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Nutritional Effects of Different Calcium Sources on Growth of Oil Palm Seedlings under Nursery Condition

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ABSTRACT

Calcium (Ca) is an essential secondary macronutrient which necessary plant mineral frequently added to fertilizers to promote plant development and resistance to abiotic and biotic stressors. Applying Ca to soils suffices to meet crops' Ca requirements. Regrettably, its function is obscure. Thus, it is critical to maintain enough nutrient availability through fertilizers or alter the soil environment for oil palm seedlings to grow and thrive. This study investigates the effects of different Ca sources on vegetative growth in oil palm seedlings. This experiment was carried out for nursery evaluation using 5-months old of oil palm seedlings with varying sources of Ca (C1–calcium chloride, $CaCl_2$; C2–calcium sulfate, $CaSO_4$; C3-calcium nitrate, $CaNO_3$; C4–calcium carbonate, $CaCO_3$; C5–calcium oxide, CaO, C6–calcium hydroxide, $Ca(OH)_2$; and C7–water leach purification and neutralization underflow, NUF-WLP) and grown in a polybag containing beach ridges interspersed with swales (BRIS) soil within six months in Malaysian Palm Oil Board (MPOB) nursery, Seksyen 15, Bandar Baru Bangi. Five concentration levels of Ca (T1–200 ppm, T2–250 ppm, T3–300 ppm, T4–1,000 ppm, and T5–1,500 ppm) were used in a completely randomized design

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(CRD) with ten replications for each. Based on the total biomass of oil palm seedlings at 24 weeks after treatment with various sources of Ca, the result confirmed that C2 oil palm seedlings were more significant in size and denser at the root than other Ca types. The result is an essential indicator that C2 effectively increased the total biomass of oil palm seedlings at 1,000 ppm of Ca (T4); hence it was the best Ca source to improve the growth and development of oil palm seedlings throughout the experimental period at $p \leq 0.05$.

Keywords: Calcium, non-soluble Ca, oil palms, optimum rate, water-soluble Ca

INTRODUCTION

Sustainable agriculture has been one of the most significant problems in agriculture in recent years. However, plant nutrient interactions and plant responses to stimuli are various. Nutrients are essential for plants' growth and development, as they provide vital and precise plant metabolism functions (Agrios, 2005). Therefore, it is crucial to maintain adequate nutrients in the soil through fertilizers or by manipulating soil conditions to maintain optimum nutrient availability in soil. Mineral nutrients would be an important metabolic regulator, widely used in fertilizers to promote plants' growth by controlling plant metabolism. Moreover, many macro and micro-nutrients are recognized as correlated with some plants' vegetative growth changes.

Ca is an essential macronutrient in plants, with shoot concentrations varying from 0.1% to over 5% per dry weight (Marschner, 1995; White & Broadley, 2003). It was found primarily on cell organelles such as the cell wall and the endoplasmic reticulum, and it was crucial in regulating plant growth and development (Thor, 2019). Therefore, it has a dual role, both as a structural part of cell walls and membranes as well as an intracellular second messenger. Consequently, the plant's uptake, delivery, and storage need to be closely controlled to fulfill both missions. In addition, Ca is also crucial for many plant functions, including cell division, cell wall growth, nitrate uptake, metabolism, enzyme activity, and starch metabolism. Thus, the Ca must be accessible to the plant in adequate quantities to fulfill the structural function.

The Ca is present in three primary forms in the soils, which are bound to exchangeable sites of clay minerals, organic matter, and minerals in soil solution (Ramírez-Builes et al., 2020). The soil solution contains only a minuscule proportion of the total Ca. Therefore, plant roots from the soil solution can absorb only calcium ions (Ca^{2+}). Several factors influence the availability of Ca in soil solution, including soil type, colloidal mineral fraction, pH, organic carbon concentration, humic acids, and exchangeable cation capacity (CEC). The Ca deficiency is most significant in acidic and sandy soils, as well as soils with high aluminum ion (Al^{3+}) saturation and a high Al^{3+} to Ca^{2+} ratio in soil solution (Bolan et al., 2007).

Ca is frequently administered to plant seedlings during the growing period to boost their development potential (Chao et al., 2021). By adding Ca to oil palm, it can be an effective way to promote the growth and productivity of plants. The Ca used exists in the form of an exchangeable cation in the nutrient solution is the main component that can transfer to and absorb by plant roots (Rahman & Punja, 2007). Exchangeable Ca is generally predominant in a nutrient solution than potassium (K) and magnesium (Mg), the next two most abundant exchangeable cations (McLean, 1975). The Ca is withdrawn from the nutrient solution through plasma membrane channels expressed in roots (White et al., 2002).

The most vital sources of Ca fertilizer used in agriculture are calcium sulfate ($CaSO_4$) or gypsum; calcium carbonate ($CaCO_3$) promoted as ground limestone or screened chalk and ground chalk; calcium hydroxide ($Ca(OH)_2$) retailed as slaked lime or hydrated lime; and calcium oxide (CaO) promoted as burnt or quick lime (Minson, 1990). However, the ability of various sources of Ca as a fertilizer to improve growth and plant production in oil palm remains unknown. Based on a previous experiment, 1,000 ppm of Ca in nutrient solution established optimum growth for oil palm seedlings (Mayzaitul Azwa, 2021). However, further research is required to identify the potential effects of different Ca sources with an optimum concentration of Ca (1,000 ppm) on the vegetative growth of oil palm seedlings. This research was, therefore, conducted to determine the effects of different Ca sources on vegetative growth in oil palm seedlings.

MATERIALS AND METHODS

Study Site

The experiment was conducted under transgenic glasshouse conditions in Taman Pertanian Universiti, Universiti Putra Malaysia, Serdang, Selangor. Five-months-old oil palm seedlings were obtained from MPOB Kluang Research Station, Johor. All seedlings were planted in black polybags (35.56 cm height × 35.56 cm diameter) filled with 25 kg of sandy soil (> 95% sand) developed from marine sediments along the beach, commonly called the beach ridges interspersed with swales (BRIS) soil series collected from Forest Research Institute Malaysia (FRIM) Setiu Research Station, Terengganu. Sandy soil was selected as the growing media as it has zero nutrients and makes it possible to control the nutrient supply and uptake by oil palm seedlings. The experiment was conducted in a transgenic glasshouse, which had 24 hours controlled and monitored environment. It provided a sensor to detect temperature and relative humidity changes in a glasshouse. Thus, the temperature was maintained between 30°C and 36°C with relative humidity between 60% and 80%. The seedlings were maintained by watering twice daily and supplemented with monthly fertilizers throughout the experiment. For the water-soluble Ca experiment, the fertilizer is based on Hoagland solution (Table 1), while for non-soluble Ca experiment is based on basic fertilizer urea (nitrogen, N: 46%); monopotassium phosphate, MKP (phosphorus pentoxide, P_2O_5: 52%; potassium oxide, K_2O: 34%); muriate of potash, MOP (potassium oxide, K_2O: 60%); kieserite (magnesium oxide, MgO: 25%); and borax (boron, B: 68%).

Table 1
Elements in Hoagland's solution based on Hoagland and Arnon (1950) for 120 L of stock solution

Stock solution	Type of fertilizer	Quantity
Stock A	Water	120 L
	EDTA-Fe	228 g
Stock B	Water	120 L
	KNO_3	8.4 kg
	KH_2PO_4	3.6 kg
	$MgSO_4$	4.8 kg
	EDTA-Mn	21.6 kg
	EDTA-Zn	18 g
	EDTA-Cu	4.8 g
	Ammonium molybdate	3.6 g
	Hibor	3.6 g

(Hoagland & Arnon, 1950)

Experimental Design and Treatments

A factorial experiment was conducted with ten replicates with three seedlings, each using a completely randomized design (CRD) experiment. Seven types of Ca sources were used in this experiment. The oil palm seedlings were treated with water-soluble and non-soluble Ca for six months throughout the experiment (Table 2). All the oil palm seedlings were sub-irrigated with modified Hoagland solution (different levels of Ca concentrations: T1–200 ppm, T2– 250 ppm, T3–300 ppm, T4–1,000 ppm, and T5–1,500 ppm). The pH of the nutrient solution was maintained at pH 6.0 by adjusting with 0.1 N hydrochloric acid (HCl) or 0.01 N sodium hydroxide (NaOH) solution and changed every week. A total of five treatment combinations were used in this study (Table 3). For the water-soluble Ca, the oil palm seedlings were supplemented with Ca fertilizer per 120 L of Hoagland solution per week throughout the six months of the experiment (Table 4). The rates of Ca concentration were T3 (300 ppm, 24 applications, total 7,200 ppm per seedlings), T4 (1,000 ppm, 24 applications, total 24,000 ppm per seedlings), and T5 (1,500 ppm, 24 applications, total 36,000 ppm). Whereas in the case of non-soluble Ca, the oil palms seedlings were added with Ca fertilizers per 25 kg of BRIS soil

Table 2
Treatments of oil palm seedlings with different Ca sources and solubility in water for plant growth analysis

	Calcium sources	Solubility in water
C1	Calcium chloride ($CaCl_2$)	Soluble
C2	Calcium sulphate ($CaSO_4$)	
C3	Calcium nitrate ($CaNO_3$)	
C4	Calcium carbonate ($CaCO_3$)	Non-soluble
C5	Calcium oxide (CaO)	
C6	Calcium hydroxide ($CaOH_2$)	
C7	Water leach purification and neutralization underflow (NUF-WLP)	

Table 3
Combination of treatments used

Treatment	Ca concentration (ppm)
T1	200
T2	250
T3	300
T4	1,000
T5	1,500

Note. T1, T2, and T3: Low concentration rate; T4: Optimum rate; T5: Excess concentration rate

Table 4
Application rate of Ca types of solubility in water

Ca sources	Application rate	Concentration of Ca per palm (ppm)				
		T1	T2	T3	T4	T5
C1	120 L of Hoagland solution	-	-	0.80 L	3.00 L	4.00 L
C2		-	-	0.88 L	2.70 L	4.40 L
C3		-	-	0.90 L	3.05 L	4.55 L
C4	25 kg of BRIS soil	7.00 g	16.80 g	14.00 g	-	-
C5		7.25 g	17.40 g	14.50 g	-	-
C6		12.51 g	30.02 g	25.0 g	-	-
C7		20.00 g	25.00 g	30.00 g	-	-

Note. A negative symbol is used to mention that no experiment for the treatment as mentioned above. C1 –$CaCl_2$, C2 – $CaSO_4$, C3 – $CaNO_3$, C4 – CaO, C5 – Ca $(OH)_2$, C6 – $CaCO_3$, and C7 – NUF-WLP (2 NUF:1 WLP). T1 – 200 ppm, T2 – 250 ppm, T3 – 300 ppm, T4 – 1,000 ppm, and T5 – 1,500 ppm

per month throughout the six months of the experiment (Table 4). The rates of Ca concentration were T1 (200 ppm, six applications, total 1,200 ppm per seedlings), T2 (250 ppm, six applications, total 1,500 ppm per seedlings), and T3 (1,000 ppm, six applications, total 6,000 ppm per seedlings).

No experiments were done for treatment T1 (200 ppm of Ca) and T2 (250 ppm of Ca) for water-soluble Ca. After being tested on their pH during pre-experiment, both treatments gave the range of soil pH below the optimal availability of plant nutrients (6.0 to 7.0). For non-soluble Ca, no experiments were done for treatment T4 (1,000 ppm) and T5 (1,500 ppm). Both treatments gave the range of soil pH above the optimal availability of plant nutrients (6.0 to 7.0).

Measurements of Vegetative Growth

The plant height (cm), girth diameter (mm), and the chlorophyll content (soil plant analysis development, SPAD) values were obtained three times throughout the experiment period, which was at two-, four-, and six-month intervals throughout the experiment period.

Data Analysis

The data were statistically analyzed using a two-way analysis of variance (ANOVA) from the Statistical Analysis Software (SAS) 9.2 package. Two-way ANOVA was used to understand whether there was an interaction between types of Ca sources on the growth of oil palm seedlings and different levels of Ca concentrations. Where types of Ca sources and different levels of Ca concentrations were independent variables, and the development of oil palm was the dependent variable. Means separation was conducted using the least significant difference (LSD) at a 5% significance level.

Pre-experiment (Water Field Capacity)

Water field capacity in BRIS soil was measured to calculate the amount of soil moisture or water content kept in the soil using the following formulae:

$$Moisture\ content\ (\%\ w/w) = \left[\left(\frac{weight\ of\ fresh\ soil\ - weight\ of\ dry\ soil}{weight\ of\ wet\ soil}\right) \times 100\right]$$

Pre-experiment (Soil pH of Oil Palm Seedlings)

All Ca sources used in the experiment were tested on their pH at a different concentration to determine which treatment gave the soil pH range the optimal availability of plant nutrients (6.0 to 7.0). The experiment was carried out for six months, and the soil pH was measured at two months intervals.

RESULTS AND DISCUSSION

Plants Height for Oil Palm Treated with Soluble and Non-soluble Ca Sources

Throughout the experiment period, there was no interaction between soluble Ca sources with Ca concentration rates at $p \geq 0.05$ (Table 5). Generally, the oil palm seedlings showed an increase in their height after two months treated with various types of water-soluble Ca at different concentration rates (low, optimum, and excess). At six months, the mean height of oil palm seedlings at 1,000 ppm of Ca (T4) treated with C3 was 7.23% higher than that in C2 and 10.50% higher than in C1. The mean height of oil palm seedlings at 1,000 ppm of Ca (T4) was almost the same as in C2 and C1, about 3.58%.

A similar trend was also observed in the height of oil palm seedlings treated with various types of non-soluble Ca (Table 6). As the seedlings grew old, the differences among the seedling's height became more pronounced. However, there was no interaction between non-soluble Ca sources with Ca concentration rates at $p \geq 0.05$. However, interactions existed between types of Ca used in the experiment with the time (month) at $p \leq 0.05$. All seedlings were observed to increase significantly in height after two to six months of treatment with various types of non-soluble Ca. After six months of treatment, the height of the seedlings at 300 ppm of Ca (T3) recorded in C7 was 3.19% significantly higher than in C6, 6.68% higher than in C4 15.48% higher than in C5. The seedlings' height treated with C6 was 3.61% higher than in C4 and 12.7% higher than in C5. The seedlings treated in C4 were 9.43% higher than in C5.

Girth for Oil Palm Treated with Soluble and Non-soluble Ca Sources

Throughout the experiment, an interaction between Ca water-soluble forms with different Ca concentrations was observed at $p \leq 0.05$ (Table 7). There was an interaction between soluble Ca sources with Ca concentration rates at $p \leq 0.05$ (Table 7). The girth of oil palm seedlings showed an improvement after two months of treatment with various forms of water-soluble Ca at different concentration rates (low, optimum, and excess). The mean value of girth at 1,000 ppm of Ca (T4) treated with C3 was 32.98% higher than that in C2 and 27.78% higher than in C1 over six months of experimental time. The mean value of the girth of oil palm seedlings at 1,000 ppm of

Table 5
Plant height for oil palm seedlings treated with soluble Ca

Sources of Ca	2 months			4 months			6 months		
	Ca concentration (ppm)								
	T3	T4	T5	T3	T4	T5	T3	T4	T5
C1	22.60c ± 0.48	23.10b ± 0.82	24.70a ± 0.99	45.20a ± 1.64	40.10b ± 0.70	44.15ab ± 1.86	66.30a ± 4.55	61.90a ± 4.54	66.40a ± 2.04
C2	28.40a ± 0.56	29.50a ± 1.06	22.10b ± 0.72	42.15a ± 4.74	46.18a ± 1.33	46.52a ± 2.48	65.50a ± 3.66	64.20a ± 1.99	64.40a ± 3.22
C3	25.60b ± 1.25	25.90b ± 0.87	23.50ab ± 0.98	47.15a ± 2.06	36.10b ± 2.00	41.30b ± 1.52	55.70a ± 7.71	69.20a ± 2.98	61.10a ± 4.29

Note. C1 - $CaCl_2$, C2 - $CaSO_4$, and C3 - $CaNO_3$. T3 - 300 ppm, T4 - 1,000 ppm, and T5 - 1,500 ppm. Data are means ± standard error using LSD ($p \leq 0.05$). Means with the same letter in the column are not significantly different

Table 6
Plant height for oil palm seedlings treated with non-soluble Ca

Sources of Ca	2 months			4 months			6 months		
	Ca concentration (ppm)								
	T1	T2	T3	T1	T2	T3	T1	T2	T3
C4	27.30a ± 1.10	42.30a ± 0.85	59.50ab ± 2.40	27.30a ± 2.12	39.70a ± 0.60	64.10a ± 1.56	28.10a ± 2.47	37.45a ± 1.91	55.70a ± 2.93
C5	23.00b ± 1.60	40.15a ± 1.12	53.00a ± 1.70	23.10b ± 4.55	37.35a ± 2.18	61.70a ± 1.28	25.80a ± 3.88	39.10a ± 3.19	63.80a ± 2.00
C6	23.40b ± 1.10	37.95a ± 1.50	60.80a ± 1.73	23.80b ± 2.10	37.50a ± 1.32	61.50a ± 0.83	27.60a ± 3.23	40.50a ± 3.86	61.50a ± 2.95
C7	24.40ab ± 1.41	40.30a ± 1.05	63.00a ± 1.19	24.50ab ± 1.37	39.05a ± 0.82	64.00a ± 1.57	24.20a ± 1.50	39.00a ± 2.21	65.90a ± 2.20

Note. C4 - $CaCO_3$, C5 - CaO, C6 - Ca $(OH)_2$, and C7 - NUF-WLP. T1 - 200 ppm, T2 - 250 ppm, T3 - 300 ppm, T4 - 1,000 ppm, and T5 - 1,500 ppm. Data are means ± standard error using LSD ($p \leq 0.05$). Means with the same letter in the column are not significantly different

Table 7
Girth for oil palm seedlings treated with soluble Ca

Sources of Ca	2 months						4 months						6 months					
	Ca concentration (ppm)																	
	T3		T4		T5		T3		T4		T5		T3		T4		T5	
C1	7.90b	± 0.45	12.25a	± 0.81	10.32a	± 0.59	18.39a	± 1.36	18.47a	± 1.14	18.32b	± 1.00	36.12ab	± 2.66	37.91b	± 2.50	38.60b	± 2.10
C2	10.58ab	± 0.56	10.27ab	± 0.72	11.59a	± 0.72	17.93a	± 2.30	22.46a	± 1.31	23.65a	± 1.30	32.08b	± 2.71	37.84b	± 3.37	37.24b	± 3.26
C3	12.17a	± 0.87	9.63b	± 0.84	11.91a	± 0.89	22.27a	± 1.35	22.10a	± 2.70	18.92b	± 1.68	43.37a	± 3.74	56.40a	± 1.95	57.54a	± 2.33

Note. C1 - $CaCl_2$, C2 - $CaSO_4$, and C3 - $CaNO_3$. T3 - 300 ppm, T4 -1,000 ppm, and T5 - 1,500 ppm. Data are means ± standard error using LSD ($p≤0.05$). Means with the same letter in the column are not significantly different

Table 8
Girth for oil palm seedlings treated with non-soluble Ca

Sources of Ca	2 months						4 months						6 months					
	Ca concentration (ppm)																	
	T1		T2		T3		T1		T2		T3		T1		T2		T3	
C4	10.03b	± 0.51	20.67a	± 0.49	30.94a	± 0.95	11.08a	± 1.04	20.44ab	± 0.77	32.71a	± 0.72	10.90a	± 1.09	20.45a	± 1.58	29.90a	± 1.72
C5	12.03ab	± 1.04	22.66a	± 0.84	33.50a	± 0.90	12.40a	± 1.14	23.08a	± 1.54	33.96a	± 1.05	12.86a	± 1.98	30.10a	± 1.15	34.60a	± 1.38
C6	12.80a	± 0.58	17.63a	± 0.70	30.05a	± 0.72	12.13a	± 1.74	18.41b	± 0.68	30.47q	± 0.18	12.20a	± 1.40	20.50a	± 1.40	30.47a	± 1.02
C7	11.20ab	± 0.78	22.81a	± 0.57	31.05a	± 0.54	11.41a	± 0.85	23.30a	± 1.36	35.52a	± 0.61	11.55a	± 1.82	30.00a	± 0.82	35.20a	± 1.09

Note. C4 - $CaCO_3$, C5 - CaO, C6 – $Ca(OH)_2$, and C7 - NUF-WLP. T1 - 200 ppm, T2 - 250 ppm, T3 - 300 ppm, T4 - 1,000 ppm, and T5 - 1,500 ppm. Data are means ± standard error using LSD ($p≤0.05$). Means with the same letter in the column are not significantly different

Ca (T4) in C1 and C2 was almost the same, around 0.16%.

A similar pattern in the girth of oil palm seedlings treated with different types of non-soluble Ca sources was observed (Table 8). As the seedlings grew old, the changes in the girth of seedlings became more pronounced. No interactions were found between non-soluble Ca sources with Ca concentration rates at $p \geq 0.05$ during the experiment period. However, interactions existed between types of Ca used in the experiment with the month at $p \leq 0.05$. After two to six months of treatment with different types of non-soluble Ca, all seedlings increased significantly in girth. After six months of treatment, the girth of seedlings at 300 ppm of Ca (T3) observed in C7 was significantly 1.70% higher than in C6, 13.44% higher than in C4, and 15.06% higher than in C5. The girth size of C6 treated seedlings was 11.94% higher than in C4 and 13.58% higher than in C5. A girth of C5 was 1.87% higher than in C4 seedlings treatment.

Chlorophyll Content for Oil Palm Treated with Soluble and Non-soluble Ca Sources

No interactions were observed between Ca water-soluble forms with Ca concentrations rates at $p \geq 0.05$ (Table 9). However, interactions were observed among the sources of Ca with the month over the entire experimental duration at $p \leq 0.05$. The results of this experiment generally showed an increase of the chlorophyll content (SPAD) in oil palm seedlings after two months of treatment with various forms of water-soluble Ca. The mean value of chlorophyll content (SPAD) at 1,000 ppm of Ca (T4) treated with C1 was 4.97% higher than that in C3 and 6.61% higher than in C2 over six months of experimental time. The mean value of the chlorophyll content (SPAD) in seedlings at 1,000 ppm of Ca (T4) in C3 and C2 was almost the same, around 2.36%.

A similar pattern in the chlorophyll content (SPAD) of oil palm seedlings treated with different sources of non-soluble Ca water was observed (Table 10). As the seedlings grew old, the changes in the chlorophyll content (SPAD) of the seedlings became more pronounced. There was no interaction between non-soluble Ca water sources with Ca concentration rates at $p \geq 0.05$ during the experiment duration. However, there were interactions between sources of Ca used in the experiment with the rate of Ca concentration at $p \leq 0.05$. All seedlings increased significantly in chlorophyll content (SPAD) after two to six months of treatment. After six months of treatment, the chlorophyll content (SPAD) of seedlings at 300 ppm of Ca (T3) observed in C6 was significantly 1.74% higher than in C4, 1.79% higher than in C7, and 13.47% higher than in C5. The chlorophyll content (SPAD) in C4 treated seedlings was 0.05% higher than in C7 and 11.93% higher than in C5. The C7 seedlings treatment showed chlorophyll content (SPAD) of 11.88 % more than in C5.

Total Biomass of Oil Palm Seedlings

There was no interaction between types of Ca used in the experiment, with the rate

Table 9
Chlorophyll content for oil palm seedlings treated with soluble Ca

Sources of Ca	2 months						4 months						6 months					
	Ca concentration (ppm)																	
	T3		T4		T5		T3		T4		T5		T3		T4		T5	
C1	24.02c	± 0.10	35.09a	± 0.85	25.16a	± 0.67	45.81a	± 4.05	46.75b	± 2.87	54.69a	± 2.59	59.44a	± 1.90	58.97a	± 2.47	52.80a	± 3.01
C2	27.01b	± 0.86	27.36b	± 1.06	30.21a	± 1.71	52.48a	± 4.41	53.62ab	± 0.99	58.12a	± 4.07	52.21b	± 2.64	55.07a	± 2.03	56.50a	± 2.47
C3	31.96a	± 1.39	24.72b	± 1.27	30.43a	± 3.23	45.85a	± 4.83	53.91a	± 3.00	52.52a	± 1.73	50.24b	± 1.53	56.40a	± 1.95	53.65a	± 2.52

Note. C1 - $CaCl_2$, C2 - $CaSO_4$, and C3 - $CaNO_3$. T3 - 300 ppm, T4 - 1,000 ppm, and T5 - 1,500 ppm. Data are means ± standard error using LSD ($p \leq 0.05$). Means with the same letter in the column are not significantly different

Table 10
Chlorophyll content for oil palm seedlings treated with non-soluble Ca

Sources of Ca	2 months						4 months						6 months					
	Ca concentration (ppm)																	
	T1		T2		T3		T1		T2		T3		T1		T2		T3	
C4	30.22a	± 1.15	55.29a	± 1.48	55.73a	± 1.31	28.35a	± 2.37	53.68a	± 2.16	49.18a	± 0.94	28.51ab	± 3.03	46.67a	± 1.76	47.75a	± 0.81
C5	27.15ab	± 0.56	51.03ab	± 1.67	51.25a	± 1.18	27.03a	± 2.78	52.80a	± 4.07	54.20a	± 2.75	28.35b	± 3.80	54.42a	± 2.46	55.18a	± 2.02
C6	25.33b	± 1.80	44.82b	± 1.08	43.22a	± 1.21	26.08a	± 2.6	50.20a	± 3.49	50.21a	± 3.21	26.46b	± 2.08	53.62a	± 2.03	54.22a	± 1.77
C7	25.39b	± 1.10	52.40ab	± 1.20	53.91a	± 1.37	28.39a	± 3.26	52.39a	± 1.84	53.60a	± 1.27	31.92a	± 2.34	52.46	± 2.07	54.19a	± 1.84

Note. C4 - $CaCO_3$, C5 - CaO, C6 – $Ca(OH)_2$, and C7 - NUF-WLP. T1 - 200 ppm, T2 - 250 ppm, T3 - 300 ppm, T4 - 1,000 ppm, and T5 - 1,500 ppm. Data are means ± standard error using LSD ($p \leq 0.05$). Means with the same letter in the column are not significantly different of Ca concentration at $p \geq 0.05$. However, the total biomass of C2 seedlings was significantly higher than that of C1, C3, C4, C5, C6, and C7 seedlings after six months throughout the entire experimental period at $p \leq 0.05$ (Figure 1). The total biomass in C2 seedlings of oil palm was 23.01% larger than C4, followed by 23.37% larger than C7, 25.56% larger than C3, 26.44% larger than C5, 27.28% larger than C6, and 29.91% larger than C1. The C2 oil palm seedlings are bigger and denser at the root compared to C1, C3, C4, C5, C6, and C7 seedlings. These results suggested that the Ca source of C2 ($CaSO_4$) effectively increased the total biomass of oil palm seedlings.

The Soil pH

The effect of 300 ppm of various Ca sources used in the experiment on the BRIS soil pH is shown in Table 11. There was an interaction between types of Ca with the rate of Ca concentration at $p \leq 0.05$. The minimum and maximum values of BRIS soil pH were 6.71 and 8.10, respectively. These results suggested that the soil pH was ideal for plant growth ranging from 6.0 to 8.0, respectively.

Table 11
Soil pH for oil palm seedling treated with 300 ppm of Ca

Types of Ca	Average of soil pH	
C1	6.85ed	±0.17
C2	6.71e	±0.07
C3	6.92d	±0.08
C4	7.94ab	±0.16
C5	8.10a	±0.19
C6	7.78bc	±0.18
C7	7.75c	±0.15

Note. Data are means ± standard error using LSD ($p \leq 0.05$). Means with the same letter are not significantly different. C1 - $CaCl_2$, C2 - $CaSO_4$, C3 - $CaNO_3$, C4 - CaO, C5 – Ca $(OH)_2$, C6 - $CaCO_3$, and C7 - NUF-WLP

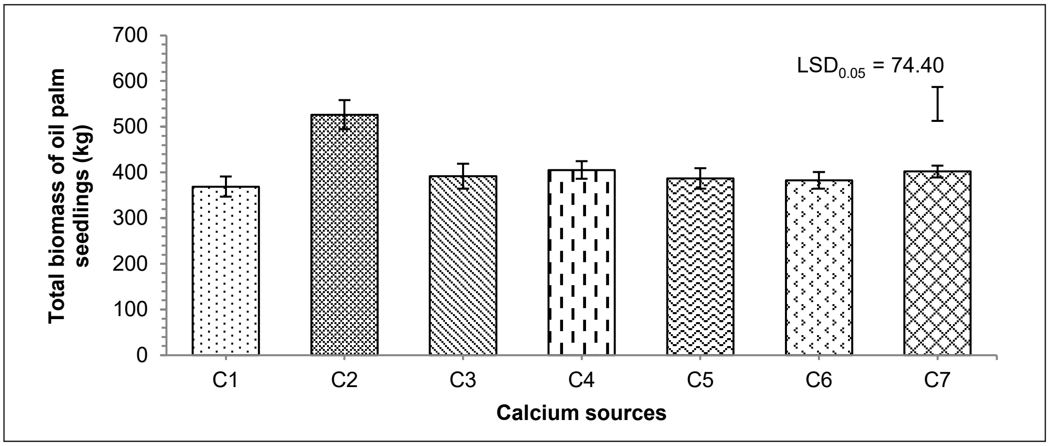

Figure 1. Total biomass of oil palm seedlings at 1,000 ppm of Ca (T4), 24 weeks after treatment with various sources of Ca
Note. C1 - $CaCl_2$, C2 - $CaSO_4$, C3 - $CaNO_3$, C4 - $CaCO_3$, C5 - CaO, C6 – Ca $(OH)_2$, and C7 - NUF-WLP. Data are means ± standard error using LSD ($p \leq 0.05$). Error bars represent LSD values between treatments. LSD bar below the LSD value shows the critical difference (CD) or least significant difference (LSD) in a graph to explain the differences between effects of different calcium sources on the total biomass of oil palm seedlings

The current study evaluated the effects of different types of Ca used in the experiment on oil palm seedlings' vegetative growth in the nursery. All oil palm seedlings increased in seedling height, girth diameter, and chlorophyll content after two months until six months treated with various types of Ca (water-soluble or non-soluble Ca) at different levels of Ca concentration. However, this experiment focused on treatment T4 (1,000 ppm of Ca), an optimum rate for oil palm seedlings in the nursery, following the previous research by Mayzaitul Azwa (2021). The results showed that C3 ($CaNO_3$) oil palm seedlings had the tallest plant height and most oversized girth diameter compared to other Ca sources. However, C1 ($CaCl_2$) showed the highest chlorophyll content than different types of Ca sources. From this experiment, the C2 ($CaSO_4$) treated oil palm seedlings at optimum Ca concentration rate (T4-1,000 ppm) were more prominent and denser at the root. This result was an essential indicator that C2 effectively increased the growth and development of oil palm seedlings, especially on total biomass. Thus, it was the best Ca source. It provides a natural source of Ca and S that can be directly absorbed by plants and is crucial for fertilization and healthy plant development. $CaSO_4$ application can enhance soil structure and physical (aeration, bulk density, and drainage) and chemical parameters (pH, CEC, EC, nutrients availability, and organic carbon) and biomass crop productivity (Alcívar et al., 2018; Kim et al., 2016; Lastiri-Hernández et al., 2019; Wang et al., 2017).

It is believed that there are three main theories involved in this research about how $CaSO_4$ changes the composition of the soil and its physical structure (Jason, 2013). First, it helps compacted soil reduce its compaction level, enhancing the quality of soil structure, which further improves the soil aeration and water permeability. The reduced compacted soil will allow the oil palm roots to penetrate deeper to acquire more usable nutrients. Second, Ca in $CaSO_4$ help to improve the soil by promoting the growth of soil organism, which then provides a more robust soil structure (Jason, 2013). The addition of $CaSO_4$ increased the soil organism's activity, which assisted in breaking down the organic material and dead plant matter. As a result, it helps bind soil particles together, stabilizing the soil structure. The transition from small particles to larger aggregates allows for greater water penetration and nutrients into the soil. Third, the application of $CaSO_4$ to the soil improves the size of soil pores (Jason, 2013). Thus, it helps to balance water drainage and holding capacity, on the other hand. The larger pores increase water and drainage flow, while the smaller pores hold the water longer and aid plant storage (Hopkins, 2013). These varying pore sizes are critical and provide the roots with the oxygen they need because of the improved aeration generated by better root penetration. Therefore, it makes the plants easier to receive more minerals and water to increase growth and development.

These findings are in accordance with the previous research findings by Winsor et al. (1963), who investigated the effect of $CaSO_4$ on lettuce growth and reported that the application of soluble $CaSO_4$ had a comparative effect on lettuce growth mainly in terms of plant size and the fresh weight. Similar findings have been reported by Gharieb et al. (1998), explaining that supplementary $CaSO_4$ in tomato plants significantly increased all the growth parameters and physiological variables, such as plant growth, fruit yield, and membrane permeability as nutrients uptake from the nutrient solution. This outcome is further strengthened by Mahmood et al.'s (2009) findings, who reported that the application of 20 mg Ca as $CaSO_4$ along with N caused a significant improvement in plant height, straw, and grain yields wheat. These previous studies also reported that the application of Ca as $CaSO_4$ had significantly increased about 34 to 52% of plant growth and 25 to 43% of wheat yield production.

The Ca does not shift easily from elder leaves to the rising tips needed. Therefore, $CaSO_4$ is required as it is relatively soluble, which acts as a good medium-term source for releasing Ca and has fair mobility through the soil profile. However, the supplementation of $CaSO_4$ as a Ca fertilizer had little or no effect on the soil pH, thus increasing the plant growth. These outcomes followed the research findings demonstrated by Carvalho and van Raij (1997), whereby the addition of $CaSO_4$ in the soil had a very little significant effect in increasing the pH value, which only ranges from 0.05 units to 0.23 units.

The current study results showed that the application of $CaSO_4$ in the soil increased the chlorophyll content in oil palm seedlings. These results strongly correlated with the membrane permeability of treated $CaSO_4$ seedlings. This statement is in line with an investigation by Bolat et al. (2006) that the addition of 5 mM of $CaSO_4$ in root medium of plum (*Prunus domestica*), Marianna GF 8-1 (*Prunuscerasifera* × *munsoniana*), Myrobolan B (*Prunus cerasifera*), and Pixy (*Prunus insititia*) increased the total chlorophyll contents in their leaves. These results could be related to membrane permeability and electrolyte leakage. The membrane permeability improved as the concentration rate of $CaSO_4$ increased, reducing the percentage of electrolyte leakage and increasing the chlorophyll contents.

CONCLUSION

The results of this study revealed that Ca supplemented as $CaSO_4$ (C2) source was the best to be used for oil palm seedlings with an optimum rate of concentration (T4 - 1,000 ppm). Therefore, the addition of $CaSO_4$ could offer an economical and simple solution to enhance the growth and development of oil palm seedlings. There was a need to consider fertilizer nutrients using the $CaSO_4$ combined with an optimum concentration rate for further research as an alternative way to control plant disease, especially in oil palm caused by *Ganoderma boninense* fungi.

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