fertiliser input under the conditions tested. Seedlings in 100% mineral soil without fertiliser (T1) performed poorest across all parameters, while conventional nursery practice with full-rate fertiliser (T2) enhanced growth and biomass. Notably, substituting 50% of the mineral soil with DFEC (T3) produced greater plant height (102.47 cm), bole circumference (12.86 cm), and dry biomass in the fronds (136.17 g), stem (100.19 g), and total dry weight (270.85 g) than T2, despite the absence of mineral fertiliser. Supplementation with half-rate fertiliser in DFEC-amended media (T4) did not significantly improve the seedlings' growth and biomass as compared to T3, although both achieved the highest seedling vigor and total biomass. Correlation analysis further confirmed strong positive relationships among growth parameters and biomass components, underscoring their collective contribution to overall seedling performance. Under the conditions tested, 50% DFEC (v/v) without mineral fertiliser performed comparably to full-rate fertiliser in mineral soil at 9 MAT, demonstrating its potential to reduce mineral fertiliser input during the nursery stage. However, because only one DFEC source, a single DFEC incorporation rate and selected fertiliser regime were evaluated, the present study does not establish the optimal level of mineral fertiliser substitution or the interaction between DFEC amendment and fertiliser rate. Future work should evaluate the seedlings performance in the field planting, assess the growth dynamics throughout the nursery stage, cost-benefit analysis, and characterize DFEC-driven shifts in soil physicochemical properties, plants' nutrients uptake, and rhizosphere microbiomes to link the observed growth enhancements, to establish its long-term sustainability as a strategy for reducing mineral fertiliser dependence while maintaining soil health and crop productivity.

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## REFERENCES

Adip ME, Meringgai JJ, Aziz NA, Lah MKC, Yusoff N. 2022. Growth performance of oil palm seedlings on different types of organic fertilizer. J Agrobiotechnol 13 (2): 65-75. https://doi.org/10.37231/jab.2022.13.2.325.

Akpo E, Stomph TJ, Kossou DK, Omore AO, Struik PC. 2014. Effects of nursery management practices on morphological quality attributes of tree seedlings at planting: The case of oil palm (*Elaeis guineensis* Jacq.). For Ecol Manag 324: 28-36. https://doi.org/10.1016/j.foreco.2014.03.045.

Ayompe LM, Nkongho RN, Acobta AN, Masso C, Egoh BN. 2025. Transforming palm oil production: Sustainable techniques and waste management strategies for Cameroon's smallholder farmers. Front Sustain Food Syst 9: 1606323. https://doi.org/10.3389/fsufs.2025.1606323.

Bernal MP, Alburquerque JA, Moral R. 2009. Composting of animal manures and chemical criteria for compost maturity assessment: A review. Bioresour Technol 100 (22): 5444-5453. https://doi.org/10.1016/j.biortech.2008.11.027.

Cheah SS, Wahid SAA, Teh CBS. 2022. Standing biomass, dry-matter production, and nutrient demand of tenera oil palm. Agronomy 12 (2): 426. https://doi.org/10.3390/agronomy12020426.

Corley RHV, Tinker PB. 2015. The Oil Palm (5th ed.). John Wiley & Sons, New York. https://doi.org/10.1002/9781118953297.

Dikr W. 2023. Effect of long-term chemical fertilizer application on soil chemical properties: A review. J Biol Agric Healthc 13 (5): 11-18. https://doi.org/10.7176/JBAH/13-5-02.

Gondek M, Weindorf DC, Thiel C, Kleinheinz G. 2020. Soluble salts in compost and their effects on soil and plants: A review. Compost Sci Util 28 (2): 59-75. https://doi.org/10.1080/1065657X.2020.1772906.

Hargreaves JC, Adl MS, Warman PR. 2008. A review of the use of composted municipal solid waste in agriculture. Agric Ecosyst Environ 123 (1-3): 1-14. https://doi.org/10.1016/j.agee.2007.07.004.

Laksono ND, Setiawati U, Nur F, Rahmaningsih M, Anwar Y, Rusfiandi H, Sembiring EH, Forster BP, Subbarao AS, Zahara H. 2019. Nursery practices in oil palm: A manual. Commonwealth Agricultural Bureaux International (CABI), Wallingford, United Kingdom. https://doi.org/10.1079/9781789242140.0000.

Lau GW, King PJH, Chubo JK, King IC, Ong KH, Ismail Z, Robin T, Shamsi IH. 2024. The potential benefits of palm oil waste-derived compost in embracing the circular economy. Agronomy 14 (11): 2517. https://doi.org/10.3390/agronomy14112517.

Malaysian Palm Oil Board (MPOB). 2016. MPOB Code of Practice: Code of Good Nursery Practice for Oil Palm Nurseries 2nd Ed. MPOB, Selangor, Malaysia.

Malaysian Palm Oil Board (MPOB). 2025. Area and Production of Crude Palm Oil 2025. MPOB, Selangor. https://mpob.gov.my/.

Murdi AA, Yahya Z, Abidin NZHAZ, Hashim K, Hashim Z, Ismail AF, Kadir IF, Arisman AM, Michael SR. 2019. Seedling age at field planting affecting the oil palm performance. Oil Palm Bull 79: 1-8.

Oueld LM, Moussadek R, Mouhir L, Sanad H, Manhou K, Ibny Halima O, Yachou H, Zouahri A, Alaoui M. 2025. Application of compost as an organic amendment for enhancing soil quality and sweet basil (*Ocimum basilicum* L.) growth: Agronomic and ecotoxicological evaluation. Agronomy 15 (5): 1045. https://doi.org/10.3390/agronomy15051045.

Palese MA, Persiani A, D'Adamo C, Pergola M, Pastore V, Sileo R, Ippolito G, Lombardi MA, Celano G. 2020. Composting as manure disposal strategy in small/medium-size livestock farms: Some demonstrations with operative indications. Sustainability 12 (8): 3315. https://doi.org/10.3390/su12083315.

Petersen SO, Sommer SG, Béline F, Burton C, Dach J, Dourmad JY, Leip A, Misselbrook T, Nicholson F, Poulsen HD, Provolo G, Sørensen P, Vinnerås B, Weiske A, Bernal MP, Böhm R, Juhász C, Mihelic R. 2007. Recycling of livestock manure in a whole-farm perspective. Livest Sci 112 (3): 180-191. https://doi.org/10.1016/j.livsci.2007.09.001.

Purwanto B, Shalihy W, Indrawati I. 2025. Effect of NPK fertilizer and *Trichoderma harzianum*-enriched oil palm empty fruit bunch compost on the growth of oil palm seedlings. Agro Bali 8 (2): 407-421. https://doi.org/10.37637/ab.v8i2.2356.

Radin R, Bakar RA, Ishak CF, Ahmad SH, Tsong LC. 2018. Biochar-compost mixture as amendment for improvement of polybag-growing media and oil palm seedlings at main nursery stage. Intl J Recycl Org Waste Agric 7 (1): 11-23. https://doi.org/10.1007/s40093-017-0185-3.

Ramachandrudu K, Suresh K, Manorama K. 2023. Morpho-physiological changes in oil palm (*Elaeis guineensis* Jacq.) tenera hybrid seedlings raised under different shade levels. J Hortic Sci 18 (2): 394-401. https://doi.org/10.24154/jhs.v18i2.1663.

Rosenani AB, Rovica R, Cheah PM, Lim CT. 2016. Growth performance and nutrient uptake of oil palm seedling in prenursery stage as influenced by oil palm waste compost in growing media. Intl J Agron 2016: 6930735. https://doi.org/10.1155/2016/6930735.

Salamat SS, Hassan MA, Shirai Y, Hanif AHM, Arifin I, Norizan MS. 2019. Application of compost in mixed media improved oil palm nursery's secondary root structure thereby reducing the fertilizer requirement for growth. Asia Pac J Mol Biol Biotechnol 27 (3): 39-49. https://doi.org/10.35118/apjmbb.2019.027.3.05.

Salamat SS, Yusoff MZM, Hassan MA, Zainuddin MHM, Shirai Y, Hanif AHM, Norizan MS, Arisah FM, Farid MAA, Maeda T, Isa MNM, Bakar MFA. 2024. Assessing microbial biodiversity in oil palm seedlings using oil palm waste compost mixed media. Intl J Recycl Org Waste Agric 13 (5): S11. https://doi.org/10.57647/ijrowa-m2gt-yd26.

Sham IN, Yap CK, Nulit R, Peng SHT, Chai EW. 2024. Nutrient leaching in oil palm plantation: A review with special reference to fertilizer application. Pak J Life Soc Sci 22 (2): 855-877. https://doi.org/10.57239/PJLSS-2024-22.2.0062.

United States Department of Agriculture. 2025. Oilseeds: World markets and trade, January 2025. Foreign Agricultural Service, Washington, DC, USA.

Zar JH. 2014. Biostatistical Analysis. 5th Ed. Pearson, New Jersey, USA.