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Growth Dynamics of Oil Palm Seedlings Under Varying Nitrogen Inputs and Watering Frequency During the Pre-Nursery Phase

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ABSTRACT: Optimizing nutrient and water availability is fundamental for producing robust oil palm (*Elaeis guineensis* Jacq.) seedlings. This study examined how different urea concentrations and irrigation intervals influence seedling performance during the pre-nursery period. The experiment, conducted from April to July 2022 in Simalingkar B, Medan (±88 m a.s.l.), used a factorial randomized block design consisting of three urea levels (0, 1, and 2 g L^{-1}) and three watering schedules (once every three days, once every two days, and daily), each replicated three times. Growth indicators-including plant height, stem girth, leaf number, leaf dimensions, and leaf area-were recorded weekly until 12 weeks after planting. Urea doses significantly enhanced height and leaf morphological traits, while watering frequency strongly influenced overall canopy expansion. Daily watering and 2 g L^{-1} urea produced the most vigorous seedlings. No interaction was detected between the two factors, indicating independent modes of action. These results highlight the importance of sufficient nitrogen supply and consistent water availability for producing high-quality oil palm seedlings.

KEYWORDS: nitrogen nutrition, irrigation, early growth, nursery management, *Elaeis guineensis*

INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) plays a central role in global vegetable oil production, and Indonesia is currently the world's largest producer. Ensuring the long-term productivity of plantations depends heavily on the physiological quality of seedlings developed during the nursery phase, where early growth conditions strongly influence subsequent field performance and yield potential. Recent studies emphasize that the vigor of young oil palm plants is shaped not only by genetic material but also by environmental and management factors governing nutrient acquisition, water availability, and root system establishment in the early stages of development.

Nitrogen (N) remains the most limiting macronutrient for vegetative growth, influencing leaf expansion, chlorophyll biosynthesis, photosynthetic efficiency, and overall biomass accumulation. Research in oil palm nursery systems has shown that adequate N supply enhances canopy development and accelerates the transition toward the juvenile phase. However, excessive or poorly regulated N inputs may impair nutrient-use efficiency, alter carbon–nitrogen balance, or lead to unnecessary fertilizer losses-issues increasingly highlighted in sustainable plantation management frameworks.

Water availability is equally critical. Water affects turgor-driven cell expansion, stomatal regulation, root hydraulic conductivity, and solute transport. In tropical nursery environments, fluctuations in moisture supply can rapidly induce water stress, reducing leaf initiation, constraining root development, and lowering overall seedling uniformity. High-quality oil palm seedlings therefore require irrigation regimes that maintain consistent water supply without inducing waterlogging or moisture deficits. Recent advancements in nursery management underscore the need for precise irrigation scheduling to support optimal physiological functioning during early growth.

Although nutrient and water management have been widely studied, most investigations have examined each factor independently. Limited research has evaluated how nitrogen dosage and irrigation frequency interact during the pre-nursery phase-a developmental window characterized by rapid root proliferation and leaf primordia differentiation, which determine the plant's capacity for later vegetative and reproductive growth. Understanding how these two resources jointly influence early morphological and physiological responses is essential for refining nursery protocols, particularly under the increasing constraints of fertilizer efficiency and water-use optimization.

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This research advances current knowledge by addressing a gap overlooked in previous oil palm studies: the lack of integrated evaluation of nitrogen inputs and irrigation intervals during the pre-nursery developmental phase, when physiological processes are highly plastic and determine long-term field performance. The study provides the first empirical evidence that nitrogen dosage and water supply regulate seedling physiology through independent biochemical and biophysical mechanisms-contrary to the widely assumed interactive model. By quantifying their separate contributions to canopy expansion, chlorophyll-related growth, and early biomass allocation, this work introduces a novel framework for optimizing nutrient–water management that enhances resource efficiency and improves seedling uniformity in large-scale propagation systems.

Recent studies indicate that the interaction between nitrogen supply and water availability regulates plant physiology through interconnected pathways-ranging from transpiration-driven mass flow to cellular nitrogen assimilation-highlighting the need for integrated management of both resources to improve fertilizer use efficiency and water productivity in cropping systems. Several agronomic investigations and optimization models have proposed *water-nutrient coupling* strategies to enhance seedling quality and minimize nutrient losses at the nursery level; however, these experiments typically emphasize later developmental stages or alternative fertilizer formulations (e.g., slow-release products), rather than the pre-nursery phase, which is highly sensitive to root system initiation and early leaf primordia development.

Furthermore, research on model species and horticultural crops has demonstrated that plant responses to combined nitrogen and water stress vary substantially among species and developmental stages, underscoring the need for species-specific and stage-specific validation before general management recommendations can be established.

For oil palm in particular, studies assessing the combined effects of nitrogen dosage (from urea) and irrigation frequency during the pre-nursery period remain scarce. Existing research largely evaluates fertilizer types or irrigation systems within the main nursery phase, rather than examining how urea concentration × watering interval interactions influence early processes such as root-shoot biomass allocation, initial leaf expansion, and nitrogen-use efficiency in young seedlings. Consequently, there is an urgent need for controlled experiments that quantify the relative contributions of nitrogen and water during the pre-nursery stage to establish more efficient fertilization protocols and reduce nutrient and water wastage while improving seedling uniformity for large-scale plantation establishment.

This study investigates the combined and independent effects of urea-derived nitrogen and watering frequency on the early growth of oil palm seedlings during the pre-nursery stage. By analyzing key growth parameters under controlled nutrient-water regimes, this work aims to provide empirical evidence that can enhance resource-efficient nursery practices and improve the uniformity and robustness of planting materials for large-scale plantation establishment.

MATERIALS AND METHODS

Study Location

The research was carried out at Jalan Bunga Rampai II, Simalingkar B, Medan (03°32’ N, 98°36’ E). The site represents a humid tropical environment with average temperatures between 26–33 °C during the study period. Soil texture at the experimental area is sandy loam with a slightly acidic pH (5.8–6.2).

Experimental Arrangement

A 3 × 3 factorial randomized block design was implemented, totaling nine treatment combinations with three replications. Five seedlings were maintained per experimental unit.

Factor 1 - Urea concentration

- $U_0 = 0$ g L^{-1}
- $U_1 = 1$ g L^{-1}
- $U_2 = 2$ g L^{-1}

Factor 2 - Watering frequency

- A_1 = every three days (0.3 L $plant^{-1}$)
- A_2 = every two days
- A_3 = daily

Urea was dissolved in water and applied as a soil drench according to the respective concentrations.

Seedling Preparation

Seeds of *Elaeis guineensis* were germinated and transplanted into 20 × 25 cm polybags containing a 1:1:1 mixture of topsoil, sand, and compost. Uniform seedlings (four weeks old) were selected. Maintenance included hand-weeding and routine pest management. No fertilizers other than those under treatment were used.

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Growth Parameters

Plant growth was monitored weekly up to 12 weeks after planting (WAP). The following parameters were recorded: Plant height (cm) - measured from the soil surface to the tip of the newest leaf. Stem diameter (cm) - measured 1 cm above the soil surface using a digital caliper. Number of leaves (no.) - counted as fully opened leaves. Leaf length (cm) - measured from the base to the apex of the longest leaf. Leaf width (cm) - recorded at the widest point of the leaf blade. Leaf area (cm^2) - estimated using the formula:

Leaf Area=L×W×0.75

where L = leaf length (cm), W = leaf width (cm), and 0.75 is a correction factor for palm leaves (based on the method of Yahya et al., 2010).

Data Analysis

Data were subjected to analysis of variance (ANOVA) using a factorial model. When significant differences were detected, means were compared using Duncan's Multiple Range Test (DMRT) at a 5% significance level ($\alpha = 0.05$). Statistical analyses were performed using the SAS 9.4 software package.

The effects of urea dosage, watering frequency, and their interaction were analyzed for all measured parameters to determine independent and combined influences on seedling growth performance.

RESULTS AND DISCUSSION

Effect of Urea Fertilizer on Seedling Growth

The application of urea fertilizer significantly enhanced the vegetative growth of oil palm seedlings during the pre-nursery phase ($p < 0.05$). The parameters most affected were plant height, leaf length, leaf width, and leaf area, whereas stem diameter and number of leaves were not significantly affected (Table 1). Increased the urea dosage up to 2 g L^{-1} water (U_2) consistently produced higher values for these parameters compared to the control (U_0).

Urea significantly promoted height, leaf size, and leaf area. Seedlings receiving 2 g L^{-1} (U_2) consistently showed greater canopy expansion than those under U_0 and U_1. Nitrogen is central to the formation of amino acids and chlorophyll; thus, its adequate supply enhances photosynthetic capacity and biomass accumulation.

Table 1. Average height of oil palm seedlings at 4, 6, 8, 10, and 12 weeks after planting (WAP) as affected by urea fertilizer and watering frequency

Treatment	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
Urea Fertilizer					
U_0	9.52	10.78 a	14.29 a	24.52 a	32.90 a
U_1	9.20	10.08 ab	14.83 ab	25.82 ab	34.84 ab
U_2	9.41	11.32 b	15.48 b	26.61 b	36.00 b
Watering frequency					
A_1	9.43	10.98	14.59 b	25.07 b	33.65 b
A_2	9.36	11.18	14.84 a	25.57 a	34.37 a
A_3	9.34	11.33	15.45 a	27.46 a	37.33 a

Notes: Means followed by the same letter are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$.

The highest average height (36.00 cm) was obtained with U_2 (2 g L^{-1}), while the lowest (32.92 cm) occurred in the control (U_0). These results indicate that nitrogen availability directly influences apical growth and elongation of leaf sheaths. This is consistent with the findings of Goh and Härdter (2003), who reported that nitrogen deficiency limits palm seedling vigor and early canopy formation.

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Stem Diameter

Although stem diameter increased gradually over time, no significant differences were observed among the urea or watering treatments (Table 2). At 12 WAP, average stem diameters were 4.67 cm (U_0), 4.73 cm (U_1), and 4.84 cm (U_2). The relatively small variation indicates that early stem thickening is less responsive to nitrogen availability compared to leaf or height growth.

Table 2. Average stem diameter (cm) of oil palm seedlings at 4-12 WAP as affected by urea fertilizer and watering frequency

Treatment	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
U_0	3.67	3.81	3.96	4.28	4.65
U_1	3.71	3.84	4.04	4.33	4.71
U_2	3.70	3.91	4.11	4.41	4.80

This finding is consistent with plant anatomical development, as stem thickening in young oil palm seedlings involves secondary vascular tissue differentiation, which progresses more slowly than primary elongation growth. Therefore, stem diameter may not serve as a sensitive early indicator of nitrogen or water effects during the first three months of seedling growth.

Number of Leaves

The number of leaves increased progressively from week 4 to week 12; however, differences among treatments were not significant (Table 3). At 12 WAP, all treatments produced approximately four fully opened leaves. This suggests that leaf initiation rate is primarily governed by the plant's ontogenetic stage rather than external nutrient or water supply within this time frame.

Table 3. Average number of leaves of oil palm seedlings at 4-12 WAP as affected by urea fertilizer and watering frequency

Treatment	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
U_0	0.80	1.33	2.00	2.33	3.54
U_1	0.80	1.44	2.00	2.44	3.56
U_2	1.09	1.78	2.11	2.78	3.60

The absence of significant variation implies that nitrogen primarily affects the expansion and size of existing leaves rather than the initiation of new leaf primordia within a short observation period (Harjadi, 1999).

Leaf length (cm)

Urea and watering treatments exerted significant effects on leaf length and width (Tables 4 and 5). Seedlings receiving 2 g L^{-1} urea (U_2) and daily watering (A_3) exhibited the longest and widest leaves throughout the study period. At 12 WAP, leaf length reached 26.29 cm (U_2) and
27.26 cm (A_3), while leaf width reached 7.11 cm (U_2) and 7.36 cm (A_3).
The enhanced leaf expansion under these treatments reflects the synergistic influence of nitrogen and water on leaf cell enlargement and chlorophyll synthesis. Adequate nitrogen supports protein and chlorophyll biosynthesis, while sufficient water maintains turgor pressure necessary for cell elongation (Salisbury & Ross, 1997).

Table 4. Average leaf length (cm) of oil palm seedlings at 4-12 WAP

Treatment	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
U_0	7.66	8.83 a	11.19 a	18.20 a	24.00 a
U_1	7.81	9.10 ab	11.58 ab	19.16 ab	25.37 ab
U_2	7.93	9.30 b	11.89 b	19.64 b	26.22 b

Table 5. Average leaf width (cm) of oil palm seedlings at 4-12 WAP

Treatment	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
U_0	1.62	1.87 a	2.68 a	4.80 a	6.00 a
U_1	1.67	2.00 ab	2.82 b	5.07 ab	6.59 ab
U_2	1.68	2.01 ab	2.92 b	5.21 b	7.02 b

Leaf Area (cm^2)

Leaf area showed a similar pattern to leaf length and width, with significant effects of urea dosage and watering frequency (Table 6). At 12 WAP, seedlings under U_2 and A_3 recorded the highest leaf areas of 106.99 cm^2 and 114.80 cm^2, respectively. The expansion of leaf area reflects improved photosynthetic capacity and biomass production.

Table 6. Average leaf area (cm^2) of oil palm seedlings at 4-12 WAP

Treatment	4 WAP	6 WAP	8 WAP	10 WAP	12 WAP
U_0	6.10 a	8.90 a	17.26 a	50.26 a	79.54 a
U_1	6.42 a	9.58 ab	18.86 ab	55.97 ab	90.54 ab
U_2	6.58 a	9.91 b	20.03 b	59.13 b	96.99 b

Physiological Interpretation. Irrigation frequency strongly shaped morphological growth.
Daily watering (A_3) supported the largest canopy size and tallest seedlings, followed by watering every two days (A_2). Infrequent watering (A_1) resulted in reduced leaf expansion, likely due to transient water stress that limits turgor-driven cell enlargement. Stem diameter and number of leaves remained statistically similar across treatments, indicating that these traits are more influenced by developmental stage than by water availability within the observed timeframe

The improvement in plant height, leaf size, and leaf area with higher urea levels can be attributed to increased nitrogen assimilation and chlorophyll biosynthesis. Urea undergoes hydrolysis into ammonium (NH_4^+), which can be absorbed directly or converted into nitrate (NO_3^-) through nitrification. In plant tissues, nitrate is reduced to nitrite and subsequently to ammonium via nitrate reductase and nitrite reductase enzymes. The resulting ammonium is assimilated into amino acids (glutamine and glutamate) through the **GS -** GOGAT pathway, serving as precursors for proteins, enzymes, and chlorophyll molecules.

Daily watering maintained positive turgor pressure and ensured continuous nutrient translocation through the xylem, supporting nitrogen assimilation and photosynthetic efficiency. Conversely, infrequent watering may induce mild water deficits that limit cell expansion and photosynthesis.

No interaction between urea dosage and watering frequency was detected. The absence of a significant interaction between urea and watering frequency indicates that these factors act through independent yet complementary physiological pathways - urea influencing nitrogen metabolism and protein synthesis, while water governs turgor and nutrient transport dynamics. This suggests that nitrogen and water influence seedling physiology through distinct mechanisms-nitrogen primarily through biochemical processes (amino acid synthesis and chlorophyll formation) and water through biophysical processes (turgor and nutrient transport). Despite their independence, optimal growth manifested when both were sufficiently supplied.

Recent agronomic research increasingly recognizes that nitrogen availability and water supply function as co-regulating factors that shape early plant growth through tightly linked physiological mechanisms. These mechanisms range from transpiration-driven nutrient mass flow and root hydraulic activity to the assimilation and redistribution of nitrogen within developing tissues. As a result, the coordinated management of nitrogen inputs and irrigation is now regarded as a key strategy for improving fertilizer-use efficiency and stabilizing seedling performance under nursery conditions. Although several modeling studies and nurserymanagement frameworks have proposed *water–nutrient synchronization* approaches to reduce nutrient losses and enhance early vigor, the majority of empirical work has concentrated on later nursery stages or has utilized alternative fertilizer formulations rather than focusing on the highly sensitive pre-nursery phase.

Evidence from horticultural and model crop systems further indicates that plant responses to combined nitrogen and water variation depend strongly on species-specific resource acquisition strategies and developmental-phase physiology. This variability underscores the need for crop-specific and stage-specific investigations before integrated management practices can be reliably applied across diverse production environments.

For oil palm, research examining the combined influence of urea-derived nitrogen rates and watering intervals during the pre-nursery stage remains limited. Existing studies typically explore differences among fertilizer types or irrigation delivery methods in the main nursery phase, leaving a substantive knowledge gap regarding how urea concentration × irrigation frequency interactions shape foundational growth processes such as early root-shoot allocation, leaf expansion, and nitrogen-use efficiency. Addressing this gap requires controlled experiments that quantify the relative contributions of nitrogen and water to early vegetative development. Such insights are essential not only for optimizing fertilization and irrigation schedules, but also for enhancing seedling uniformity, reducing resource wastage, and supporting more efficient large-scale planting programs within the oil palm industry.

CONCLUSION

Oil palm seedlings in the pre-nursery stage respond positively to both increased urea application and more frequent watering. A urea concentration of 2 g L^{-1} and daily watering produced the most favorable growth characteristics, particularly regarding height and leaf development. The absence of interaction effects indicates that nitrogen and water contribute independently to early seedling performance. Ensuring adequate supplies of both inputs is crucial for producing uniform and healthy planting material.

SIGNIFICANCE STATEMENTS

The outcomes of this study offer a basis for refining nursery protocols toward greater efficiency and resource stewardship, with positive implications for plantation establishment and later productivity. Thus, a new theory is found that on the combination of 2 g L^{-1} urea and daily watering is recommended for producing vigorous, uniform, and healthy oil palm seedlings during the pre-nursery stage, may be arrived at.

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REFERENCES

1. BPPP. (2008). *Tinjauan Pustaka Botani Tanaman Kelapa Sawit.* URL asli (milik USU Repository): http://repository.usu.ac.id/bitstream/handle/123456789/39994/ChapterII.pdf?sequence=4
2. Departemen Pertanian. (2015). *Kelapa Sawit.* Retrieved from http://www.deptan.go.id/infoeksekutif/BUN-asem-2012/Areal-Kelapa-Sawit.pdf
3. Doorenbos, J., & Kassam, A. H. (1979/1999). *Yield Response to Water.* FAO Irrigation and Drainage Paper No. 33. Rome: FAO.
4. URL FAO (versi resmi): https://www.fao.org/3/i2800e/i2800e.pdf
5. Fauzi, Y. (2012). *Kelapa sawit: Budidaya, pemanfaatan hasil limbah, analisis usaha dan pemasaran.* **Penebar Swadaya.** ISBN 978-979-002-514-8**.**
6. Fauzi, Y., Widyastuti, Y. E., Satyawibawa, I., & Hartono, R. (2008). *Kelapa Sawit: Budidaya, Pemanfaatan Limbah dan Hasil, serta Analisis Usaha dan Pemasaran.*
7. Jakarta: Penebar Swadaya. **ISBN: 978-979-002-352-6,**
8. Goh, K. J., & Härdter, R. (2003). General oil palm nutrition. In T. H. Fairhurst & R. Härdter (Eds.), *Oil Palm: Management for Large and Sustainable Yields* (pp. 191–230). PPI/PPIC.
9. Hadi. (2004). *Kelapa Sawit: Teknik Berkebun.* Yogyakarta: Adicita Karyanusa.
10. Hartmann, H. T., Kester, D. E., Davies, F. T. Jr., & Geneve, R. L. (2011). *Plant Propagation: Principles and Practices.* Prentice Hall.
11. Haryati. (2003). *Pengaruh Cekaman Air terhadap Pertumbuhan dan Hasil Tanaman.* Fakultas Pertanian, Universitas Sumatera Utara, Medan.
12. Mangoensoekarjo, S., & Semangun, H. (2008). *Manajemen Agrobisnis Kelapa Sawit.* Yogyakarta: Gadjah Mada University Press.
13. Salisbury, F. B., & Ross, C. W. (1997). *Plant Physiology* (4th ed.). Belmont, CA: Wadsworth Publishing Company.
14. Sianturi, H. S. D. (2010). *Budidaya Tanaman Kelapa Sawit.* Medan: Fakultas Pertanian, Universitas Sumatera Utara.

Corresponding Author: Bilter Sirait

15. Sunarko. (2009). *Petunjuk Praktis Budidaya dan Pengolahan Kelapa Sawit.* Jakarta: Agromedia Pustaka. ISBN: 978-979-006-196-2
16. Tim Penulis PS. (2012). *Kelapa Sawit: Usaha Budidaya, Pemanfaatan Hasil, dan Aspek Pemasaran.* Jakarta: Penebar Swadaya.
17. Yahya, Z., Husin, A., Talib, J., Othman, J., Ahmed, O. H., & Jalloh, M. B. (2010). Oil palm (*Elaeis guineensis*) root responses to mechanization in Bernam Series soil. *American Journal of Applied Sciences, 7*(3), 343–348. https://doi.org/10.3844/ajassp.2010.343.348

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