JUATIKA
JURNAL AGRONOMI TANAMAN TROPIKA
VOL. 8 No. 2 May 2026

DOI :https://doi.org/10.36378/juatika.v8i2.5465
eissn 2656-1727
pissn 2684-785X
pages : 510 – 519

RESEARCH ARTICLE Open Access

Correlation Analysis of Aloe Vera-Based Liquid Organic Fertilizer and SP-36 Application on The Growth of Sugar Palm Seedling (*Arenga pinnata* Merr.)

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Abstract

This study aimed to analyse the relationship between vegetative growth parameters of sugar palm seedlings after administration of Aloe vera-based liquid organic fertiliser combined with SP-36 fertiliser using correlation analysis. This experiment used a randomised block design consisting of five treatment levels & five replications. Data were analysed using Pearson correlation analysis with SPSS version 25. The findings revealed that these treatment combinations generated relationships classified as strong to very strong among the observed growth parameters. A very strong correlation was identified between the number of leaf sheaths and both plant height and stem diameter, highlighting the crucial function of leaves in enhancing photosynthetic activity and biomass production. In addition, plant height exhibited a very strong association with stem diameter, indicating an interconnection between primary and secondary growth processes. Statistical analysis demonstrated that several variables had a significant influence (Sig. F < 0.05), particularly in the relationships involving leaf sheath number with plant height and stem diameter, as well as between plant height and stem diameter. Although higher LOF dosages tended to promote plant growth, there were signs of a threshold beyond which nutrient uptake efficiency may decline. Overall, the integration of Aloe vera-based LOF with SP-36 fertiliser shows promising potential to improve vegetative growth in sugar palm effectively, and may represent a sustainable fertilisation approach. The optimum response was observed at moderate LOF doses, indicating that balanced nutrient management is essential to maximise vegetative growth efficiency in sugar palm seedlings.

Keywords: Aloe vera liquid organic fertilizer, correlation analysis, SP-36 Fertilizer, Sugar Palm Seedlings, Vegetative Growth

1. Introduction

The sugar palm (*Arenga pinnata*) is a tropical plantation crop that holds significant economic and ecological importance. It serves as a primary source for palm sugar production and bioenergy, while also contributing to soil conservation due to its extensive root system and adaptability to marginal environments. Within the framework of sustainable agriculture, this crop has considerable potential to rehabilitate degraded land and enhance rural livelihoods (Gong et al., 2022; Martins et al., 2023). Nevertheless, the low quality of seedlings remains a key constraint on improving sugar palm productivity under field conditions.

Plant growth at the seedling stage is strongly influenced by the availability of essential macronutrients, especially phosphorus (P), which is vital for root development, cell division, & energy transfer via ATP (Singh et al., 2022; Huang et al., 2021). However, phosphorus in the soil is frequently unavailable to plants due to rapid fixation by soil minerals, leading to low efficiency of phosphate fertilisers (Zhang et al., 2021; Chen et al., 2022). Consequently, optimising the application of phosphate fertilisers such as SP-36 through improved nutrient management strategies is necessary.

At the same time, prolonged reliance on inorganic fertilisers has been associated with declines in soil quality

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across physical, chemical, & biological aspects (Wang et al., 2020; Silva et al., 2021). This issue has driven the exploration of organic fertilisers as more sustainable alternatives. Liquid organic fertilisers (LOF) have emerged as a promising option because of their high nutrient availability, rapid uptake by plants, and ability to stimulate soil microbial activity (Nguyen et al., 2020; Patel et al., 2023).

Aloe vera is one natural material with strong potential as a source of LOF, as it contains plant growth regulators such as auxins and cytokinins, along with various bioactive compounds that can promote plant development (Liu et al., 2021; Jaramillo et al., 2025). Recent findings suggest that aloe vera residues can be utilised as organic fertilizer to enhance plant growth and improve soil fertility. In addition, the application of LOFs has been shown to positively influence both plant performance and soil microbial communities, which are essential for nutrient cycling processes.

A growing body of research indicates that combining organic and inorganic fertilisers can produce synergistic effects, resulting in better plant growth compared to single fertiliser applications. Such integration can improve nutrient use efficiency, enhance soil structure, and support sustainable increases in crop productivity (Ali et al., 2022; Garcia et al., 2022). Other studies also report that plant-based extracts, including aloe vera, can significantly increase plant height, leaf number, and biomass accumulation (El-Sayed et al., 2023; Hassan et al., 2023).

Recent agricultural research has increasingly emphasised environmentally friendly fertilisation systems through the integration of organic biostimulants and inorganic fertilisers (Rouphael & Colla, 2020; du Jardin, 2021). Current studies also highlight the importance of improving nutrient use efficiency, reducing environmental impacts of chemical fertilisers, and enhancing soil biological activity as key components of sustainable agriculture (Bulgari et al., 2019; Canellas et al., 2023). In this context, Aloe vera-based liquid organic fertiliser has attracted attention due to its bioactive compounds, phytohormones, and potential role in stimulating plant physiological processes and soil microbial activity (Chaudhary et al., 2022; Yakhin et al., 2021).

Despite these advances, many previous studies have primarily focused on the direct effects of fertilisers on plant growth, with limited attention given to the relationships among growth variables. In reality, parameters such as plant height, stem diameter, and leaf number are closely interconnected in determining overall plant vigour (Li et al., 2021; Rahman et al., 2022). Therefore, correlation analysis is important to quantitatively and systematically evaluate these relationships (Abdullah et al., 2024; Abdullah et al., 2025).

In addition, limited information is available regarding the physiological relationships among vegetative growth parameters of sugar palm seedlings under integrated fertilisation systems. Most previous studies primarily focused on the direct effects of fertilizers on individual growth variables, such as plant height, leaf number, or stem diameter, without comprehensively examining the interdependence among these parameters (Li et al., 2021; Rahman et al., 2022). Several studies have emphasised that vegetative growth traits are physiologically interconnected through nutrient allocation, photosynthetic activity, and biomass accumulation processes (García-Caparrós et al., 2023; Shi et al., 2025). However, the mechanisms underlying the coordinated development of leaf formation, stem elongation, and stem thickening remain insufficiently understood, particularly in sugar palm cultivation systems and under integrated organic–inorganic fertilisation management (Liu et al., 2024; Kamel et al., 2025).

Furthermore, studies on the use of aloe vera-based LOF in sugar palm remain scarce. Most existing research has focused on horticultural crops such as chilli, bok choy, and other leafy vegetables. Investigations into plantation crops, particularly sugar palm, remain limited, particularly those assessing the combined application of SP-36 fertiliser and aloe vera-based LOF.

The research gaps addressed in this study include the limited exploration of aloe vera liquid fertiliser on sugar palm, the lack of studies integrating phosphate fertilisers with plant-based organic inputs, the minimal use of correlation analysis to assess relationships among growth parameters, and the limited investigation of staged fertiliser application techniques to enhance nutrient efficiency.

The phased fertilisation method applied in this study—at planting, 10 days after planting (DAP), and 30 DAP—offers a potential approach to better align nutrient availability with plant needs. Previous studies have shown that such synchronisation can improve fertiliser efficiency while minimising nutrient losses (Sun et al., 2021; Torres et al., 2022). This research is highly relevant in the context of sustainable agriculture, where innovative fertilisation strategies are needed not only to increase productivity but also to maintain environmental quality. The use of locally available natural resources, such as aloe vera, further adds value by providing cost-effective and accessible inputs.

The novelty of this study lies in the integration of three key components: the combined application of SP-36 fertilizer and aloe vera-based LOF on sugar palm seedlings, the use of correlation analysis (CA) to examine relationships among growth variables, and the implementation of a staged fertilisation approach to enhance nutrient uptake efficiency. Therefore, this research is expected to contribute scientifically to the development of integrated organic–inorganic fertilisation systems and to provide a basis for more efficient and sustainable sugar palm nursery practices. The objective of this study is to analyse the correlation between the application of aloe vera LOF & the growth of sugar palm seedlings (Arenga

pinnata), particularly in terms of leaf sheath number (NL), plant height (PH), and stem diameter (SD).

2. Material and Methods

2.1. Research Location and Time

This study took place at the experimental garden of the Program Studi Pengelolaan Perkebunan Politeknik Indonesia Venezuela. The research was carried out over a period of two months, spanning from January to March 2025. Geographically, the research location is at coordinates of approximately 5.509827° N and 95.392646° E, with an altitude of approximately 13 meters above sea level. This area is a lowland area with relatively flat topography and a humid tropical climate. The average annual rainfall in this area is approximately 1,247.2 mm per year, with an average of approximately 154 rainy days per year. The rainy season generally occurs from September to February, while the dry season occurs from March to August. The average air temperature ranges from 25–28 °C. Based on soil conditions in Ingin Jaya District, the dominant soil type belongs to the Aquen Entisols group, namely young soil with a low level of profile development and is generally found in alluvial plains with fairly good drainage.

2.2. Tools and Materials

The study utilized various tools and materials, including scissors, knives, hoes, machetes, measuring rulers, calipers, small polybags, and weighing scales. The materials consisted of rice husks, soil, one-month-old pre-nursery sugar palm (*Arenga pinnata*) seedlings, SP 36 fertiliser, and LOF derived from aloe vera.

2.3. Research Design

This research employed a non-factorial Randomised Block Design with five treatment levels and five replications, resulting in a total of 25 experimental units. The treatment sequences were as follows: P0 = Without SP-36 Fertilizer and Aloe Vera Liquid Fertilizer (LOF), P1 = Application of SP-36 Fertilizer 10 g/seedling + Aloe Vera Liquid Fertilizer 50 ml/seedling, P2 = Application of SP-36 Fertilizer 10 g/seedling + Aloe Vera Liquid Fertilizer 100 ml/seedling, P3 = Application of SP-36 Fertilizer 10 g/seedling + Aloe Vera Liquid Fertilizer 150 ml/seedling, P4 = Application of SP-36 Fertilizer 10 g/seedling + Aloe Vera Liquid Fertilizer 200 ml/seedling (Haaland, 2020).

2.4. Research Variables

The application of SP-36 fertilizer and aloe vera-based LOF was carried out in three stages, namely at planting, 10 days after planting (DAP), and 30 DAP. This staged application of phosphate fertilizer was intended to enhance phosphorus availability during the early growth phase, a period that is critical for root development and vegetative growth processes (Ghong et al., 2022; Singh et al., 2022). The SP-36 fertilizer was applied by distributing it evenly in a circular pattern around the base of the plant. In contrast, the LOF was applied by pouring it along the circular edge of the polybag. This method has been reported to improve nutrient absorption efficiency through the root system (Kumar et al., 2020; El Sayed et al., 2023). The dosage of both SP-36 fertilizer and LOF varied according to the treatment levels outlined in the experimental design.

The variables observed in this study included the number of leaf sheaths (NL), plant height (PH), and stem diameter (SD). The NL was determined by counting all fully expanded leaves, as this parameter is widely used to indicate vegetative growth performance (Li et al., 2021). Observations were conducted at 40, 50, and 60 DAP to capture changes in growth over time. PH was measured from the base of the stem to the apical growing point using a measuring ruler, a method commonly applied to assess plant responses to fertilization treatments (Rahman et al., 2022). SD, on the other hand, was measured with a vernier calliper at 2 cm above the soil surface, as this parameter reflects stem robustness and overall plant vigour (Adekiya et al., 2020; Hassan et al., 2023). Measurements of stem diameter were also taken at 40, 50, and 60 days after transplanting to provide a more accurate assessment of plant structural development. The flow diagram of this research is shown in Figure 1.

2.5. Data Analysis

The data analysis was conducted using the Statistical Package for the Social Sciences (SPSS), version 25. Correlation analysis represents a quantitative approach used to determine both the direction and the strength of the relationship among two or more variables. This relationship is expressed through a correlation coefficient with values ranging from minus one to plus one. A positive value indicates a direct relationship between variables, whereas a negative value reflects an inverse relationship. The magnitude of the association is commonly represented by the correlation coefficient symbolized as r Abdullah et al., 2025. The criteria for interpreting multiple correlation tests in SPSS are as follows: if the significance value of change is less than 0.05, then:

$$r = \frac{n\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{(n\Sigma X^2 - (\Sigma X)^2)\,(n\Sigma Y^2 - (\Sigma Y)^2)}}$$

This formula represents the Pearson correlation coefficient, which is used to evaluate the direction and strength of the linear association between variables X and Y. In this expression, n denotes the number of paired observations, $\sum XY$ refers to the total product of corresponding X and Y values, $\sum X$ and $\sum Y$ indicate the sums of each variable, while $\sum X^2$ and $\sum Y^2$ represent the sums of squared values for each variable. The criteria used for interpreting the correlation analysis are outlined in

Table 1 (Abdullah et al., 2024).

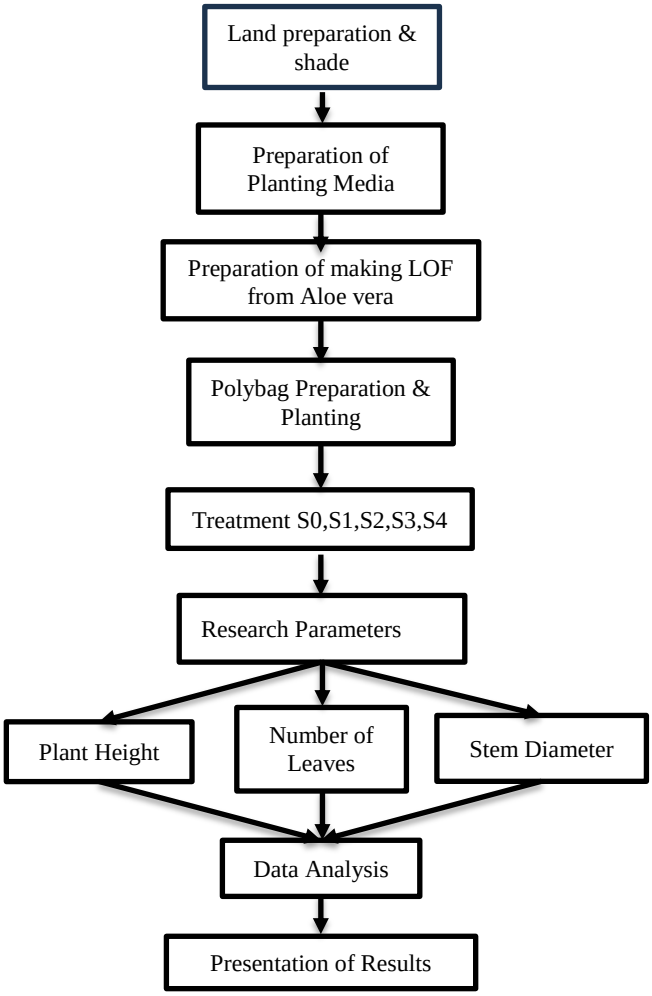


Figure 1. Diagram of This Research

Table 1 . Analysis Test Correlation

No.	Correlation value	Information
1	0	No relationship is observed between the two variables.
2	> 0 – 0.25	The relationship between variables is categorized as very weak.
3	> 0.25 – 0.5	The variables show a moderate level of association.
4	> 0.50 – 0.75	A strong relationship exists between the variables.
5	> 0.75 – 0.99	The correlation is considered highly strong.
6	. = 1	A perfectly positive relationship is identified between the variables.
7	. = -1	A perfectly negative relationship is observed between the variables.

Data collected from field observations were first subjected to normality and homogeneity tests. When the data met the assumptions of normal distribution and homogeneity, further analysis was conducted using statistical correlation methods (Abdullah et al., 2025). The quantitative analysis methods used in this research are: normality test: Shapiro-Wilk ($p > 0.05$), Homogeneity test: Leven's test ($p > 0.05$), Correlations analysis: Pearson correlation, and significance level: $\alpha = 0.05$ (two-tailed) (Alharbi, 2022).

3. Results and Discussion

Based on Table 2, the treatment without LOF (Aloe vera) but with 10 g of SP-36 fertilizer showed a very strong correlation (**) with the number of leaf sheaths. These findings indicate that phosphorus P acts as a primary limiting factor in the vegetative development of sugar palm. This nutrient is essential for the formation of new tissues and for energy transfer via ATP, ultimately contributing to increased leaf production. Recent studies have reported that improved phosphorus availability can significantly enhance PH, stem thickness, & chlorophyll content by improving nutrient absorption and stimulating soil microbial activity (Deng et al., 2024). In addition, the use of slow-release phosphate fertilizers has been found to sustain a consistent supply of phosphorus, thereby supporting more stable and continuous vegetative growth (Yu et al., 2025).

The observed strong correlation between PH and NL, along with the very strong relationship with SD, suggests an allometric association among plant organs. From a physiological perspective, increases in PH are closely related to active cell division and elongation, which are accompanied by expansion of leaf area and enhanced photosynthetic capacity. The efficiency of nutrient allocation within plant tissues also influences this relationship. Supporting evidence from recent research published in Scientific Reports in 2025 shows that higher nutrient availability, particularly nitrogen and phosphorus derived from fertilizers, leads to greater leaf biomass, which is directly associated with increases in plant height (Lu et al., 2025).

Similarly, SD exhibited a strong relationship with NL and a very strong association with PH, indicating its role as an important indicator of biomass accumulation and nutrient transport efficiency within the plant. Thicker stems generally possess a more developed vascular system, which facilitates the movement of photosynthates from the leaves to other plant parts. This is consistent with recent findings showing that the combined application of phosphate fertilizers and growth-promoting substances can improve root system architecture, expand leaf area, and increase SD by enhancing phosphorus uptake (Cuesta et al., 2024).

The analysis further revealed that treatments without LOF had a significant effect on NL, while SD significantly influenced PH with a significance value below 0.05. This suggests that, under certain conditions, inorganic fertilizers such as SP-36 may exert a more dominant influence compared to liquid organic inputs. Although an aloe vera-

based LOF contains bioactive compounds such as auxins and cytokinins, its effectiveness largely depends on the availability of essential nutrients in the soil. When phosphorus is sufficiently available, the addition of biostimulants does not necessarily result in a marked increase in growth. Nevertheless, several recent studies indicate that LOF can still contribute to improving overall growth efficiency, including PH, SD, and leaf production, particularly when combined with adequate nutrient supply (Abdullah et al., 2025).

Table 2. CA between P0, NL, PH & SD

Correlations					
		LOF 0 mL (P0)	**NL**	**PH**	**SD**
LOF 0 mL (P0)	PC	1	0.846**	0.658**	0.431
	Sig. (2-tailed)		0.000	0.008	0.109
NL	PC	0.846**	1	0.558*	0.533*
	Sig. (2-tailed)	0,000		0,031	0,041
PH	PC	0.658**	0.558*	1	0.827**
	Sig. (2-tailed)	0,008	0,031		0,000
SD	PC	0,431	0.533*	0.827**	1
	Sig. (2-tailed)	0,109	0,041	0,000	

**. Double asterisks denote that the correlation reaches statistical significance at the 0.01 level based on a two-tailed test.
*. The correlation is considered statistically significant at the 0.05 level based on a two-tailed test.
PC. Pearson Correlation

Table 3. CA between P1, NL, PH & SD

Correlations					
		LOF 50 mL (P1)	**NL**	**PH**	**SD**
LOF 50 mL (P1)	PC	1	0.287	0,177	0.101
	Sig. (2-tailed)		0.299	0.528	0.721
NL	PC	0.287	1	0.685**	0.702**
	Sig. (2-tailed)	0.299		0.005	0.004
PH	PC	0.177	0.685**	1	0.787**
	Sig. (2-tailed)	0.528	0.005		0.001
SD	PC	0.101	0.702**	0.787**	1
	Sig. (2-tailed)	0.721	0.004	0.001	

**. Double asterisks denote that the correlation reaches statistical significance at the 0.01 level based on a two-tailed test.

Referring to Table 3, the treatment combining 50 mL of aloe vera-based LOF with 10 g of SP-36 fertilizer exhibited a very strong correlation between the number of fronds and both PH & SD of sugar palm (*Arenga pinnata*). This finding suggests a synergistic interaction between liquid organic inputs and phosphorus in promoting vegetative development. Phosphorus is essential for energy transfer and tissue formation, while LOF acts as a biostimulant that enhances nutrient uptake efficiency. Recent studies have demonstrated that the application of phosphorus can significantly improve PH, SD, and total biomass through increased photosynthetic performance and metabolic activity (Deng et al., 2024).

The very strong relationship observed between PH & SD reflects a close physiological connection in plant growth. PH is associated with vertical growth driven by apical meristem activity, whereas SD represents secondary growth and biomass accumulation. These two variables tend to develop concurrently as they are both influenced by nutrient availability and photosynthetic processes. Supporting evidence indicates that fertilization using NPK, particularly phosphorus, has a significant effect on PH, SD, & NL simultaneously due to enhanced metabolic processes within the plant (Mohammed et al., 2024).

In addition, the strong association between the NL and both PH and SD indicates that increased leaf production directly contributes to higher photosynthetic capacity and biomass accumulation. As leaves function as the primary sites of photosynthesis, an increase in leaf sheath number enhances the plant's ability to support both vertical growth and stem development. Recent findings also confirm that phosphorus application can significantly increase leaf number and leaf area, thereby improving overall photosynthetic efficiency (Ali et al., 2025).

Moreover, the significant influence of SD on both leaf sheath number and plant height (p-values < 0.05) suggests that stem diameter can serve as a reliable indicator of plant vigour. Larger stem size reflects a more developed vascular system, which facilitates the efficient transport of water, nutrients, and photosynthates throughout the plant. Previous research has shown that increases in stem diameter are closely linked to higher nutrient availability and greater physiological activity, particularly following the application of LOF that supply nutrients in forms

readily accessible to plants (Wulandari, 2023).

Furthermore, the combined use of LOF and inorganic inputs, such as SP-36, has been shown to strengthen relationships among plant growth parameters. This effect is attributed to the role of LOF in enhancing soil microbial activity and nutrient availability, while inorganic fertilizers directly supply essential nutrients required for growth. Recent studies indicate that integrated nutrient management approaches that combine organic & inorganic fertilizers result in stronger correlations among variables such as PH, NL, & SD compared to the application of a single fertilizer source (Liu et al., 2024).

The findings of this study are consistent with those reported by Ali et al. (2025), who observed that phosphorus fertilization significantly improved leaf development and biomass accumulation in several tropical crops. Similarly, Liu et al. (2024) demonstrated that integrated organic and inorganic fertilization strengthened the relationships among vegetative growth parameters through improved nutrient availability and soil microbial activity. However, the present study specifically contributes new evidence regarding the use of Aloe vera-based LOF in sugar palm seedlings, which remains rarely investigated.

Table 4. CA between P2, NL, PH & SD

Correlations					
		LOF 100 mL (P2)	**NL**	**PH**	**SD**
LOF 100 mL (P2)	PC	1	0.695**	0.623*	0.515*
	Sig. (2-tailed)		0.004	0.013	0.049
NL	PC	0.695**	1	0.597*	0.658**
	Sig. (2-tailed)	0.004		0.019	0.008
PH	PC	0.623*	0.597*	1	-0.018
	Sig. (2-tailed)	0.013	0.019		0.949
SD	PC	0.515*	0.658**	-0.018	1
	Sig. (2-tailed)	0.049	0.008	0.949	

**. Double asterisks denote that the correlation reaches statistical significance at the 0.01 level based on a two-tailed test.
*. The correlation is considered statistically significant at the 0.05 level based on a two-tailed test.

Referring to Table 4, the treatment combining 100 mL of aloe vera-based LOF with 10 g of SP-36 fertilizer resulted in a very strong correlation between the number of leaf sheaths and a strong association with both PH & SD of sugar palm (*Arenga pinnata*). This finding suggests that a higher dose of LOF can intensify the physiological interactions among vegetative plant organs. In this context, liquid organic fertilizer functions as a biostimulant that enhances soil microbial activity and nutrient availability, thereby promoting leaf development as the main organ responsible for photosynthesis. Previous studies have reported that the application of N, P, & K fertilizers significantly improves vegetative growth, including leaf number, PH, & SD, through increased nutrient uptake efficiency and microbial activity in the soil (Fang et al., 2023).

The strong relationship between leaf sheath number and PH indicates that leaf development directly supports vertical growth. An increase in leaf number increases photosynthetic capacity, which in turn facilitates stem elongation. Empirical evidence shows that phosphorus fertilisation can increase leaf production, which is closely associated with higher PH levels due to its involvement in energy metabolism and the formation of new tissues (Khoso et al., 2024).

In addition, the very strong association between leaf sheath number and SD suggests that an expanded photosynthetic surface contributes significantly to biomass accumulation in the stem. SD is closely related to the development of vascular tissues that regulate the transport of water and photosynthates. Supporting research indicates that the combined application of phosphorus and other nutrients can significantly increase stem thickness and total plant biomass by improving the distribution of assimilates within the plant (Choudhary et al., 2022).

The strong interrelationship among leaf sheath number, PH, & SD also reflects an allometric pattern in plant growth. This is consistent with findings that these growth parameters are closely interconnected, as they are influenced by shared physiological processes and nutrient availability (Kamel et al., 2025).

Furthermore, the application of LOF at a dose of 100 mL appears to strengthen the relationships among growth variables by enhancing nutrient uptake efficiency and overall physiological activity. LOF are known to improve the availability of both macro and micronutrients while also enhancing soil physical properties, which collectively accelerate vegetative growth. This is supported by previous studies showing that balanced soil nutrient conditions are closely associated with plant growth and yield components, as indicated by positive correlations among growth parameters (Syamsiyah et al., 2024).

Based on Table 5, the combination treatment of 150 mL of Aloe vera LOF with 10 g of SP-36 fertilizer showed a strong correlation (*) with the number of leaf sheaths. This indicates that increasing the dosage of LOF does not always provide a linear growth response, as high doses can decrease nutrient utilization efficiency. Nutrient imbalances

at high doses can reduce the effectiveness of plant vegetative growth (Detti *et al*., 2024).

Table 5. CA between P3, NL, PH & SD

Correlations					
		LOF 150 mL (P3)	**NL**	**PH**	**SD**
LOF 150 mL (P3)	PC	1	0.527*	0.398	0.295
	Sig. (2-tailed)		0.043	0.142	0.286
NL	PC	0.527*	1	0.841**	0.464
	Sig. (2-tailed)	0.043		0.001	0.082
PH	PC	0.398	0.841**	1	0.757**
	Sig. (2-tailed)	0.142	0.001		0.001
SD	PC	0.295	0.464	0.757**	1
	Sig. (2-tailed)	0.286	0.082	0.001	

**. Double asterisks denote that the correlation reaches statistical significance at the 0.01 level based on a two-tailed test.
*. The correlation is considered statistically significant at the 0.05 level based on a two-tailed test.

The strong relationship between the number of leaf sheaths & the height of sugar palm (*Arenga pinnata*) suggests that leaves play a central role in driving vegetative development. As the primary sites of photosynthesis, leaves produce assimilates that support stem elongation. An increase in leaf number is directly associated with greater photosynthetic capacity, which in turn promotes overall plant growth. This observation is consistent with findings indicating that leaf physiological traits are closely linked to plant growth performance and biomass accumulation (Shi et al., 2025).

In addition, the strong association between PH and SD reflects an allometric relationship between primary and secondary growth processes. PH represents vertical or longitudinal growth, whereas SD indicates biomass accumulation and structural development. These two parameters tend to increase concurrently due to efficient allocation and transport of photosynthates within the plant (Liu et al., 2024).

The statistically significant influence of leaf sheath number on PH with a significance level below 0.05 further confirms the dominant role of leaves in regulating plant growth. A higher number of leaves enhances light interception and photosynthetic activity, thereby accelerating vertical growth. This is supported by previous research demonstrating a close relationship between leaf physiological activity and the enhancement of vegetative growth (Zhang et al., 2023).

Moreover, the significant effect of PH on SD indicates a functional linkage between vertical growth and stem thickening. As plants grow taller, the demand for water and nutrient transport increases, leading to the development of a thicker stem as both a structural and physiological adaptation. This pattern aligns with studies showing that increases in PH & SD occur in a coordinated manner under conditions of adequate nutrient availability (García et al., 2023). Unlike previous studies that reported linear increases in plant growth with higher fertilizer doses, the present findings indicate that excessive LOF application may reduce nutrient utilization efficiency. This result supports the findings of Detti et al. (2024), who reported that excessive nutrient concentrations can negatively affect physiological balance and vegetative development.

Referring to Table 6, the treatment combining 200 mL of aloe vera-based LOF with 10 g of SP-36 fertilizer resulted in a strong association with both plant height and SD of sugar palm (*Arenga pinnata*). This finding suggests that although increasing fertilizer dosage continues to influence vegetative growth, the response does not reach its maximum due to limitations in nutrient use efficiency. Such a pattern is consistent with the concept that plant responses to fertilization are not linear but instead approach an optimum level (Li et al., 2020).

Table 6. CA between P4, NL, PH & SD

Correlations					
		LOF 200 mL (P4)	**NL**	**PH**	**SD**
LOF 200 mL (P4)	PC	1	0.341	0.589*	0.519*
	Sig. (2-tailed)		0.213	0.021	0.048
NL	PC	0.341	1	0.355	0.844**
	Sig. (2-tailed)	0.213		0.194	0.001
PH	Pearson Correlation	0.589*	0.355	1	0.355
	Sig. (2-tailed)	0.021	0.194		0.222
SD	PC	0.519*	0.844**	0.335	1
	Sig. (2-tailed)	0.048	0.001	0.222	

**. Double asterisks denote that the correlation reaches statistical significance at the 0.01 level based on a two-tailed test.
*. The correlation is considered statistically significant at the 0.05 level based on a two-tailed test.

The strong relationship between leaf sheath number & SD indicates that leaves are the primary source of photosynthates required for stem development. A greater number of leaves enhances photosynthetic capacity, which ultimately contributes to increased biomass production. Previous studies have demonstrated that leaf characteristics and photosynthetic performance are closely linked to plant growth and biomass accumulation (Poorter et al., 2019).

The statistically significant effect of leaf sheath number on SD ($p < 0.05$) further indicates a direct relationship between these two variables. Leaves produce photosynthates that are subsequently used to form structural components, including the stem. Empirical evidence shows that an increase in leaf area leads to higher photosynthetic rates and improved plant growth (Sun et al., 2023). In addition, the strong association between plant height and stem diameter reflects an allometric relationship between primary and secondary growth processes. As plants grow taller, they require greater structural support, which is reflected in increased SD. This observation is in line with findings that plant height and stem thickness tend to develop in a coordinated manner in response to environmental and nutritional factors (St Pierre et al., 2023).

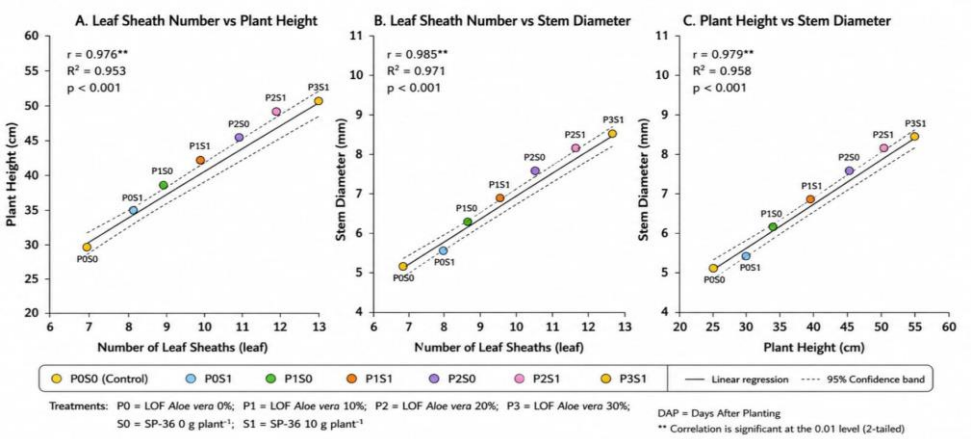
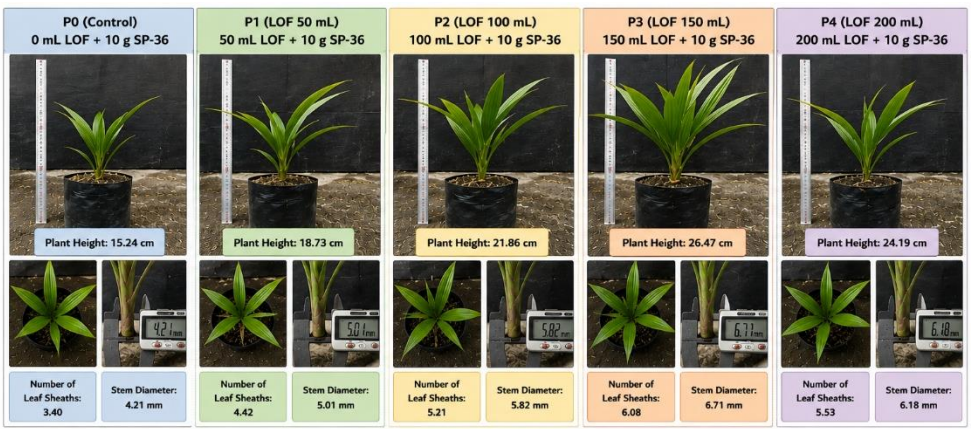


Figure 2. Scatter plots showing the relationships among leaf sheath number, plant height, and stem diameter of sugar palm seedlings under different fertilization treatments.



Parameters	P0 (Control) 0 mL LOF + 10 g SP-36	P1 (LOF 50 mL) 50 mL LOF + 10 g SP-36	P2 (LOF 100 mL) 100 mL LOF + 10 g SP-36	P3 (LOF 150 mL) 150 mL LOF + 10 g SP-36	P4 (LOF 200 mL) 200 mL LOF + 10 g SP-36
Plant Height (cm)	15.24 ± 0.61	18.73 ± 0.58	21.86 ± 0.67	**26.47 ± 0.71**	24.19 ± 0.65
Number of Leaf Sheaths (sheaths)	3.40 ± 0.15	4.42 ± 0.18	5.21 ± 0.19	**6.08 ± 0.20**	5.53 ± 0.17
Stem Diameter (mm)	4.21 ± 0.18	5.01 ± 0.20	5.82 ± 0.22	**6,71 ± 0,23**	6.18 ± 0.21
Overall Performance	Low	Moderate	Good	**Very Good**	Good

Note: Treatment P3 (LOF 150 mL + 10 g SP-36) produced the best results for all growth parameters of sugar palm seedlings at 60 days after planting (DAP).

Figure 3. Comparison of results for each treatment on Sugar Palm (*Arenga pinnata*) seedlings at 60 DAP

4. Conclusion

The results of this study indicate that the combined application of aloe vera-based LOF and SP-36 fertilizer significantly influences the vegetative growth of sugar palm (*Arenga pinnata*), as reflected in the strong relationships observed among growth parameters. The number of leaf sheaths, plant height, and stem diameter are closely interconnected, with an increase in leaf sheath

number directly contributing to greater plant height and stem diameter through enhanced photosynthetic activity and biomass accumulation. Although increasing the dose of liquid organic fertilizer can stimulate plant growth up to a certain point, it does not consistently strengthen correlations among all variables, suggesting the presence of an optimal threshold in nutrient utilization by the plant. The significant relationships observed between leaf sheath number and both PH & SD, as well as between PH & SD, further confirm the existence of physiological and structural linkages in the growth dynamics of sugar palm. Overall, the integration of aloe vera-based LOF with SP-36 fertilizer demonstrates considerable potential as an effective approach to promote vegetative growth, particularly during the early stages of development. Consequently, this study provides valuable insights to advance more efficient and sustainable sugar palm cultivation practices.

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