ISSN: 2621-4709 E-ISSN: 2621-2528
Journal of Applied Agricultural Science and Technology
Vol. 9 No. 4 (2025): 544-556

Additional Oil Palm Ash and Nitrogen Fertilizer as Soil Ameliorant for the Oil Palm Seedlings (*Elaies guineensis* Jacq.) in Pre Nursery Stage

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Abstract. *Oil palm has high economic value and is one of Indonesia's most significant contributors to foreign exchange. The management of oil palm seedlings is important in determining their growth and subsequent development in the field. Research on the application of oil palm ash and nitrogen fertilizer was conducted at the pre-nursery stage. This study aims to determine the effects of oil palm ash and nitrogen fertilizer on the growth performance of oil palm seedlings in the pre-nursery stage. The experiment employed a factorial randomized block design with two factors. The first factor was the dose of oil palm ash (A), consisting of A1 = 600 g/g/polybag, A2 = 800 g/g/polybag, A3 = 1000 g/g/polybag. The second factor was the dose of nitrogen fertilizer (N), consisting of N1 = 100 mg/polybag, N2 = 200 mg/polybag, and N3 = 300 mg/polybag. The results showed that the interaction between the dose of oil palm ash and nitrogen fertilizer significantly affected both fresh weight and dry weight of oil palm seedlings. The combination of 1000 g/g/ g/polybag of oil palm ash and 200 mg/polybag of nitrogen fertilizer produced the best growth, yielding 7.77 g/g/plant of fresh weight and 2.39 g/g/plant of dry weight. Based on observation of plant growth, the application of oil palm ash did not show a significant effect on plant height, leaf length, or number of leaves. However, the highest stem diameter was recorded in treatment A2 (0.77 cm), which was significantly different from treatment A3. In contrast, the application of nitrogen fertilizer at a rate of 100 g per (N1) resulted in the lowest plant height (21.70 cm) and the shortest leaf length (17.36 cm), both of which were significantly different from the other treatments. The largest stem diameter was obtained in treatment N2 (0.79 cm), which was substantially different from N1. No significant differences were observed in the number of leaves among the treatments.*

Keywords: *Fertilizer; nitrogen; oil palm ash; pre-nurser; seedling.*

Type of the Paper: Regular Article.

1. Introduction

Oil palm (*Elaeis guineensis* Jacq.) is a strategic crop with a significant role in the global economy, particularly in major producing countries such as Indonesia and Malaysia [1,2]. It has become a cornerstone of the global vegetable oil market due to its high productivity and versatile applications in food, oleochemicals, and biofuels [3]. Between 2020 and 2024, global palm oil production increased steadily, reaching 76.8 million tons in 2024, with Indonesia contributing approximately 44 million tons, or 57% of total output [1,3]. Global consumption also grew significantly and is projected to reach 87.7 million tons in 2026, up from 76.8 million tons in 2021, reflecting rising demand for vegetable oils driven by population growth, urbanization, and

https://doi.org/10.55043/jaast.v9i4.471.
Received June 22, 2025; Received in revised form September 25, 2025; Accepted November 13, 2025; Published November 30, 2025
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industrial needs [2].

Projections indicate that global palm oil demand in 2070 could reach up to 300 million tons, highlighting the importance of ensuring sustainable supply chains and efficient production systems [4]. Growing global demand requires the expansion of plantations, the provision of high-quality seedlings, and suitable nursery media [5]. Seedling quality is crucial because suboptimal growth in the nursery stage can significantly affect long-term plantation productivity [6]. Ultisol soils, widely used in Indonesian nurseries, are acidic, low in organic matter, and deficient in essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K), which can restrict early growth and vigor of oil palm seedlings [7]. Therefore, the selection and optimization of nursery media are critical for improving seedling performance and ensuring plantation sustainability [7].

Organic amendments have been recognized as an effective strategy for improving soil fertility and structure in nursery media [8]. One promising amendment is oil palm ash, a byproduct of the palm oil industry, generated from the combustion of various parts of the oil palm tree, such as empty fruit bunches. Oil palm ash is rich in macronutrients, including potassium (K, 30–40%), calcium (Ca, 8–15%), and magnesium (Mg, 3–6%) [8,9]. It can enhance soil chemical properties, including pH and cation exchange capacity, and improve soil physical conditions for root development [8]. However, its nitrogen content is relatively low (<0.5%), while nitrogen is essential for vegetative growth and leaf development in oil palm seedlings [9]. To compensate for this deficiency, supplementation with inorganic nitrogen fertilizers such as urea is necessary to meet the nutrient demands of the seedlings [10].

Previous studies have demonstrated the potential of combining oil palm ash with fertilizers to improve crop growth. Fahrunsyah et al. [7] indicated that the use of oil palm ash-based compost mixed with coal fly ash, significantly increased phosphorus uptake and maize yield in Ultisol soils. Zahrah and Kustiawan [8] reported that integrating oil palm ash with organic fertilizers improved growth parameters and yield of onion seedlings, while Adu et al. [9] found that oil palm ash applications as mulch, biochar, or compost enhanced plant growth and yield by up to 49.2%, with additional benefits when combined with mineral fertilizers. These findings suggest that oil palm ash is an effective soil amendment, but research specifically examining its use remains limited, particularly in Ultisol-based media.

This study aims to systematically evaluate multiple doses of oil palm ash combined with nitrogen fertilizer (urea) as a mixed nursery medium for oil palm seedlings. Unlike prior studies that focused on single crops or single nutrient amendments, this research aims to determine the optimal combination that improves soil physical and chemical properties, provides balanced nutrition, and enhances seedling vigor [7–9]. The results are expected to provide practical recommendations for nursery management, contributing to more efficient, environmentally friendly, and sustainable oil palm production systems [11].

2. Materials and Methods

2.1. Place and Time

This study was conducted at the Experimental Farm of Graha Karya University, Muara Bulian, Jambi Province, from March to June 2024. The location is at an altitude of 12 m above sea level, with an average daily temperature of 24°C.

2.2. Experimental Design

The experiment employed a factorial randomized block design. The first factor was the application of oil palm ash as a mixed planting medium (amendment), consisting of three levels: A1 = 600 g/ g/seedling, A2 = 800 g/seedling, and A3 = 1,000 g/seedling. The second factor was the application of nitrogen (N) fertilization at three levels: N1 = 100 mg/seedling, N2 = 200 mg/seedling, and N3 = 300 mg/seedling. The experiment consisted of three replications, resulting in 27 experimental units. Each experimental unit consisted of six plants.

2.3. Preparation of Treatment Materials

The planting media used in this research consist of the top layer of Ultisol soil collected from the experimental farm of Graha Karya University, Muara Bulian, Jambi Province. Each polybag was filled with 2 kg of soil or soil thoroughly mixed with oil palm ash according to the treatments. The oil palm ash was obtained from PT. Kedaton Mulia Primas, Durian Luncuk, Jambi Province. An initial soil analysis was conducted, including measurements of pH, organic carbon, nitrogen, phosphorus, and potassium. The ash used for treatments was also analyzed for pH and organic K. At the end of the experiment, composite soil samples from all treatments were collected and analyzed for pH, organic carbon, nitrogen, phosphorus, and potassium.

2.4. Treatment Testing on Pre-nursery Oil Palm Seedlings

The pre-nursery seedlings used were germinated DxP Simalungun oil palm seeds. The seedlings were planted in polybags filled with the respective planting media, with the radicle facing downward and the plumule facing upward, at a depth of 2 cm.

Nitrogen fertilization was applied using urea. Urea was applied to the growing media at 4 weeks after planting (WAP), 6 WAP, 8 WAP, and 10 WAP. The fertilizer was dissolved in 50 mL of water for each nitrogen dosage treatment, and 12.5 mL (25%) of the solution was applied to each polybag at every application time. Basal fertilization with SP-36 at 100 mg/polybag was applied to all seedlings by spot placement at 2 weeks after planting.

Seedling growth observations were conducted from 4 WAP until 12 WAP. Growth parameters observed included plant height, leaf number, leaf length, stem diameter, root length, fresh weight, and dry weight. At 12 WAP, sample plants were uprooted, roots were cleaned, and root length was measured. Fresh plant biomass was weighed to determine fresh weight, then ovendried at 60°C for 48 hours to determine dry weight.

The collected data were analyzed using CoStat 8.0 software. The effects of treatments on the observed variables were tested using analysis of variance (ANOVA). Significant differences among treatments were further analyzed using Duncan's New Multiple Range Test (DNMRT) at the 5% significance level.

3. Results and Discussion

3.1. Result and Discussion

The initial soil analysis showed that the Ultisol used in this study had an acidic reaction, with a relatively low soil pH of 5.01 (Table 1). The organic C content was 2.71%, categorized as low. Nutrient contents were also low, with total N, P_2O_5, and K_2O levels of 0.13%, 0.42%, and 0.34%, respectively. Ultisol soils are generally characterized by very low organic carbon (<2%) and low base saturation (<35%), along with an acidic soil pH [12].

Table 1. Characteristics of Ultisol soil before and after treatment.

No	Chemical Characteristics of Soil	Initial Soil	Final Soil	Oil Palm Ash
1	pH H_2O	5.01	5.16	6.23
2	C organik (%)	2.71	2.74	1.06
3	N total (%)	0.13	0.28	0.04
4	P_2O_5 (%)	0.42	0.43	4.64
5	K_2O (%)	0.34	1.57	36.72

The oil palm ash used contained 36.7% K_2O, 4.64% P_2O_5, and 0.04% N, with a pH of 6.23. Its relatively high pH increased the soil pH from 5.01 at the beginning of the study to 5.16 at the end. Oil palm ash has been reported to improve Ultisol quality by reducing soil acidity and enhancing soil chemical properties, particularly as a source of potassium, thereby improving oil palm growth [13,14].

The initial analysis of the Ultisol revealed low fertility, characterized by an acidic pH (5.01), low organic carbon content (2.71%), and low macronutrient levels. The application of oil palm ash improved soil K_2O content from 0.34% to 1.57%, likely due to the high K_2O content in the ash (36.72%). The increases in both soil pH and K_2O content following ash application have also been reported by Arfiana et al. [15], who suggested that oil palm ash can serve as an amendment material for acidic soils such as Ultisols owing to its high potassium content and alkaline properties.

3.2. Plant Height

Analysis of variance showed that the application of oil palm ash had no significant effect on the height of Oil palm seedlings. However, nitrogen fertilization significantly influenced seedling height. The impacts of Oil palm ash and nitrogen fertilization on pre-nursery oil palm seedling height are presented in Table 2.

Table 2 shows that the application of nitrogen fertilizer at 200 mg/polybag (N2) and 300 mg/polybag (N3) produced greater plant height compared to 100 mg/polybag (N1). The highest plant height, 24.18 cm, was observed under the N3 treatment, which was not significantly different from N2. The lowest plant height, 21.70 cm, occurred under N1 treatment. Increasing the nitrogen dosage from 100 mg/seedling to 200 mg/seedling significantly enhanced plant height by 2.37 cm. However, increasing the nitrogen application from 200 mg to 300 mg/polybag did not significantly affect plant height.

Table 2. Effect of Oil palm ash and nitrogen fertilizer on the height of Oil palm seedlings in the pre-nursery stage.

Treatments	Oil palm seedlings' height (cm)
Oil Palm Ash	
A 1 (600 g/seedling)	23.75 a
A2 (800 g/ seedling)	22.83 a
A3 (1000 g /seedling)	23.38 a
Nitrogen Fertilizer	
N1 (100 mg /seedling)	21.70 b
N2 (200 mg/ seedling)	24.07 a
N3 (300 mg/ seedling)	24.18 a

Description: Means followed by the same letters are not significantly different according to Duncan's New Multiple Range Test (DNMRT) at$\alpha = 0.05$.

The reduced effectiveness at 300 mg/polybag may be due to nitrogen losses through volatilization and leaching. Excess nitrogen in the soil during the pre-nursery stage is not fully absorbed by the seedlings, leading to nutrient loss. In conventional systems, significant losses occur through NH_3 volatilization and NO_3^- leaching, accounting for approximately 0.1–42% and 1–34% of the applied mineral nitrogen, respectively [16]. Formanglio et al. [17] also emphasized that high fertilizer requirements in oil palm cultivation often result in nutrient loss due to leaching, inefficient nitrogen uptake, soil nutrient retention, antagonistic interactions among fertilizers, and other factors.

Plant height results from cell division and elongation. Increased plant height is likely associated with optimal nitrogen uptake. Nitrogen plays a key role in vegetative growth by enhancing cell division and elongation [18]. It is also essential for amino acid formation and contributes to cell division [19,20], ultimately improving plant growth and producing taller oil palm seedlings.

3.3. Leaf Length and Number of Leaves

Analysis of variance showed that the interaction between oil palm ash application and nitrogen fertilization was not significant for leaf length and leaf number. The application of oil palm ash alone did not significantly affect leaf length or leaf number, while nitrogen fertilization significantly influences leaf length but not leaf number (Table 3).

Table 3 shows that the number of leaves was not affected by the application of oil palm ash or nitrogen fertilizer. Similar findings were reported by Namohaji et al. [21], who observed that planting media and nitrogen fertilization treatments in the pre-nursery stage did not significantly influence the number of Oil palm leaves. Furthermore, Sari et al. [22] also reported that the Kirinyu liquid organic fertilizer (POC) does not influence leaf number in oil palm seedlings, with all treatments producing 3 to 4 leaves at three months of age. In the present study, the number of leaves at the end of the experiment ranged from 4 to 5. This phenomenon suggests that genetic factors play a role in determining leaf number in oil palm seedlings. Madusari [23] also confirmed that environmental conditions have little effect on leaf number, which is primarily controlled by genetic factors.

Table 3. Effect of Oil palm ash and nitrogen fertilizer on leaf length and number of leaves of Oil palm seedlings at the pre-nursery stage.

Treatments	Leaf Length (cm)	Number of Leaves (blade)
Oil Palm Ash		
A 1 (600 g/ seedling)	19.14 a	4.73 a
A2 (800 g/ seedling)	18.26 a	4.84 a
A3 (1000 g/ seedling)	18.23 a	4.92 a
Nitrogen Fertilizer		
N1 (100 mg/ seedling)	17.36 b	4.80 a
N2 (200 mg /seedling)	19.53 a	4.80 a
N3 (300 mg/ seedling)	19.35 a	4.90 a

Description: Means followed by the same letters are not significantly different according to Duncan's New Multiple Range Test (DNMRT) at $\alpha = 0.05$.

In contrast to leaf number, leaf length was influenced by nitrogen dosage. The 200 mg/seedling and 300 mg/seedling treatment produced similar leaf lengths of 19.53 cm and 19.35 cm, respectively, both of which were significantly longer than the 17.36 cm obtained with the 100 mg/seedling treatment. Nitrogen enhances leaf elongation by increasing photosynthesis and metabolic activity, particularly when sufficient potassium is available to support nutrient transport within the plant [24,25].

Table 3 also indicates that oil palm ash application did not significantly affect leaf length. The relatively high dosages used in this study (600, 800, and 1,000 g/seedling) were likely already sufficient to improve the planting medium by increasing porosity and hygroscopic properties, thereby enhancing the soil's physico-chemical conditions. The application of oil palm ash to soil has been reported to improve its chemical properties, such as cation exchange capacity, soil pH, and available phosphorus [26]. In this study, the availability of potassium from oil palm ash in all treatments was assumed to be adequate for plant growth. The availability of potassium and nitrogen promotes photosynthate production, a key process that is crucial in developing leaf tissues. Mohr and Schopfer [24] explained that nutrient availability strongly influences plant cell metabolism. Adequate potassium in the soil enables maximum absorption of other nutrients. Optimal nitrogen and phosphorus uptake is highly dependent on potassium availability [25,27].

3.4. Stem Diameter

Analysis of variance showed that the interaction between oil palm ash application and nitrogen fertilization was not significant for the stem diameter of oil palm seedlings in the pre-nursery stage. However, both oil palm ash application and nitrogen dosage had significant main effects. The effects of oil palm ash and nitrogen fertilization on stem diameter are presented in Table 4.

Table 4. Effect of oil palm ash and nitrogen fertilizer on the stem diameter of Oil palm seedlings at the pre-nursery stage.

Treatments	Stem Diameter (cm)
Oil Palm Ash	
A 1 (600 g/seedling)	0.76 a
A2 (800 g/seedling)	0.77 a
A3 (1000 g/seedling)	0.72 b
Nitrogen Fertilizer	
N1 (100 mg/seedling)	0.72 b
N2 (200 mg/seedling)	0.79 a
N3 (300 mg/seedling)	0.76 ab

Description: Means followed by the same letters are not significantly different according to Duncan's New Multiple Range Test (DNMRT) at $\alpha = 0.05$.

Table 4 shows that the application of 600 g/seedling and 800 g/seedling of oil palm ash (A1 and A2) produced stem diameters of 0.76 cm and 0.77 cm, respectively, which were not significantly different. However, increasing the dosage to 1,000 g/seedling (A3) significantly reduced the stem diameter to 0.72 cm. The highest ash dosage in A3 likely made the growing media more porous, resulting in greater water loss and affecting stem diameter growth. Insufficient water availability in the planting media can also reduce nutrient availability and uptake, thereby limiting optimal stem diameter development.

Nitrogen fertilization at 200 mg/seedling (N2) produced the best stem diameter (0.79 cm). Increasing the dosage to 300 mg/seedling (N3) did not significantly improve stem diameter, while reducing the nitrogen dosage to 100 mg/seedling (N1) significantly decreased it to 0.72 cm. This indicates that 200 mg/seedling of nitrogen was sufficient to meet the nutritional requirements for stem diameter growth in pre-nursery oil palm seedlings.

In this experiment, the optimal stem diameter was achieved using 200 mg/seedling of nitrogen fertilizer and 800 g/seedling of oil palm ash in the planting media. Potassium from oil palm ash contributed to better stem diameter development. These findings align with Usodri and Utoyo [19], who reported that the best stem diameter growth in pre-nursery oil palm seedlings was obtained by applying nitrogen and potassium from KNO_3 at a concentration of 4%. The stem functions as a conduit between roots and leaves, supporting nutrient uptake and photosynthate transport. Hapsoh et al. [28] also reported that potassium enhances stem diameter in oil palm seedlings. Potassium contributes to carbohydrate synthesis and positively affects water transport and cell elongation [29].

3.5. Root Length

Analysis of variance showed that applying oil palm ash does not influence the root length of oil palm seedlings. However, nitrogen fertilization significantly influenced seedling height. The impacts of oil palm ash and nitrogen fertilization on pre-nursery oil palm seedling root length are presented in Table 5.

Table 5. Effect of oil palm ash and nitrogen fertilizer on root length of oil palm seedlings at the pre-nursery stage.

Treatments	Root Length (cm)
Oil Palm Ash	
A 1 (600 g/ seedling)	31.15 a
A2 (800 g/ seedling)	29.67 a
A3 (1000 g/ seedling)	30.39 a
Nitrogen Fertilizer	
N1 (100 mg/ seedling)	28.21 b
N2 (200 mg/ seedling)	31.56 a
N3 (300 mg/ seedling)	31.44 a

Description: Means followed by the same letters are not significantly different according to Duncan's New Multiple Range Test (DNMRT) atα = 0.05.

Table 5 shows that nitrogen fertilizer application at 200 mg/polybag (N2) and 300 mg/polybag (N3) produced greater root length compared to 100 mg/polybag (N1). The highest root length, 31.56 cm, was observed under the N3 treatment, which was not significantly different from the N2 treatment. The lowest root length, 28.21 cm, occurred under N1 treatment. Increasing the nitrogen dosage from 100 mg/seedling to 200 mg/seedling significantly enhanced root length by 3,35 cm. However, increasing the nitrogen application from 200 mg to 300 mg/polybag did not considerably affect root length.

Nitrogen plays an essential role in root development. Maximum root length was achieved at 200–300 mg/seedling. This element is absorbed by plants in the form of ammonium and nitrate, which enhance drought tolerance in oil palm seedlings and play a critical and crucial role in plantation productivity under limited water availability [30]. De la Peña et al. [31] further reported that ammonium enhances shoot growth across different oil palm genotypes and promotes primary root elongation, amino acid synthesis, and protein formation. Therefore, nitrogen, either as ammonium or nitrate, stimulates root development and increases nutrient absorption capacity [30,31].

3.6. Fresh Weight and Dry Weight of Plants

Analysis of variance showed that the application of oil palm ash and nitrogen fertilizer had a highly significant effect on the fresh weight and dry weight of oil palm seedlings. However, the interaction between the two treatments did not significantly affect either fresh or dry weight at the pre-nursery stage. The effects of oil palm ash and nitrogen fertilization on pre-nursery oil palm seedlings are shown in Table 6.

Table 6 shows that the application of oil palm ash or nitrogen fertilizer affected both fresh and dry weight. Application of nitrogen fertilizer at 200 mg/polybag (N2) produced 7.49 g fresh weight, the highest among treatments, compared to 300 mg/polybag (N3) and 100 mg/polybag (N1). The lowest fresh weight, 7.02 g, was observed under N1 treatment. Furthermore, the application of oil palm ash at 1000 g/polybag (A3) yielded the highest fresh weight. The A3 treatment produced 7.43 g of fresh weight, which was substantially different from A1 and A2. The application of oil palm ash 800 g/polybag (A2) produced 7.21 g fresh weight, which was not substantially different from A1, which produced 7.21 g fresh weight. The application of Oil palm ash 800 g/polybag (A2) was also not significantly different from A1 at the dry weight. The application of 1,000 g/kg seedling (A3) provided optimal potassium for the seedlings and created the best media conditions for fresh and dry weight growth.

Table 6. Effect of Oil palm ash and nitrogen fertilizer on fresh and dry weight of Oil palm seedlings at the pre-nursery stage.

Treatments	Fresh weight of the Plant (g)	Dry Weight of the Plant (g)
Oil Palm Ash		
A 1 (600 g/seedling)	7.20 b	2.18 b
A2 (800 g/ seedling)	7.21 b	2.25 ab
A3 (1000 g/ seedling)	7.43 a	2.31 a
Nitrogen Fertilizer		
N1 (100 mg/ seedling)	7.02 c	2.13 b
N2 (200 mg/ seedling)	7.49 a	2.31 a
N3 (300 mg/ seedling)	7.32 b	2.30 a

Description: numbers followed by the same letter indicate no significant difference in the Duncan's New Multiple Range Test (DNMRT) atα = 0.05.

Table 6 also shows that the application of nitrogen fertilizer at 200 mg/polybag (N2) produced 2.31g dry weight. The N2 treatment yielded the highest dry weight compared to 100 mg/polybag (N1), but was not significantly different from N3, which produced 2.30 g. The lowest dry weight, 2.13 g, was observed under N1 treatment. Furthermore, more application of oil palm ash at 1000 g/polybag (A3) produced 2.31g dry weight and was not significantly different from A2. A1 produced 2.18 g of dry weight, the lowest among the treatments, indicating the weakest performance.

The appropriate use of oil palm ash improves media conditions by enhancing aeration, thereby supporting water and nutrient availability as they are absorbed by the seedlings. Rusmayandi et al. [32] explained that a suitable growing medium for nurseries should have proper soil structure and a sufficient nutrient supply. An ideal medium enhances the efficiency of nutrient absorption by seedlings.

Nitrogen is essential for tissue formation in plants. During the nursery stage, optimal nitrogen availability is crucial for biomass growth. Ruiz-Romero et al. [30] reported that nitrogen application affects seedling biomass. Even under drought stress, ammonium plays a vital role in maintaining water availability for root development. Improved soil structure by oil palm ash, and optimal nitrogen uptake, support seedling growth. Adequate nitrogen and potassium in the soil enhance biomass accumulation and nutrient–water use efficiency, particularly in well-aerated soils [30].

Nitrogen fertilizer treatments in Table 6 also showed different effects on seedling dry weight.

Treatment N2 (200 mg/seedling) produced the highest dry weight of 2.31 g. N2 was not significantly different from N3 but differed significantly from N1. The lowest dry weight of 2.13 g was obtained from N1. Thus, 200 mg of nitrogen fertilizer per seedling was optimal for dry weight growth, while increasing the dose to 300 mg/seedling did not significantly improve dry weight.

The combined effects of Oil palm ash and nitrogen fertilizer showed synergistic roles in enhancing seedling growth. Potassium from Oil palm ash and nitrogen fertilization promoted better tissue formation. This reflects long-term nutrient integration, where potassium supports metabolic efficiency and nitrogen enhances tissue synthesis [33]. Research by Ayeni et al. [34] demonstrated that the use of [34] was also effective. Chidi et al. [35] also demonstrated that palm ash significantly increased seedling dry weight during the early nursery phase compared with traditional methods [34]. Similarly, Fahrunsyah et al. [7] reported that the addition of fly ash and EFB compost significantly improved plant biomass dry weight (cobs, roots, stems, leaves, and seeds).

The urgency of this research is reinforced by projections of increasing global palm oil demand over the next 50 years, potentially reaching 300 million tons by 2070 [4]. Without optimized nursery practices and high-quality seedlings, future plantations may experience suboptimal productivity, compromising global supply and market stability. Therefore, developing and validating effective nursery media that combine organic (oil palm ash) and inorganic (urea) nutrients sources is critical for ensuring the long-term sustainability of the palm oil industry [7–9].

4. Conclusions

The present study investigated the effects of oil palm ash and nitrogen fertilizer on the early growth performance of oil palm seedlings. The application of oil palm ash and nitrogen showed no interaction effect on plant height, leaf length and number, stem diameter, and root length. However, oil palm ash influenced stem diameter growth and positively affected seedling fresh and dry weight. Among the ash treatments, 1,000 g/seedling (A3) produced the highest fresh and dry biomass, while 800 g/seedling (A2) supported optimal stem diameter development. Meanwhile, nitrogen fertilization consistently enhanced all growth parameters, with 200 mg/seedling (N2) identified as the most effective dosage for promoting plant height, leaf elongation, stem diameter, root length, and biomass accumulation.

Abbreviations

N	Nitrogen
K	Potassium
MST	Weeks after planting

DNMRT	Dunis able to's New Multiple Range Test
CPO	Crude Palm Oil.

Data availability statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Credit authorship contribution statement

Enita: Conceptualization, Methodology, Writing – original draft. **Eddiwal**: Investigation, Data curation. **Ratna Dewi**: Validation, Writing – review and editing. **Handy Sahputra**: Formal analysis, Visualization, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank Graha Karya University and PT. Kedaon Mulia Prima for their support during the field and laboratory work of this study.

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