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Morphological and Biomass Responses of Oil Palm Varieties to Salinity in Early Nursery

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ABSTRACT

Salinity is an important constraint in oil palm nurseries because it may limit seedling growth and reduce the potential use of marginal land or growing media. This study evaluated the morphological and biomass responses of five oil palm varieties to salinity in early nursery and identified practical variables for early selection under saline conditions. The experiment was conducted in a greenhouse using a factorial randomized complete block design with five varieties, three salinity levels, and three replications. The observed variables were stem diameter, number of leaves, canopy length, root length, shoot fresh weight, root fresh weight, shoot dry weight, root dry weight, and root-shoot ratio. Data were analyzed using analysis of variance followed by Duncan's Multiple Range Test at the 5% level. Varietal effects were significant for all observed variables, whereas salinity as a single factor was not significant within the tested range. However, the interaction between variety and salinity significantly affected most variables, indicating that seedling responses to salinity depended on varietal background. DxP Socfindo Yangambi and DxP Socfindo Lame showed the best performance under saline conditions, particularly at 6-7 mmhos cm^{-1}, as reflected in canopy growth, root elongation, and biomass accumulation. In contrast, DxP Simalungun showed the weakest response across most variables. Canopy length, root length, shoot dry weight, and root dry weight were the most informative variables for early selection of oil palm seedlings under saline conditions.

Keywords: biomass allocation; early nursery; oil palm; salinity tolerance; varietal response

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INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is one of the most important plantation crops in Indonesia because it contributes substantially to export earnings, employment, and rural economic development. In 2023, the national planted area reached 15.93 million ha and crude palm oil production reached 47.08 million tons (BPS-Statistics Indonesia, 2023). At the same time, expansion and nursery establishment increasingly confront sub-optimal land conditions, including salinity. In Indonesia, saline soils occur in coastal and tidal areas such as Banyuasin, Deli Serdang, Lamongan, Tuban, and Tanjung Jabung Timur, where sea-water intrusion, tidal influence, poor drainage, and salt accumulation may constrain crop establishment (Karolinoerita & Yusuf, 2020; Pradiko et al., 2017; Prasetya et al., 2018; Hamidah et al., 2025; Bisri et al., 2026). These conditions make salinity a relevant constraint for nursery management and early seedling establishment.

The nursery stage is critical in oil palm because seedling quality is shaped by the interaction of genetic background and growing environment. During the early nursery phase, seedlings begin to express differences in vigor through stem thickening, leaf emergence, canopy expansion, root extension, and biomass formation. These early traits are agronomically important because they influence transplant readiness and subsequent field establishment (Gea et al., 2019; Silitonga et al., 2020). Therefore, identifying varieties that maintain stable growth in sub-optimal media is a practical need for oil palm production systems, especially where high-quality topsoil is limited.

Salinity affects plant growth through osmotic effects, ionic imbalance, and ion toxicity, which collectively reduce water uptake, cell expansion, assimilate distribution, and dry matter accumulation (Carillo et al., 2011; Liu et al., 2024). Across many crops, saline conditions reduce root elongation, leaf development, and biomass production, and proteomic studies indicate marked changes in stress-response pathways under salt exposure (Kausar & Komatsu, 2023; Athar et al., 2022; Raggi et al., 2024). However, the magnitude of growth reduction is not uniform across genotypes, indicating that tolerance is expressed through genotype-specific capacity to maintain coordinated growth under saline conditions.

In oil palm, information on varietal response under saline nursery conditions is still limited, particularly for commercial planting materials evaluated at the early nursery stage. Most available nursery studies emphasize medium composition, irrigation, or general seedling vigor, whereas comparative evidence on how several commercial varieties maintain canopy development, root growth, and biomass allocation under moderate salinity remains scarce. This gap is important because early nursery screening is expected to identify planting material that remains productive in sub-optimal environments without relying on destructive and technically demanding measurements at the first screening stage.

The present study is novel in two respects. First, it compares five commercial oil palm varieties under the same controlled moderate-salinity range that is relevant to nursery media in coastal and tidal environments. Second, it identifies a compact set of morphological and biomass variables that can discriminate varietal performance at the early nursery stage. Thus, the study does not aim to explain physiological mechanisms directly; instead, it focuses on practical early screening traits that can be applied before more advanced physiological validation. This scope is relevant because morphological and biomass variables remain the first line of selection in many nursery programs (Buana et al., 2019; Darmawan et al., 2020; Gunawan et al., 2024; Febrianto et al., 2024).

Therefore, this study was conducted to evaluate the vegetative growth of several oil palm varieties under moderate salinity at the early nursery stage. The specific objectives were to assess varietal differences, determine the effect of salinity and variety × salinity interaction, and identify practical morphological and biomass variables for early screening of oil palm seedlings with better adaptation to saline nursery conditions.

MATERIALS AND METHODS

The experiment was conducted in a greenhouse at Institut Teknologi Sawit Indonesia, Medan, from July to September 2025. The study used a factorial randomized complete block design with two factors and three replications. The first factor was oil palm variety, consisting of V1 = DyxP Dumpy, V2 = DxP Simalungun, V3 = DxP Yangambi, V4 = DxP Socfindo Lame, and V5 = DxP Socfindo Yangambi. The second factor was salinity level, consisting of S0 = without NaCl (control), S1 = NaCl solution with electrical conductivity of 5-6 mmhos cm^{-1}, and S2 = NaCl solution with electrical conductivity of 6-7 mmhos cm^{-1}. The selected salinity range followed a previous study on oil palm grown under saline conditions, in which the same electrical conductivity levels were used to assess varietal resistance and were shown to produce measurable differences in plant height, number of leaves, root dry weight, and root volume. Therefore, the range of 5-7 mmhos cm^{-1} was considered appropriate for evaluating early varietal responses under moderate salinity while still allowing seedling establishment in nursery conditions (Gunawan et al., 2018). Fifteen treatment combinations were obtained. Each treatment was replicated three times, and each experimental unit consisted of 10 seedlings, resulting in 45 experimental units and a total of 450 seedlings.

Uniform germinated seeds were obtained from PPKS Medan and Socfindo and were selected to ensure relatively similar early growth and freedom from pests and diseases. Seedlings were planted in polybags containing topsoil and compost. After four weeks of normal growth, salinity stress was applied by watering the seedlings with NaCl solution according to the assigned treatment. Salinity levels were prepared by dissolving NaCl in water and measuring the electrical conductivity using a salinity meter. Salinity treatment was maintained for approximately two months until seedlings reached three months of age.

The selected variables used in this manuscript were stem diameter, number of leaves, canopy length, root length, shoot fresh weight, root fresh weight, shoot dry weight, root dry weight, and root-shoot ratio. Stem diameter was measured at the basal stem using a digital caliper. Number of leaves was counted from the oldest fully opened leaf to the youngest leaf that had completely unfolded. Canopy length was measured on sampled plants. Root length was measured from the bole to the root tip at the end of the experiment. Shoot fresh weight and root fresh weight were recorded after separating shoot and root tissues. Shoot dry weight and root dry weight were obtained after oven-drying plant parts to constant weight. Root-shoot ratio was calculated from root and shoot dry matter allocation.

Data were subjected to analysis of variance, and treatment means were compared using Duncan's Multiple Range Test at the 5% level. The manuscript emphasizes variables considered most relevant for publication because they represent upper-canopy growth, root performance, biomass accumulation, and biomass partitioning under saline conditions.

RESULT AND DISCUSSION

Varietal Effect on Selected Growth Variables

The varietal factor significantly affected all selected variables observed in this study. In general, V4 and V5 showed superior growth performance, whereas V2 consistently produced the lowest values for most traits (Table 1). This pattern indicates that seedling performance under moderate salinity was strongly associated with varietal background. Similar results have been reported in oil palm nursery studies showing that varietal identity influences early vegetative traits and biomass accumulation because each genotype differs in growth vigor and resource-use efficiency (Buana et al., 2019; Darmawan et al., 2020). Although some early-stage studies have found limited differentiation among varieties, such variation may become clearer when seedlings begin to express differences in canopy and root development more fully (Afrillah et al., 2020).

For basal stem development, V1 produced the highest stem diameter (6.50 mm), followed by V3 (6.17 mm), whereas V2 had the lowest value (3.69 mm). For leaf production, V4 produced the highest number of leaves (2.77), while V2 had the lowest (2.14). Canopy length was greatest in V5 (27.97 cm), followed by V4 (25.94 cm), whereas V2 again showed the lowest value (19.27 cm). These differences suggest that varietal superiority was expressed through both structural vigor and canopy expansion. In nursery crops, thicker stems and better canopy development generally indicate stronger assimilate supply and greater capacity for subsequent establishment after transplanting (Buana et al., 2019; Gea et al., 2019).

Table 1. Stem diameter, number of leaves, and canopy length as affected by variety, salinity, and their interaction

Treatment	Stem diameter (mm)	Number of leaves	Canopy length (cm)
V1	6.50 a	2.37 b	23.36 c
V2	3.69 d	2.14 c	19.27 d
V3	6.17 b	2.18 c	23.97 c
V4	5.98 b	2.77 a	25.94 b
V5	4.64 c	2.43 b	27.97 a
S0	5.37	2.34	23.80
S1	5.48	2.40	24.30
S2	5.34	2.39	24.20
V1S0	6.42 ab	2.27	23.90 def
V1S1	6.69 a	2.50	24.01 def
V1S2	6.40 ab	2.33	22.17 f
V2S0	3.70 f	2.10	19.25 g
V2S1	3.88 f	2.17	19.56 g
V2S2	3.50 f	2.17	19.00 g
V3S0	6.15 ab	2.27	23.55 ef
V3S1	6.25 ab	2.13	24.14 def
V3S2	6.09 cd	2.14	24.23 def
V4S0	5.59 d	2.64	24.99 cde
V4S1	6.08 cd	2.85	26.22 bcd
V4S2	6.28 ab	2.83	26.63 bc
V5S0	4.97 e	2.44	27.33 ab
V5S1	4.51 ef	2.37	27.57 ab
V5S2	4.42 f	2.48	29.00 a

Description: Means followed by the same letter within a column are not significantly different according to DMRT at 5%.

Root growth and biomass traits further strengthened the superiority of V4 and V5. Root length was greatest in V4 (22.46 cm), followed by V5 (21.20 cm), while V1 produced the shortest roots (18.08 cm). Shoot fresh weight was highest in V5 (3.57 g), and shoot and root dry weights were also highest in V5 and V4. These results indicate that the best-performing varieties not only produced larger canopies but also maintained stronger belowground growth and dry matter accumulation. Such a pattern is important because root development supports water and nutrient acquisition, while dry matter accumulation reflects more effective conversion of assimilates into new tissue (Nugroho et al., 2022; Raggi et al., 2024).

The root-shoot ratio showed a slightly different pattern. V2 had the highest ratio (0.33), while V1 had the lowest (0.24). However, a higher ratio in V2 did not indicate superior adaptation because it was associated with relatively low absolute biomass. In contrast, V4 and V5 combined balanced root-shoot allocation with higher total dry matter. Therefore, the ratio must be interpreted together with absolute root and shoot weight. Balanced biomass partitioning is often considered more informative than ratio alone because stress adaptation depends on both biomass magnitude and the efficiency of allocation between plant organs (Nugroho et al., 2022).

Salinity Effect and Interaction Pattern

Although salinity as a single factor did not significantly affect the observed variables within the tested electrical conductivity range, this does not mean that seedling growth responded uniformly to saline conditions. The significant variety × salinity interaction indicates that salinity effects were strongly genotype dependent (Table 2). This pattern was evident in morphological and especially biomass-related traits, where DxP Socfindo Yangambi and DxP Socfindo Lame maintained better canopy growth, root development, and dry matter accumulation under S2, whereas DxP Simalungun consistently showed lower values under the same condition. Therefore, the non-significant main effect of salinity reflects the averaging of contrasting varietal responses, while the significant interaction demonstrates that moderate salinity was sufficient to distinguish differences in growth performance among oil palm genotypes. This result suggests that varietal background plays an important role in determining how seedlings maintain growth under saline conditions (Rahman et al., 2016; Masganti et al., 2023; Liu et al., 2024).

This genotype-dependent response was clearly reflected in biomass accumulation. DxP Socfindo Yangambi (V5) and DxP Socfindo Lame (V4) maintained higher shoot and root biomass across saline treatments than the other varieties, indicating better growth persistence under moderate salinity. Under S2, V4 produced one of the highest shoot dry weights (0.79 g) and root dry weights (0.21 g), while V5 also maintained high values for shoot dry weight (0.74 g) and root dry weight (0.20 g). In contrast, DxP Simalungun (V2) showed the lowest biomass under the same salinity level, with shoot dry weight of only 0.33 g and root dry weight of 0.11 g. A similar pattern was observed in shoot fresh weight, where V4S2 and V5S2 remained relatively high, whereas V2S2 was the lowest. These results indicate that V4 and V5 were more capable of sustaining assimilate production and biomass partitioning under saline conditions, whereas V2 was more sensitive, as reflected in the sharper decline of both shoot and root biomass. This supports the use of biomass-related variables as effective indicators for distinguishing varietal

Table 2. Root length, shoot fresh weight, and root fresh weight as affected by variety, salinity, and their interaction

Treatment	Root length (cm)	Shoot fresh weight (g)	Root fresh weight (g)
V1	18.08 c	2.24 c	0.60 b
V2	19.70 bc	1.60 d	0.42 c
V3	20.96 ab	2.51 c	0.68 ab
V4	22.46 a	2.81 b	0.62 b
V5	21.20 ab	3.57 a	0.77 a
S0	19.97	2.56	0.56
S1	20.58	2.51	0.62
S2	20.90	2.57	0.68
V1S0	18.82 cde	2.19 cd	0.48 def
V1S1	17.80 de	2.34 c	0.69 abc
V1S2	17.64 e	2.19 cd	0.63 a-d
V2S0	19.64 b-e	1.69 de	0.40 ef
V2S1	21.08 b-e	1.75 de	0.52 c-f
V2S2	18.39 cde	1.35 e	0.35 f
V3S0	20.36 b-e	2.52 c	0.57 b-e
V3S1	21.73 abc	2.41 c	0.65 a-d
V3S2	20.79 b-e	2.59 c	0.82 a
V4S0	19.57 b-e	2.52 c	0.53 b-f
V4S1	22.88 ab	2.62 c	0.53 b-f
V4S2	24.94 a	3.28 b	0.80 a
V5S0	21.44 bcd	3.85 a	0.80 a
V5S1	19.38 b-e	3.42 ab	0.71 ab
V5S2	22.78 ab	3.44 ab	0.78 a

Description: Means followed by the same letter within a column are not significantly different according to DMRT at 5%

performance under moderate salinity at the early nursery stage.

However, the interaction between variety and salinity significantly affected most variables. This means that the effect of salinity depended on varietal background rather than acting as a uniform stress across all seedlings. For example, V5S2 produced the highest canopy length (29.00 cm), V4S2 produced the highest root length (24.94 cm), and V4S2 or V5S1 produced the highest dry matter values. By contrast, V2S2 consistently ranked among the lowest combinations for canopy length, shoot fresh weight, shoot dry weight, and root dry weight. This genotype-specific pattern is consistent with studies showing that varietal or genotype × salinity interaction can be expressed through differential maintenance of shoot and root growth under stress (Gunawan et al., 2018; Novita et al., 2023a).

The interaction pattern is particularly important for early selection. If only the main effect of salinity were considered, the conclusion would suggest little growth response to salinity. However, the interaction data reveal clear contrasts among varieties in how growth traits were maintained under the same salinity range. This supports the argument that salinity screening should emphasize genotypic stability rather than average treatment response alone. Similar screening logic has been applied in salinity studies on other plant materials, where tolerant genotypes are identified from their ability to sustain growth and biomass under saline environments relative to sensitive ones (Novita et al., 2023a; Rahman et al., 2016).

Implications of Biomass Allocation and Selection Criteria

Biomass-related variables provide a clearer biological interpretation of adaptation than single size variables alone. V5 and V4 maintained not only better canopy growth but also greater dry matter accumulation, indicating more effective conversion of assimilates into plant tissue. Shoot dry weight and root dry weight therefore appear to be among the most informative indicators for screening. Under salinity, dry matter retention is closely related to the maintenance of metabolic activity, membrane function, and stress-response pathways that reduce the damaging effects of osmotic and ionic stress (Kausar & Komatsu, 2023; Athar et al., 2022).

The relatively balanced root-shoot ratios of the superior varieties are also meaningful. V4 and V5 showed ratios of 0.28 and 0.26, respectively, which indicates that improved growth was not caused by excessive allocation to either the roots or shoots alone (Table 3). By contrast, the higher ratio in V2 reflected reduced shoot biomass rather than a genuinely vigorous root system. This distinction is important because root-shoot balance under stress should represent coordinated growth, not only a proportional shift caused by growth suppression in one organ (Nugroho et al., 2022; Raggi et al., 2024).

The present findings support the use of a smaller but informative set of variables for early screening. Canopy length represents upper-growth development, root length represents exploratory root capacity, shoot fresh and dry weights reflect accumulated assimilate production, root dry weight reflects belowground biomass investment, and root-shoot ratio complements the interpretation of allocation patterns. Similar nursery based studies in oil palm have also emphasized that morphological and biomass variables can be used effectively to distinguish seedling vigor among varieties and nursery treatments (Buana et al., 2019; Darmawan et al., 2020; Gunawan et al., 2024; Febrianto et al., 2024).

Table 3. Shoot dry weight, root dry weight, and root-shoot ratio as affected by variety, salinity, and their interaction

Treatment	Shoot dry weight (g)	Root dry weight (g)	Root-shoot ratio
V1	0.61 b	0.15 b	0.24 c
V2	0.37 c	0.12 b	0.33 a
V3	0.57 b	0.14 b	0.25 bc
V4	0.70 a	0.19 a	0.28 b
V5	0.77 a	0.20 a	0.26 bc
S0	0.59	0.15	0.26
S1	0.62	0.16	0.27
S2	0.60	0.17	0.29
V1S0	0.58 bc	0.13 b	0.22 f
V1S1	0.70 abc	0.16 bc	0.23 ef
V1S2	0.54 cd	0.15 cd	0.28 bc
V2S0	0.38 e	0.13 ef	0.34 a
V2S1	0.40 de	0.12 f	0.29 ab
V2S2	0.33 e	0.11 g	0.35 a
V3S0	0.58 bc	0.13 ef	0.22 f
V3S1	0.54 cd	0.14 de	0.26 de
V3S2	0.60 bc	0.16 bc	0.27 cd
V4S0	0.63 abc	0.18 ab	0.28 bc
V4S1	0.69 abc	0.20 a	0.29 ab
V4S2	0.79 a	0.21 a	0.26 de
V5S0	0.80 a	0.18 ab	0.23 ef
V5S1	0.78 a	0.21 a	0.27 cd
V5S2	0.74 ab	0.20 a	0.27 cd

Description: Means followed by the same letter within a column are not significantly different according to DMRT at 5%.

The present findings are consistent with the view that varietal response in oil palm seedlings is primarily determined by genetic background and is expressed through growth vigor, biomass accumulation, and the ability to sustain root and shoot development under moderate salinity. The results reinforce the idea that salinity tolerance at the nursery stage is not necessarily expressed as complete insensitivity to salt, but rather as the capacity to maintain coordinated growth under osmotic and ionic pressure. This interpretation is in line with broader physiological evidence showing the importance of ion homeostasis, osmotic regulation, and stress-responsive pathways in saline environments (Rahman et al., 2016; Athar et al., 2022; Ferreira et al., 2022; Liu et al., 2024).

From an applied perspective, the data indicate that DxP Socfindo Yangambi (V5) and DxP Socfindo Lame (V4) should be prioritized for further testing under saline or other sub-optimal nursery conditions. Their performance in canopy growth, root elongation, and biomass accumulation suggests better adaptation potential than the other tested varieties. This is relevant for oil palm development in areas where saline or marginal soils may become increasingly important, including coastal and tidal environments reported in several Indonesian regions (Karolinoerita & Yusuf, 2020; Pradiko et al., 2017; Prasetya et al., 2018; Hamidah et al., 2025; Bisri et al., 2026).

CONCLUSION

Variety significantly affected all selected morphological and biomass variables of oil palm seedlings at the early nursery stage. Salinity as a single factor did not significantly affect the observed variables within the tested electrical conductivity range, but the significant variety × salinity interaction indicated that seedling responses to salinity were strongly influenced by varietal background. DxP Socfindo Yangambi and DxP Socfindo Lame maintained relatively better canopy growth, root development, and biomass accumulation across the tested salinity levels than the other varieties, whereas DxP Simalungun consistently showed the weakest growth response. These results indicate relative differences in growth maintenance under moderate salinity, rather than formal genotype stability. Among the evaluated traits, canopy length, root length, shoot dry weight, and root dry weight were the most informative variables for early screening of oil palm seedlings under saline conditions.

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