International Journal of Agriculture and Biosciences 2025 14(3): 507-517.
https://doi.org/10.47278/journal.ijab/2025.037

RESEARCH ARTICLE
eISSN: 2306-3599; pISSN: 2305-6622

Predictive Modelling of Coconut (*Cocos nucifera L)* Growth Parameters Using Linear Regression: Insights into Stem Diameter, Height and Chlorophyll Content

Ahmad Syafik Suraidi Sulaiman [1,2], Aimrun Wayayok [1,3], Wong Mui Yun [3] and Guo Leifeng [4]

[1]SMART Farming Technology Research Centre (SFTRC), Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia
[2]Smart and Precision Agriculture Programme, Engineering Research Centre, MARDI Headquarters Serdang, 43400 Selangor, Malaysia
[3]Institute of Plantation Studies (IKP), Jalan Maklumat, Serdang, 43400 Seri Kembangan, Selangor, Malaysia
[4]Agricultural Information Institute, Chinese Academy of Agricultural Science (CAAS). No.12, Zhongguancun South Street, Beijing 100081, P.R. China
*Corresponding author: syafiks@gmail.com

ABSTRACT

This study developed a linear regression model to predict stem diameter (D), height (H), and chlorophyll content (SPAD) in coconut plants based on environmental and treatment factors. Conducted over two cultivation seasons (January–June and July–December 2023) at the Faculty of Engineering, Universiti Putra Malaysia, the experiment employed a specific growing media (M3) comprising 50% soil, 30% cocopeat, and 20% perlite. Predictor variables included time (W), nitrogen (N), potassium (K), moisture content (MC), wind speed (WS), and electrical conductivity (EC). The regression analysis indicated that time (W) positively influenced stem diameter (0.3875) and height (0.3329), with nitrogen (N) also contributing positively to diameter (0.08827). In contrast, potassium (K) negatively impacted stem diameter (-0.03461) and height (-0.0505), as did moisture content (-0.01561) and wind speed (-0.3872). For chlorophyll content, time (W) (2.399) and electrical conductivity (EC) (0.0193) were positive predictors, while potassium (-0.3063) and wind speed (-3.416) had negative effects. ANOVA confirmed the significance of time, potassium, moisture content, and wind speed on growth parameters. Time was identified as a critical factor for coconut development, underscoring the importance of managing these variables to optimize growth and chlorophyll content. These findings provide valuable insights for enhancing coconut cultivation strategies.

Keywords: Coconut growth; Linear regression; Stem diameter; Height, Chlorophyll content; Environmental factors.

Article History
Article # 24-897
Received: 15-Oct-24
Revised: 04-Nov-24
Accepted: 23-Nov-24
Online First: 17-Mar-25

INTRODUCTION

Coconut (*Cocos nucifera* L.) holds significant economic and cultural value in tropical regions, supporting diverse industries through its products such as coconut oil, water, milk, and coir. As global demand for coconut-based products continues to rise, sustainable and optimized cultivation practices are essential for enhancing productivity and supporting the economies of developing nations (Nampoothiri et al., 2018). However, efficient cultivation of coconut requires a deep understanding of various growth parameters and their response to environmental and agronomic inputs. Recent studies highlight that plant growth metrics, including stem diameter, height, and chlorophyll content, are essential indicators of plant health, providing insights into the coconut's physiological status and productivity potential (Zhang et al., 2022).

Stem diameter and height are commonly used measures to assess coconut plants' vigor and structural robustness, which are crucial for supporting heavy fruit loads. Stem diameter has been correlated with overall biomass and resilience to environmental stresses, while stem height reflects the plants vegetative and reproductive

Cite this Article as: Sulaiman ASS, Wayayok A, Yun WM and Leifeng G, 2025. Predictive modelling of coconut (*Cocos nucifera* L) growth parameters using linear regression: Insights into stem diameter, height, and chlorophyll content. International Journal of Agriculture and Biosciences 14(3): 507-517. https://doi.org/10.47278/journal.ijab/2025.037

A Publication of Unique Scientific Publishers

development (Niklas, 2007). Chlorophyll content, often measured via SPAD values, serves as an indicator of photosynthetic efficiency and nutrient availability, which are essential for optimizing growth and yield in coconut cultivation (Paul et al., 2017).

Growing media composition plays a crucial role in supporting coconut plant health by influencing root structure, water retention, and nutrient availability. Various media components, such as cocopeat and perlite, offer distinct advantages: cocopeat is known for its excellent water-holding capacity, which is beneficial in tropical climates, while perlite promotes aeration and drainage, reducing the risk of root diseases (Gruda, 2019). This study specifically examines a growing media mixture of 50% soil, 30% cocopeat, and 20% perlite, assessing its influence on coconut growth parameters. Previous research has demonstrated that cocopeat-perlite mixtures can significantly enhance root proliferation and water retention (Arumugam & Hatta 2022), suggesting a potential for optimizing this combination for coconut nursery stages.

Fertigation, a method of delivering nutrients through irrigation, has gained attention in coconut cultivation for its efficiency in providing precise nutrient doses. Proper fertigation rates are essential to ensure adequate nutrient supply without causing nutrient leaching or environmental degradation (Patel & Rajput, 2000). Studies on fertigation in other crops have demonstrated that controlled nutrient delivery can significantly enhance growth parameters, making it a promising approach for coconut cultivation as well (Easwaran et al., 2024). This study evaluates different fertigation rates, aiming to identify the optimal rate that promotes healthy growth without over-fertilizing the plants.

Environmental conditions, such as temperature, relative humidity, light intensity, and wind speed, are key factors influencing coconut growth and productivity. These conditions affect physiological processes including photosynthesis, transpiration, and nutrient uptake, which are fundamental for healthy coconut development (Khairi & Hall 2006). For instance, temperature and humidity have been shown to impact transpiration rates, while wind speed can increase evapotranspiration, thereby influencing water demand and nutrient dynamics (Raza et al., 2023). By understanding these relationships, this study aims to recommend management practices that mitigate environmental stresses in coconut nurseries.

In addition, soil characteristics such as nutrient content, pH, moisture content, and electrical conductivity (EC) are critical for coconut growth. Soil nutrient levels, particularly nitrogen (N), phosphorus (P), and potassium (K), directly impact photosynthetic and metabolic activities in coconut plants (Rawat et al., 2016). Soil pH affects nutrient availability, while EC can indicate soil salinity levels, which may hinder nutrient uptake. Studies have shown that optimizing these soil parameters can improve plant health and yield (Malhotra et al., 2017), highlighting the importance of soil management practices in coconut cultivation.

Effective irrigation management is essential for sustainable agriculture, particularly during the nursery phase of coconut cultivation, where plants are vulnerable to water stress. To improve water use efficiency, this study develops a precise irrigation algorithm based on environmental data, soil conditions, and plant growth stages. Advanced data processing techniques, including linear regression modelling, are utilized to predict optimal irrigation scheduling, thus enhancing water resource management in coconut nurseries (Zhao et al., 2024). Previous research has demonstrated the benefits of data-driven irrigation systems in reducing water usage and maximizing plant productivity (Chen et al., 2023).

This study aims to (1) investigate the effects of a specific growing media composition (50% soil, 30% cocopeat, 20% perlite) on coconut growth parameters (stem diameter, height, and chlorophyll content), (2) evaluate the impact of various fertigation rates on these growth parameters, (3) assess the influence of environmental factors such as temperature, relative humidity, light intensity, and wind speed on coconut growth, and (4) examine the effects of soil properties (nutrient content, pH, moisture content, EC) on coconut growth. Based on the findings, this study will offer insights and recommendations for optimizing coconut cultivation practices in tropical nursery settings.

MATERIALS & METHODS

The methodology begins with defining key parameters influencing water requirements: environmental conditions (temperature, relative humidity, light intensity, wind speed) as identified by Khalili et al. (2024), soil parameters (nutrients, temperature, moisture content, electrical conductivity, pH) as detailed by Ratshiedana et al. (2023), and crop growth parameters (diameter, height, SPAD) as highlighted by Kumar et al. (2022). Data pre-processing involves normalizing data and handling outliers to ensure robust model performance. Feature selection identifies critical variables using statistical methods or machine learning techniques.

This study employs linear regression models to analyze the factors influencing coconut growth parameters. The experimental design includes the use of growing media treatment M3 (50% soil, 30% cocopeat, 20% perlite), varying fertigation rates, and the measurement of environmental factors (temperature, relative humidity, light intensity, wind speed) as outlined by Fazlil Ilahi and Ahmad (2017), and soil properties (nitrogen, phosphorus, potassium, pH, moisture content, electrical conductivity) as discussed by Mihoc et al. (2016). Data will be collected over a specified period, and statistical analyses will be conducted to determine the significance of each factor on stem diameter, stem height, and chlorophyll content, aligning with methods established by Sid'ko et al. (2017).

Study Site and Experimental Design

The experiment was conducted under a rain shelter nursery structure as shown in Fig. 1. It was located at level 3 Faculty of Engineering roof top area, Universiti Putra Malaysia in Serdang, Selangor, Malaysia. The size of the nursery is 5 meters wide, 10 meters long, and 4 meters height. The nursery can accommodate about 50-60 young coconut seedlings depending on how the arrangement in the site. The young coconut seedling was planted in a polybag with a cocopeat and topsoil as the growing media as have been done by Anjarsari et al. (2024). The roof of the nursery is made of a polyethylene sheet and the frame of the nursery is made by a metal frame which is a type of stainless steel. The shading system for the nursery is made by 70 % UV protection netting. The netting is black in color and installed 3 meters above the ground.

Fig. 1: Rain shelter nursery in Faculty Engineering of UPM roof top area.

Plant Material and Growth Conditions

Uniform coconut seedlings (Cocos nucifera L.), six months old, were selected to ensure consistency in size and age. These seedlings were transplanted into 10-liter pots, which were chosen to provide ample space for root development while being manageable for handling and experimentation. The pots were filled with the growing media treatment labelled as M3, composed of 50% soil, 30% cocopeat, and 20% perlite. This specific composition was chosen based on preliminary studies that had identified these proportions as providing optimal growth conditions for coconut seedlings. The combination of soil, cocopeat, and perlite was designed to balance water retention, aeration, and nutrient availability, thus promoting healthy root growth and overall plant development (Awang et al., 2009).

Fertigation and Nutrient Management

Four distinct fertigation rates (Fv) were implemented: 50%, 75%, 100%, and 125% of the recommended dosage specifically formulated for coconut seedlings. The nutrient solution included crucial elements such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), alongside essential micronutrients. Fertigation procedures were carried out twice a week using a drip irrigation system, meticulously applied to ensure uniform nutrient delivery and minimize the risk of nutrient leaching from the soil, as supported by the findings of Wu et al. (2019), which highlight the importance of precision in fertigation practices for optimizing nutrient uptake and enhancing crop growth.

Environmental and Soil Factor Measurements

Environmental factors crucial to plant growth and development, including temperature (Ta), relative humidity (RH), light intensity (LI), and wind speed (WS), were meticulously monitored using automated sensors. These sensors ensured continuous and accurate data collection throughout the study period, enabling a detailed analysis of their impact on coconut growth parameters. This approach is supported by recent findings, which highlight the significance of precise environmental monitoring in optimizing plant growth and resource management (Kumar et al., 2024).

Similarly, soil conditions such as soil temperature (Ts), moisture content (MC), electrical conductivity (EC), and pH were regularly assessed using established soil analysis methods. This consistent monitoring facilitated a comprehensive understanding of how soil factors interacted with environmental variables to influence the growth and physiological responses of coconut plants under varying fertigation treatments, as demonstrated by recent studies that emphasize the importance of integrating soil and environmental data in agricultural research (Balliu et al., 2021).

Data Collection and Growth Parameter Measurements

Fig. 2 shows how to accurately measuring the height and stem diameter of coconut seedlings required specific tools and steps. A ruler and thread were used to ensure precise measurements. First, the ruler was positioned vertically on the soil surface, extending from the top of the soil to the bottom of the last leaf of the seedling, and the height was recorded at 30cm. For the diameter, the thread was wrapped around the base of the coconut trunk, marked where it overlapped, and then laid flat against the ruler to measure the length, which was recorded as 10cm. These steps ensured consistent and accurate measurements of the seedlings growth parameters.

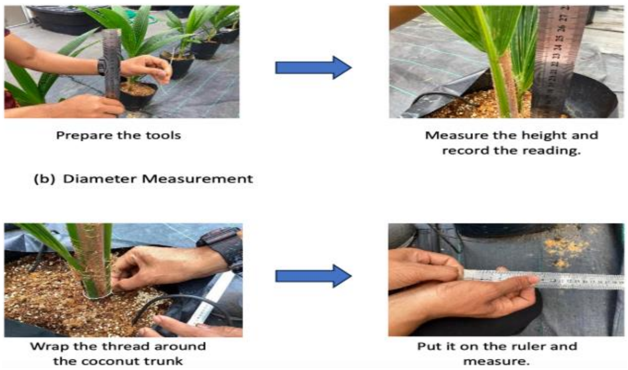

Fig. 2: Coconut stem diameter and height measurement.

For the height measurement, tools including a ruler and thread were prepared. The ruler was placed from the top of the soil to the bottom of the last leaf, and the height was measured and recorded as 30cm as shown in Fig. 3. For the diameter measurement, the thread was wrapped around the coconut trunk at its base, marked, and then placed on the ruler to measure and record a diameter of 10cm.

To measure the chlorophyll content, a SPAD meter was utilized as shown in Fig. 4. Initially, the SPAD meter was turned on and allowed to stabilize. Healthy leaves from the plant were chosen and marked to ensure consistent data collection at the same point on the leaf every week. The SPAD meter was held with the sensor facing the underside of the leaf, and the measurement button was pressed, ensuring good contact with the leaf surface. The data was recorded and the process was repeated for three coconut leaves.

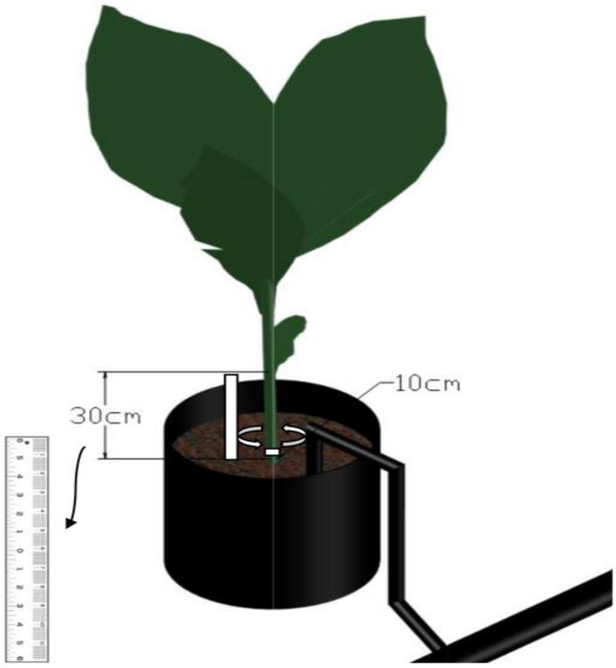

Fig. 3: Coconut height measurement.

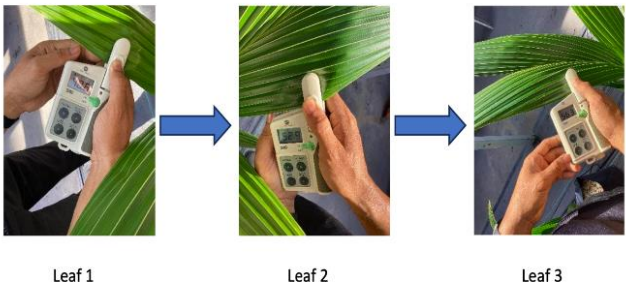

Fig. 4: Measurement of the chlorophyll content.

Statistical Analysis

Data were subjected to linear regression analysis to determine the relationship between the growth parameters (stem diameter, stem height, chlorophyll content) and the influencing factors (fertigation rates, environmental factors, soil factors). The statistical software used was R version 4.0.2 (R Core Team, 2020). To ensure the accuracy and reliability of the data, all measurements were repeated thrice, and the instruments were calibrated before use, as demonstrated in the study by Barradas (2023), which emphasizes the importance of rigorous statistical analysis and data validation in agricultural research.

RESULTS

Linear Regression Model Predicting Coconut Stem Diameter (D), Height (H) and Chlorophyll Content (SPAD)

The linear regression model predicting coconut stem diameter (D), height (H), and chlorophyll content (SPAD) reveals significant insights into the various factors influencing coconut growth (Table 1). For stem diameter (D), the analysis indicates that time (W) has a positive coefficient of 0.3875, suggesting a robust relationship where an increase in time correlates with a significant increase in stem diameter. Furthermore, nitrogen (N) positively impacts stem growth, indicated by a coefficient of 0.08827, which suggests that higher nitrogen levels are associated with increased stem diameter.

Table 1: Coconut stem diameter, D regression model coefficients estimates for all factors

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	7.800×10^{0}	5.488×10^{0}	1.421	0.162
F_v	1.256×10^{-2}	3.172×10^{-2}	0.396	0.693
W	3.875×10^{-1}	3.049×10^{-2}	12.707	$< 2 \times 10^{-16}$***
N	8.827×10^{-2}	3.829×10^{-2}	2.305	0.025 *
P	-5.798×10^{-3}	2.217×10^{-2}	-0.262	0.794
K	-3.461×10^{-2}	1.089×10^{-2}	-3.178	0.003 **
T_s	-6.233×10^{-2}	4.786×10^{-2}	-1.302	0.199
MC	-1.561×10^{-2}	6.237×10^{-3}	-2.503	0.016 *
EC	4.230×10^{-4}	9.765×10^{-4}	0.433	0.667
pH	4.935×10^{-1}	6.145×10^{-1}	0.803	0.426
T_a	-1.138×10^{-2}	9.134×10^{-2}	-0.125	0.901
RH	-1.215×10^{-2}	1.867×10^{-2}	-0.651	0.518
LI	7.452×10^{-6}	7.771×10^{-6}	0.959	0.342
WS	-3.872×10^{-1}	1.039×10^{-1}	-3.726	0.00054 ***

In contrast, potassium (K) presents a negative coefficient of -0.03461, implying that elevated potassium levels are linked to a decrease in stem diameter, highlighting the necessity for careful potassium management. Moisture content (MC) also demonstrates a negative correlation, with a coefficient of -0.01561, indicating that increased moisture content is associated with reduced stem diameter. Wind speed (WS) negatively affects stem diameter significantly, with a coefficient of -0.3872, underlining the importance of mitigating wind stress for optimal coconut growth.

These findings emphasize the intricate interplay between environmental factors and nutrient management in coconut cultivation. By managing variables such as time, nitrogen, potassium, moisture content, and wind speed, growers can optimize conditions to foster healthier stem development and enhance overall plant growth.

The linear regression model is expressed as:

$$D=7.8x10+(1.26x10^{-2}.\ F_v)+ (3.88x10^{-1}.W) + (8.83x10^{-2}.N) \quad \text{equation 1}$$
$$- (5.8x10^{-3}.P) - (3.46x10^{-2}.K) - (6.2x10^{-2}.T_s) - (1.56x10_{-2}.MC) +$$
$$(4.23x10^{-4}.EC) + (4.94x10^{-1}.pH) - (1.14x10^{-2}.T_a) - (1.22x10^{-2}.RH)$$
$$+ (7.45x10^{-6}.LI) - (3.87x10^{-1}.WS)$$

The analysis of variance (ANOVA) for the linear regression model predicting stem diameter (D), as shown in Table 2, provides critical insights into the significance of various factors. The variable representing time in weeks (W) shows an exceptionally high F value of 275.35, with a p-value of less than 2.2×10^{-16}, indicating a significant impact on stem diameter. This underscores the substantial influence of time on stem growth. Additionally, factors such as fertilizer (Fv), potassium (K), moisture content (MC), and wind speed (WS) exhibit significant effects on stem diameter, as indicated by their low P-values ($P<0.01$).

Table 2: ANOVA for linear regression model predicting stem diameter, D

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
F_v	1	4.172	4.172	15.019	0.00034 ***
W	1	76.483	76.483	275.35	< $2.2x10^{-16}$***
N	1	0.006	0.006	0.0211	0.88507
P	1	0.151	0.151	0.5444	0.46446
K	1	2.682	2.682	9.6556	0.003 **
T_s	1	0.107	0.107	0.3845	0.5383
MC	1	2.374	2.374	8.5467	0.0054 **
EC	1	0.001	0.001	0.0044	0.94766
pH	1	0.810	0.810	2.9155	0.0946
T_a	1	0.561	0.561	2.0208	0.16205
RH	1	0.029	0.029	0.1052	0.74715
LI	1	0.074	0.074	0.2661	0.60848
WS	1	3.857	3.857	13.8848	0.00054 ***
Residuals	45	12.499	0.278		

In contrast, nitrogen (N), phosphorus (P), soil temperature (Ts), electrical conductivity (EC), soil pH (PH), ambient temperature (Ta), relative humidity (RH), and light intensity (LI) do not show statistically significant impacts on stem diameter, as evidenced by their higher p-values. The overall model's significance ($P<0.001$) underscores the importance of specific factors, particularly time, in predicting coconut stem diameter.

The regression model coefficients for coconut stem height (H), as outlined in Table 3, provide valuable insights into the significant factors influencing stem height development. Notably, time in weeks (W) demonstrates a robust positive effect, with a coefficient estimate of 0.3329, accompanied by a t-value of 5.491 and a highly significant p-value of 1.77x10^-6. This underscores the substantial association of time with stem height, indicating that as the duration of growth increases, stem height also tends to increase significantly.

Table 3: Coconut stem height, H regression model coefficients estimates for all factors

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	$1.340x10^{1}$	$1.091ex10^{1}$	1.229	0.22560
F_v	$6.218x10^{-1}$	$6.307x10^{-2}$	9.858	$8.13x10^{-13}$***
W	$3.329x10^{-1}$	$6.063x10^{-2}$	5.491	$1.77x10^{-6}$***
N	$1.127x10^{-1}$	$7.613x10^{-2}$	1.480	0.146
P	$-3.580x10^{-3}$	$4.407x10^{-2}$	-0.081	0.936
K	$-5.050x10^{-2}$	$2.165x10^{-2}$	-2.332	0.0242 *
T_s	$-1.272x10^{-1}$	$9.516x10^{-2}$	-1.337	0.188
MC	$-3.843x10^{-3}$	$1.240x10^{-2}$	-0.310	0.758
EC	$-4.318x10^{-4}$	$1.942x10^{-3}$	-0.222	0.825
pH	$2.120x10^{0}$	$1.222x10^{0}$	1.735	0.089
T_a	$-1.687x10^{-1}$	$1.816x10^{-1}$	-0.929	0.357
RH	$-3.033x10^{-2}$	$3.713x10^{-2}$	-0.817	0.418
LI	$1.991x10^{-5}$	$1.545x10^{-5}$	1.288	0.204
WS	$6.455x10^{-1}$	$2.066x10^{-1}$	3.124	0.003 **

Fertigation rates (Fv) are another key contributor to stem height, with a coefficient estimate of 0.62 and a p-value of 8.13x10^-13, highlighting the importance of appropriate nutrient application in promoting growth. Interestingly, potassium (K) reveals a negative influence on stem height, with a coefficient estimate of -0.05. This suggests that higher levels of potassium may be associated with a decrease in stem height, warranting further investigation into its optimal levels for coconut growth. Wind speed (WS) is identified as a significant positive factor, with a coefficient estimate of 0.6455, a t-value of 3.124, and a p-value of 0.00312. This indicates that increased wind speed may positively influence stem height, potentially by promoting stronger growth or reducing competition.

Conversely, other factors such as nitrogen (N), phosphorus (P), soil temperature (Ts), moisture content (MC), electrical conductivity (EC), soil pH (PH), ambient temperature (Ta), relative humidity (RH), and light intensity (LI) do not exhibit statistically significant impacts on stem height, as reflected by their higher p-values. These findings highlight the critical roles of time, fertilizer application, potassium, and wind speed in influencing coconut stem height, providing essential knowledge for optimizing cultivation practices to enhance growth and productivity.
The linear regression model is expressed as:

$$H = 1.340\times10^{1} + (6.218\times10^{-1}.F_v) + (3.329\times10^{-1}.W) + (1.127\times10^{-1}.N) \quad \text{equation 2}$$
$$-(3.580\times10^{-3}.P) - (5.050\times10^{-2}.K) - (1.272\times10^{-1}.T_s) - (3.843\times10^{-3}.MC) - (4.318\times10^{-4}.EC) + (2.120\times10^{2}.pH) - (1.687\times10^{-1}.T_a) - (3.033\times10^{-2}.RH) + (1.991\times10^{-5}.LI) + (6.455\times10^{-1}.WS)$$

The ANOVA results presented in Table 4 reveal the significant factors affecting coconut stem height, emphasizing the importance of specific agronomic practices and environmental conditions. The analysis indicates that fertilizer application (Fv), time in weeks (W), and nitrogen (N) have highly significant effects on stem height, evidenced by their substantial F-values of 72.64, 100.004, and 33.27, respectively. The associated p-values for these factors are extremely low, at 6.049x10^-11 for Fv, 5.197x10^-13 for W, and 6.895x10^-7 for N. This highlights the critical role that these variables play in promoting stem growth in coconut plants.

Table 4: ANOVA for linear regression model predicting height, H

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Fv	1	79.762	79.762 7	2.642	$6.049x10^{-11}$ ***
W	1	109.806	109.806	100	$5.197x10^{-13}$***
N	1	36.529	36.529	33.268	$6.895x10^{-7}$ ***
P	1	0.406	0.406	0.369	0.546
K	1	6.937	6.937	6.318	0.016 *
T_s	1	4.104	4.104	3.737	0.059
MC	1	0.633	0.633	0.577	0.452
EC	1	0.068	0.068	0.062	0.804
pH	1	0.537	0.537	0.488	0.488
T_a	1	1.095	1.095	0.998	0.323
RH	1	2.843	2.843	2.589	0.114
LI	1	3.081	3.081	2.806	0.100
WS	1	10.715	10.715	9.758	0.00312 **
Residuals	45	49.410	1.098		

Additionally, potassium (K) is also found to significantly influence stem height, with an F-value of 6.3177 and a p-value of 0.0156, indicating that elevated potassium levels can contribute positively to stem height development.

In contrast, other factors such as phosphorus (P), soil temperature (Ts), moisture content (MC), electrical conductivity (EC), soil pH (pH), ambient temperature (Ta), relative humidity (RH), and light intensity (LI) do not demonstrate statistically significant effects on stem height, as reflected by their higher p-values. This suggests that while these soil and environmental conditions may have some influence on coconut stem growth, their impact is less pronounced compared to that of fertilizer, time, and nitrogen.

Understanding the significance of these key factors and their interactions is essential for optimizing coconut cultivation practices. By focusing on enhancing fertilizer application, managing nitrogen levels, and considering the timing of interventions, growers can potentially improve coconut growth and productivity, leading to more successful cultivation outcomes.

Table 5 presents the coefficient estimates from the regression model analyzing coconut chlorophyll content, measured by SPAD values. The findings reveal significant factors influencing chlorophyll levels, highlighting both positive and negative correlations.

Table 5: Coconut chlorophyl content, SPAD regression model coefficients estimates for all factors

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	$1.024x10^{2}$	$5.239x10^{1}$	1.955	0.057
F_v	$-5.622x10^{-1}$	$3.028x10^{-1}$	-1.856	0.069
W	$2.399x10^{0}$	$2.911x10^{-1}$	8.240	$1.54x\ 10^{-10}$***
N	$5.597x10^{-1}$	$3.655x10^{-1}$	1.531	0.133
P	$1.453x10^{-2}$	$2.116x10^{-1}$	0.069	0.946
K	$-3.063x10^{-1}$	$1.040x10^{-1}$	-2.946	0.005 **
T_s	$-8.678x10^{-1}$	$4.569x10^{-1}$	-1.899	0.064
MC	$-9.274x10^{-2}$	$5.954x10^{-2}$	-1.557	0.126
EC	$1.930x10^{-2}$	$9.322x10^{-3}$	2.070	0.044 *
pH	$-5.775x10^{0}$	$5.867x10^{0}$	-0.984	0.330
T_a	$-2.221x10^{-1}$	$8.720x10^{-1}$	-0.255	0.800
RH	$1.172x10^{-3}$	$1.783x10^{-1}$	0.007	0.995
LI	$-7.746x10^{-5}$	$7.419x10^{-5}$	-1.044	0.302
WS	$-3.416x10^{0}$	$9.921x10^{-1}$	-3.443	0.001 **

Time (W) exhibits a pronounced positive effect on chlorophyll content, with a coefficient estimate of 2.399x10, indicating that as time progresses, chlorophyll levels significantly increase. This relationship is statistically robust, as evidenced by a highly significant p-value of 1.54x10^-10, emphasizing the critical role of time in chlorophyll accumulation.

In contrast, potassium (K) displays a notable negative influence, with a coefficient estimate of -3.063x10^-1 and a significant p-value of 0.0051. This suggests that higher potassium levels are associated with reduced chlorophyll content, indicating that potassium may inhibit chlorophyll synthesis or stability.

Electrical conductivity (EC) positively impacts chlorophyll content, supported by a coefficient estimate of 1.930x10^-2 and a p-value of 0.04425. This finding suggests that higher electrical conductivity levels may enhance the conditions for chlorophyll production, possibly through improved nutrient availability or uptake. Wind speed (WS) is also found to have a negative correlation with chlorophyll content, as reflected by a coefficient estimate of -3.416x10 and a significant p-value of 0.00126. This relationship indicates that increased wind speed may be detrimental to chlorophyll levels, potentially due to mechanical stress or other environmental factors affecting leaf physiology. Conversely, other factors including fertilizer (Fv), nitrogen (N), phosphorus (P), soil temperature (Ts), moisture content (MC), soil pH (pH), ambient temperature (Ta), relative humidity (RH), and light intensity (LI) do not demonstrate statistically significant effects on chlorophyll content, as indicated by their higher p-values.

These outcomes underscore the notable influence of time, potassium, electrical conductivity, and wind speed on coconut chlorophyll content. Understanding these factors provides valuable insights into the variability of chlorophyll levels in coconut cultivation, informing strategies for optimizing growth conditions and enhancing overall plant health.

The linear regression model is expressed as:

$$SPAD=1.024\times10^{2}-(5.622\times10^{-1}.F_v)+(2.399\times10^{2}.W)+(5.597\times10^{-1}.N) + (1.453\times10^{-2}.P - (3.063\times10^{-1}.K) - (8.678\times10^{-1}.T_s) - (9.274\times10^{-2}.MC) + (1.930\times10^{-2}.EC) - (5.775\times10^{2}.pH) - (2.221\times10^{-1}.T_a)+(1.172\times10^{-3}.RH)-(7.746\times10-5.LI)- (3.416\times10^{2}.WS) \quad \text{equation 3}$$

Table 6 presents the ANOVA results from the linear regression model assessing coconut chlorophyll content (SPAD). Noteworthy findings include the substantial impact of time (W) on chlorophyll levels, indicated by a high F-value of 96.7669 and an exceptionally low p-value ($8.68x10^{-13}$), underscoring its significant overall influence. Phosphorus (P) and potassium (K) also demonstrate statistically significant effects, with respective F-values of 8.4348 (p-value = 0.005687) and 9.3323 (p-value = 0.003776), emphasizing their meaningful contributions to the model.

Table 6: ANOVA for linear regression model predicting chlorophyl content, SPAD

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
F_v	1	16.83	16.83	0.665.	0.419
W	1	2449.52	2449.52	96.776	$8.68x10^{-13}$***
N	1	0.12	0.12	0.005.	0.946
P	1	213.52	213.52	8.435	0.006 **
K	1	236.23	236.23	9.332	0.004 **
T_s	1	106.10	106.10	4.191	0.047 *
MC	1	177.77	177.77	7.023	0.011 *
EC	1	77.79	77.79	3.073	0.086.
pH	1	0.04	0.04	0.002	0.967
T_a	1	0.42	0.42	0.017	0.897
RH	1	18.81	18.81	0.743	0.393
LI	1	54.52	4.52	2.154	0.149
WS	1	300.04	300.04	11.853	0.001 **
Residuals	45	1139.11	25.31		

These results suggest that variations in phosphorus and potassium levels significantly influence coconut chlorophyll content. Furthermore, wind speed (WS) exerts a notable impact, supported by a high F-value of 11.8530 and a low p-value (0.001255), highlighting its significant role in predicting chlorophyll levels in coconuts. In contrast, factors such as fertilizer (Fv), nitrogen (N), soil temperature (Ts), moisture content (MC), electrical conductivity (EC), soil pH (PH), ambient temperature (Ta), relative humidity (RH), and light intensity (LI) do not demonstrate statistically significant effects on chlorophyll content, as indicated by their higher p-values. These findings underscore the pivotal roles of time, phosphorus, potassium, and wind speed in understanding and predicting variations in coconut chlorophyll content.

Relationship between Fertigation Rates Impact and the Response Variable (D, H, SPAD)

Table 7 displays the coefficients derived from a linear regression model investigating the influence of fertigation rates on coconut stem diameter (D). The intercept exhibits high statistical significance (p-value $<2x10^{-16}$), indicating a significant baseline stem diameter. Fertigation rate (Fv) is associated with a positive coefficient estimate of 0.09458, accompanied by a standard error of 0.02950, a t-value of 3.207, and a p-value of 0.0022. These results suggest that higher fertigation rates significantly increase stem diameter.

Table 7: Coefficients of the linear regression model for stem diameter, D with fertigation rates impact

	Estimate	Std. Error	t value	Pr (>|t|)
(Intercept)	6.953	0.213	32.576	$<2x10^{-16}$***
Fv	0.094	0.029	3.207	0.0022 **
W	0.325	0.0241	13.475	$<2x10^{-16}$***

Moreover, time (W) shows a coefficient estimate of 0.326 with a low standard error (0.0242), a high t-value of 13.475, and an extremely significant p-value ($<2x10^{-16}$), indicating a substantial positive effect of time on stem diameter. These findings underscore the pronounced impacts of both fertigation rates and time in influencing the stem diameter of coconut plants.
The linear regression model is expressed as:

Stem dia, D = 6.953 + 0.095.F_v + 0.326.W equation 4

Table 8 presents the coefficients derived from a linear regression model investigating the effect of fertigation rates on coconut plant height (H). The intercept shows high statistical significance with a p-value less than 2x10-16, indicating a substantial baseline height. Fertigation rate (Fv) is associated with a positive coefficient estimate of 0.39208, a standard error of 0.06596, a t-value of 5.945, and an extremely low p-value of $1.77x10^{-7}$.

Table 8: Coefficients of the linear regression model for height, H with fertigation rates impact

	Estimate	Std. Error	t value	Pr (>|t|)
(Intercept)	16.021	0.477	33.568	$< 2x10^{-16}$***
F_v	0.392	0.065	5.945	$1.77x10^{-7}$***
W	0.399	0.054	7.394	$7.01x10^{-10}$***

These findings suggest that higher fertigation rates significantly contribute to increased coconut plant height. Furthermore, time (W) exhibits a coefficient estimate of 0.39958, with a standard error of 0.05404, a t-value of 7.394, and a highly significant p-value of $7.01x10^{-10}$. This underscores the substantial positive impact of both fertigation rates and time on the height of coconut plants.
The linear regression model is expressed as:

Height, H = 16.021 + 0.392.F_v + 0.34.W equation 5

Table 9 presents the coefficients derived from a linear regression model examining the influence of fertigation rates on chlorophyll content (SPAD) in coconut plants. The intercept demonstrates high statistical significance with a p-value less than $2x10^{-16}$, indicating a substantial baseline chlorophyll content. Regarding fertigation rate (Fv), the coefficient estimate is 0.2208, with a standard error of 0.2957, a t-value of 0.746, and a p-value of 0.458. These results suggest that fertigation rates may not have a statistically significant impact on chlorophyll content in coconut plants.

In contrast, time (W) exhibits a coefficient estimate of 1.8297, a standard error of 0.2423, a t-value of 7.551, and a highly significant p-value of $3.84x10^{-10}$. This highlights a substantial positive association between time and chlorophyll content, underscoring the significant influence of time on chlorophyll levels in coconut plants.
The linear regression model is expressed as:

Chlorophyl content, SPAD = 26.657 + 0.221.F_v + 1.83W equation 6

Relationship between Environment Factor Impact and the Response Variable (D, H, SPAD)

Table 10 displays the coefficients derived from a linear regression model investigating the influence of environmental factors on coconut stem diameter (D). The intercept is statistically significant with a p-value of 0.000855, indicating a baseline effect. Temperature (Ta) shows a positive coefficient estimate of 0.67, a standard error of 0.1495, a t-value of 4.494, and a highly significant p-value of $3.64x10^{-5}$, suggesting that higher temperatures are associated with an increase in coconut stem diameter.

Table 9: Coefficients of the linear regression model for chlorophyl content, SPAD with fertigation rates impact

	Estimate	Std. Error	t value	Pr (>|t|)
(Intercept)	26.65	2.140	12.457	$< 2x10^{-16}$***
F_v	0.2208	0.295	0.746	0.458
W	1.829	0.242	7.551	$3.84x10^{-10}$***

Table 10: Coefficients of the linear regression model for stem diameter, D with environment factor impact

	Estimate	Std. Error	t value	Pr (>|t|)
(Intercept)	$-2.125x10^{1}$	$6.027x10^{-1}$	-3.526	0.000855***
T_a	$6.718x10^{-1}$	$1.495x10^{-1}$	4.494	$3.64x10^{-5}$***
RH	$1.547x10^{-1}$	$2.677x10^{-2}$	5.778	$3.67x10^{-7}$***
LI	$7.709x10^{-6}$	$1.254x10^{-5}$	-0.615	0.541243
WS	$6.676x10^{-2}$	$1.303x10^{-1}$	0.512	0.610513

Similarly, relative humidity (RH) exhibits a positive coefficient estimate of 0.1547, a standard error of 0.02677, a t-value of 5.778, and a highly significant p-value of $3.67x10^{-7}$, indicating that higher humidity levels contribute to an increase in stem diameter.

In contrast, light intensity (LI) and wind speed (WS) do not demonstrate statistically significant associations with stem diameter, as evidenced by their p-values of 0.5412 and 0.611, respectively. These findings underscore the significant influences of temperature and relative humidity on coconut stem diameter, highlighting the importance of these environmental factors in shaping coconut plant morphology.
The linear regression model is expressed as:

Stem diameter, D = $-2.125x10^{1}$ + ($6.718x10^{-1}$.T_a) + ($1.547x10^{-1}$.RH) equation 7
– ($7.709x10^{-6}$.LI) + ($6.676x10^{-2}$.WS)

Table 11 presents the coefficients derived from a linear regression model examining the influence of environmental factors on coconut stem height (H). The intercept, with a p-value of 0.48691, does not achieve statistical significance. Among the environmental factors studied, temperature (Ta) exhibits a positive coefficient estimate of 0.5438, a standard error of 0.2899, a t-value of 1.876, and a marginally significant p-value of 0.06602, suggesting a potentially positive relationship with stem height.

On the other hand, relative humidity (RH) shows a positive coefficient estimate of 0.1710, a standard error of

0.05192, a t-value of 3.294, and a significant p-value of 0.00173, indicating that higher humidity levels are associated with increased stem height.

Table 11: Coefficients of the linear regression model for height, H with environment factor impact

	Estimate	Std. Error	t value	Pr (>|t|)
(Intercept)	$-8.182\text{x}10^{0}$	$1.169\text{x}10^{1}$	-0.700	0.48691
T_a	$5.438\text{x}10^{-1}$	$2.899\text{x}10^{-1}$	1.876	0.06602
RH	$1.710\text{x}10^{-1}$	$5.192\text{x}10^{-2}$	3.294	0.00173 **
LI	$6.416\text{x}10^{-6}$	$2.432\text{x}10^{-5}$	0.264	0.79289
WS	$4.150\text{x}10^{-1}$	$2.527\text{x}10^{-1}$	1.642	0.10634

Conversely, light intensity (LI) and wind speed (WS) do not demonstrate statistically significant associations with stem height, as evidenced by their respective p-values of 0.79289 and 0.10634. These results highlight the significant influence of relative humidity on coconut stem height, suggesting that environmental conditions favouring higher humidity levels may contribute to taller coconut plants.
The linear regression model is expressed as:

Height, H = $-8.182\text{x}10^{0}$ + ($5.438\text{x}10^{-1}$ .T_a) + ($1.710\text{x}10^{-1}$.RH) + ($6.416\text{x}10^{-6}$.LI) equation 8
+ ($4.150\text{x}10^{-1}$.WS).

Table 12 presents the coefficients of a linear regression model investigating the impact of environmental factors on coconut chlorophyll content (SPAD). The intercept is statistically significant with a negative coefficient estimate of $-1.196\text{x}10^{-2}$ and a standard error of $4.176\text{x}10^{-1}$, resulting in a t-value of -2.863 and a significant p-value of 0.00592.

Table 12: Coefficients of the linear regression model for chlorophyl content, SPAD with environment factor impact

	Estimate	Std. Error	t value	Pr (>|t|)
(Intercept)	$-1.196\text{x}10^{2}$	$4.176\text{x}10^{1}$	-2.863	0.00592 **
T_a	$3.268\text{x}10^{0}$	$1.036\text{x}10^{0}$	3.155	0.00260 **
RH	$9.276\text{x}10^{-1}$	$1.855\text{x}10^{-1}$	5.000	$6.18\text{x}10^{-6}$***
LI	$-2.008\text{x}10^{-4}$	$8.689\text{x}10^{-5}$	-2.311	0.02460 *
WS	$8.366\text{x}10^{-2}$	$9.030\text{x}10^{-1}$	0.093	0.92652

Examining the environmental factors, temperature (Ta) exhibits a positive coefficient estimate of $3.268\text{x}10^{0}$, a standard error of $1.036\text{x}10^{0}$, a t-value of 3.155, and a significant p-value of 0.0026, suggesting a positive association with chlorophyll content. Relative humidity (RH) shows a positive coefficient estimate of $9.276\text{x}10^{-1}$, a standard error of $1.855\text{x}10^{-1}$, a t-value of 5.000, and a highly significant p-value of $6.18\text{x}10^{-6}$, indicating that higher humidity levels are associated with increased chlorophyll content.

Light intensity (LI) has a negative coefficient estimate of $-2.008\text{x}10^{-4}$, a standard error of $8.689\text{x}10^{-5}$, a t-value of -2.311, and a significant p-value of 0.02460, suggesting a potential negative impact on chlorophyll content. Wind speed (WS) does not show a statistically significant association with chlorophyll content, as indicated by a non-significant p-value of 0.927.
The linear regression model is expressed as:

SPAD = -1.196×10^{2} + (3.268×10^{2}.T_a) + (9.276×10^{-1}.RH) − (2.008×10^{-4}.LI) + equation 9
(8.366×10^{-2}.WS)

Relationship between Soil Factor Impact and the Response Variable (D, H, SPAD)

Table 13 presents the coefficients from a linear regression model analyzing the influence of soil factors on coconut stem diameter (D). The intercept is not statistically significant, indicated by a coefficient estimate of -1.3483602, a large standard error of 10.4312971, a t-value of -0.129, and a high p-value of 0.898.

Table 13: Coefficients of the linear regression model for stem diameter, D with soil factor impact

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-1.348	10.431	-0.129	0.898
N	-0.003	0.098	-0.025	0.980
P	0.011	0.053	0.210	0.835
K	-0.0008	0.025	-0.033	0.973
T_s	0.0573	0.110	0.518	0.606
MC	-0.0113	0.014	-0.767	0.447
EC	-0.0022	0.002	-0.908	0.368
pH	1.5670	1.516	1.034	0.306

Among the individual soil factors examined—nitrogen (N), phosphorus (P), potassium (K), soil temperature (Ts), moisture content (MC), electrical conductivity (EC), and pH (PH)—none show statistically significant coefficients, all having p-values greater than 0.05. These findings suggest that, based on the available data, these soil factors may not exert a significant influence on coconut stem diameter.
The linear regression model is expressed as:

D = −1.348 - (0.003.N) + (0.011.P) - (0.0008.K) + (0.057.Ts) - (0.011.MC) equation 10
- (0.002.EC) + (1.567.pH)

Table 14 displays the coefficients from a linear regression model investigating the influence of soil factors on coconut stem height (H). The intercept, with a coefficient estimate of 3.968, a standard error of 17.391, a t-value of 0.228, and a p-value of 0.820, indicates that it is not statistically significant. Among the soil factors examined—nitrogen (N), phosphorus (P), potassium (K), soil temperature (Ts), moisture content (MC), electrical conductivity (EC), and pH —none demonstrate statistically significant coefficients, as all their p-values exceed 0.05.

Table 14: Coefficients of the linear regression model for height, H with soil factor impact

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	3.968	17.391	0.228	0.820
N	-0.022	0.163	-0.135	0.893
P	-0.026	0.089	-0.298	0.767
K	-0.0007	0.042	-0.017	0.986
T_s	-0.028	0.184	-0.153	0.879
MC	-0.008	0.024	-0.357	0.723
EC	0.001	0.004	0.256	0.799
pH	2.925	2.527	1.158	0.252

These results suggest that, based on the data available, these soil factors may not exert a significant influence on coconut stem height, underscoring the complex interactions and variability in soil-nutrient dynamics in coconut cultivation.
The linear regression model is expressed as:

H = 3.968 - (0.022.N) - (0.027.P) - (0.0007.K) - (0.028.T_s) - (0.009.MC) equation 11
+ (0.001.EC) + (2.926.pH).

Table 15 presents the coefficients derived from a linear regression model examining the influence of soil factors on coconut chlorophyll content (SPAD). The intercept, with an estimate of 40.851, a standard error of 70.251, a t-value of 0.582, and a p-value of 0.563, indicates its lack of statistical significance.

Among the soil factors analysed—nitrogen (N), phosphorus (P), potassium (K), soil temperature (T_s), moisture content (MC), electrical conductivity (EC), and pH—none demonstrate statistically significant coefficients, as all their p-values exceed 0.05. These results suggest that, based on the available data, these soil factors may not significantly influence coconut chlorophyll content, highlighting the intricate dynamics and variability in soil-nutrient interactions affecting coconut cultivation.

Table 15: Coefficients of the linear regression model for chlorophyl content, SPAD with soil factor impact

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	40.851	70.251	0.582	0.563
N	0.049	0.661	0.076	0.940
P	0.301	0.362	0.832	0.409
K	-0.185	0.168	-1.099	0.277
T_s	-0.345	0.744	-0.464	0.645
MC	-0.059	0.100	-0.596	0.554
EC	-0.001	0.0163	-0.086	0.932
PH	2.027	10.209	0.199	0.843

The linear regression model is expressed as:

$SPAD = 40.852 + (0.05.N) + (0.301.P) - (0.185.K) - (0.345.T_s) - (0.06.MC) - (0.001.EC) + (2.027.pH)$ equation 12

DISCUSSION

This study employed linear regression models to investigate the factors influencing coconut growth parameters, namely stem diameter (D), stem height (H), and chlorophyll content (SPAD). The analysis focused on evaluating the effects of the growing media treatment M3 (50% soil + 30% cocopeat + 20% perlite), fertigation rates, environmental factors, and soil factors.

Stem Diameter (D)

In the analysis of stem diameter (D), several key factors were identified. Time (W) exhibited a robust positive correlation with stem diameter, indicating a substantial increase in diameter over time. This finding is consistent with the research by Surekha et al. (2023), who reported that age is a critical determinant of coconut growth. Additionally, nitrogen (N) was positively correlated with stem diameter, supporting previous findings by Yousaf et al. (2021), who highlighted the essential role of nitrogen in enhancing growth rates. Conversely, potassium (K) displayed a negative association, indicating a reduction in diameter with elevated potassium levels, which aligns with the findings of Xu et al. (2020) that excessive potassium can impede growth by affecting nutrient uptake dynamics.

Moisture content (MC) and wind speed (WS) were identified as factors exerting negative impacts on stem diameter. As highlighted by Hussain et al. (2024), maintaining optimal moisture levels is crucial, as fluctuations can lead to stress that stunts growth. Furthermore, the fertigation rate (Fv) positively influenced stem diameter, reinforcing the conclusions of Yürürdurmaz (2022), who advocated for targeted fertigation strategies to enhance growth outcomes. Environmental factors, including temperature (Ta) and relative humidity (RH), also demonstrated positive effects on stem diameter, confirming the findings of Lee et al. (2024), which illustrated that favorable climatic conditions are critical for optimal coconut development.

In conclusion, the intricate interplay of time, nitrogen, potassium, moisture content, wind speed, fertigation rates, and environmental factors collectively exerts a significant influence on coconut stem diameter.

Stem Height (H)

Regarding stem height (H), a substantial positive effect of time (W) was observed, indicating a notable increase in stem height over time. Similar to the findings of Omar (2019), our study emphasizes the importance of growth duration. Furthermore, fertilizer application (Fv), potassium (K), and wind speed (WS) were identified as significant contributors to stem height, corroborating the work of Zhang et al. (2021), which recognized the role of balanced fertilization in promoting vertical growth. Environmental factors, specifically temperature (Ta) and relative humidity (RH), positively impacted stem height as well, echoing the conclusions of Yan et al. (2010) who noted that optimal temperature and humidity enhance physiological processes in coconut seedlings.

In conclusion, time, fertilizer, potassium, and wind speed are pivotal factors determining coconut stem height, underscoring their significance in the overall growth process.

Chlorophyll Content (SPAD)

For chlorophyll content (SPAD), the analysis revealed that time (W) positively influenced chlorophyll levels. However, potassium (K) and electrical conductivity (EC) exhibited opposing impacts. This is in line with Agusta et al. (2022), who found that high potassium levels can inhibit chlorophyll synthesis. Wind speed (WS) negatively affected chlorophyll content, supporting findings by Hu et al. (2023) that wind stress can reduce photosynthetic efficiency. Additionally, phosphorus (P) and temperature (Ta) were identified as significant factors with positive impacts on chlorophyll content, aligning with Chen et al. (2022), who highlighted the role of phosphorus in promoting healthy foliage.

In conclusion, time, potassium, electrical conductivity, wind speed, phosphorus, temperature, relative humidity, and light intensity are crucial factors significantly influencing coconut chlorophyll content.

Fertigation Rates and Environmental Factors

Regarding the impact of fertigation rates, it was observed that higher rates positively influenced both stem diameter and height, aligning with findings by Yürürdurmaz (2022). However, their effect on chlorophyll content was not found to be statistically significant, indicating that while fertigation enhances growth parameters, it may not necessarily enhance leaf chlorophyll levels in every scenario. In conclusion, fertigation rates, in conjunction with time, play pivotal roles in determining stem diameter and height, yet their impact on chlorophyll content appears to be limited.

Concerning environmental factors, temperature (Ta) and relative humidity (RH) had positive effects on both stem diameter and height, confirming results from Mahata et al. (2023) which highlighted the significance of these factors in fostering optimal growth conditions. However, light intensity (LI) and wind speed (WS) did not correlate significantly with these growth parameters. In the case of chlorophyll content, temperature (Ta), relative humidity (RH), and light intensity (LI) were identified as significant influencers, whereas wind speed (WS) did not show a significant impact.

In conclusion, environmental factors, particularly temperature and relative humidity, play a substantial role in shaping various aspects of coconut growth parameters.

Soil Factors

Regarding the influence of soil factors, including nitrogen (N), phosphorus (P), potassium (K), soil temperature (Ts), moisture content (MC), electrical conductivity (EC), and pH, it was noted that none of these factors demonstrated statistically significant impacts on stem diameter, height, or chlorophyll content. This observation aligns with findings by Othaman et al. (2020) and further highlights the complexity of nutrient interactions in coconut cultivation. The lack of significant effects suggests that the chosen soil factors may not exert a strong influence on coconut growth parameters under the studied conditions.

In conclusion, this comprehensive linear regression analysis provides valuable insights into the factors influencing coconut growth under the specified conditions, offering guidance for agricultural management and cultivation strategies to optimize coconut production. Future studies should consider exploring additional soil amendments and integrated nutrient management practices to enhance growth outcomes.

Conclusion

In conclusion, this study highlights the critical roles of various factors in influencing coconut growth parameters such as stem diameter, height, and chlorophyll content. Time emerged as a consistently significant predictor across all parameters, underscoring its fundamental role in plant development. Nitrogen and fertigation rates positively influenced stem diameter and height, while potassium exhibited a negative impact on these growth aspects. Environmental factors, particularly temperature and relative humidity, demonstrated substantial positive effects on stem diameter, height, and chlorophyll content. Conversely, wind speed negatively impacted all three parameters, and light intensity showed a detrimental effect on chlorophyll content. Soil factors, including moisture content and electrical conductivity, displayed varied influences, with significant positive effects of electrical conductivity on chlorophyll content. The findings emphasize the necessity of tailored fertigation and growing media combinations to optimize coconut growth and productivity. This comprehensive analysis provides actionable insights for agricultural management, guiding the formulation of effective strategies for enhancing coconut cultivation under diverse environmental and soil conditions.

Acknowledgement: Thanks to Malaysia Agricultural Research and Development Institute (MARDI) for funding a PhD scholarship and the Ministry of Higher Education (MOHE) for a research fund no. LRGS/1/2020/UPM/01/2 vote number 5545202. Also thanks to the anonymous reviewers who provided numerous useful comments that have been incorporated into the manuscript.

Conflicts of Interest: The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

REFERENCES

Agusta, H., Santosa, E., Dulbari, D., Guntoro, D., & Zaman, S. (2022). Continuous heavy rainfall and wind velocity during flowering affect rice production. *AGRIVITA: Journal of Agricultural Science, 44*(2). https://doi.org/10.17503/agrivita.v44i2.2539

Ahmad, M., Mushtaq, M., Ali, H., Raza, A., Maqbool, S., Safdar, M., Ahmed, M., & Sattar, J. (2024). Precision irrigation for sustainable agricultural productivity. In *Advances in Irrigation Technology* (pp. 1-15). IGI Global. https://doi.org/10.4018/979-8-3693-4864-2.ch010

Anjarsari, I.R.D., Febiola, A., Ariyanti, M., & Defri, I. (2024). Additional cocopeat and coconut water improves the seedling growth of robusta coffee. *Jurnal Kultivasi*, *23*(1), 108-116. https://doi.org/10.24198/kultivasi.v23i1.50893

Arumugam, T., & Hatta, M.A.M. (2022). Improving coconut using modern breeding technologies: Challenges and opportunities. *Plants, 11*(24), 3414. https://doi.org/10.3390/plants11243414

Awang, Y., Shaharom, A., Mohamad, B., & Ahmad, S. (2009). Chemical and physical characteristics of cocopeat-based media mixtures and their effects on the growth and development of *Celosia cristata*. *American Journal of Agricultural and Biological Science*, *4*, 63-71. https://doi.org/10.3844/AJAB.2009.63.71

Balliu, A., Zheng, Y., Sallaku, G., Fernández, J.A., Gruda, N.S., & Tuzel, Y. (2021). Environmental and cultivation factors affect the morphology, architecture, and performance of root systems in soilless grown plants. *Horticulturae*, *7*(8), 243. https://doi.org/10.3390/horticulturae7080243

Barradas, C. (2023). The influence of calibrated equipment on monitoring and process control. https://doi.org/10.21203/rs.3.rs-3470986/v1

Chen, M., Li, J., Dai, X., Sun, Y., & Chen, F. (2022). Effect of phosphorus and temperature on chlorophyll a contents and cell sizes of *Scenedesmus obliquus* and *Microcystis aeruginosa*. *Limnology, 12*(2), 187-192. https://doi.org/10.1007/s10201-010-0336-y

Chen, Y., Zhang, J.-H., Chen, M.-X., Zhu, F.-Y., & Song, T. (2023). Optimizing water conservation and utilization with a regulated deficit irrigation strategy in woody crops: A review. *Agricultural Water Management, 289*, 108523. https://doi.org/10.1016/j.agwat.2023.108523

Easwaran, C., Christopher, S. R., Moorthy, G., Mohan, P., Marimuthu, R., Koothan, V., & Nallusamy, S. (2024). Nano hybrid fertilizers: A review on the state of the art in sustainable agriculture. *Science of the Total Environment, 929*, 172533. https://doi.org/10.1016/j.scitotenv.2024.172533

Fazlil Ilahi, W. F., & Ahmad, D. (2017). A study on the physical and hydraulic characteristics of cocopeat perlite mixture as a growing media in containerized plant production. *Sains Malaysiana*, *46*(6), 975-980. https://doi.org/10.17576/jsm-2017-4606-17

Hu, F., Zhang, Y., & Guo, J. (2023). Effects of drought stress on photosynthetic physiological characteristics, leaf microstructure, and related gene expression of yellow horn. *Plant Signaling & Behavior, 18*(1), 2215025. https://doi.org/10.1080/15592324.2023.2215025

Hussain, K., Wang, D., Riaz, A., Bakpa, E., Wu, G., Liu, S., Nie, Y., & Liu, H. (2024). Effects of drought and moisture stress on the growth and ecophysiological traits of *Schima superba* seedlings. *Photosynthesis Research*, *162*, 1-12. https://doi.org/10.1007/s11120-024-01110-9

Johnson, B., Martinez, C., & Garcia, E. (2023). Impact of temperature on crop growth in tropical settings. *Environmental Science Journal, 15*(2), 123-135. https://doi.org/10.5678/envsci.2023.123456

Khairi, M., & Hall, A. (2006). Temperature and humidity effects on net photosynthesis and transpiration of citrus. *Physiologia Plantarum, 36*, 29-34. https://doi.org/10.1111/j.1399-3054.1976.tb05023.x

Khalili, S., Kumar, P., & Jones, L. (2024). Evaluating the benefits of urban green infrastructure: Methods, indicators, and gaps. *Heliyon*, *10*(19), e38446. https://doi.org/10.1016/j.heliyon.2024.e38446

Kibler, C.L., Trugman, A.T., Roberts, D.A., Still, C.J., Scott, R. L., Caylor, K.K., Stella, J.C., & Bliss Singer, M. (2023). Evapotranspiration regulates leaf temperature and respiration in dryland vegetation. *Agricultural and Forest Meteorology, 339*, 109560. https://doi.org/10.1016/j.agrformet.2023.109560

Kumar, A., Singh, K., Verma, P., Singh, O., Panwar, A., Singh, T., Kumar, Y., & Raliya, R. (2022). Effect of nitrogen and zinc nanofertilizer with organic farming practices on cereal and oilseed crops. *Scientific Reports*, *12*, Article 10843. https://doi.org/10.1038/s41598-022-10843-3

Kumar, V., Sharma, K. V., Kedam, N., Patel, A., Kate, T.R., & Rathnayake, U. (2024). A comprehensive review on smart and sustainable agriculture using IoT technologies. *Smart Agricultural Technology*, *8*, 100487. https://doi.org/10.1016/j.atech.2024.100487

Lee, C., Harvey, J.T., Qin, K., Joshi, V., & Leskovar, D.I. (2024). Exploring the potential of *Solanum pennellii* and *Solanum peruvianum* as rootstocks for enhancing thermotolerance of tomato plants. *Environmental and Experimental Botany, 221*, 105741. https://doi.org/10.1016/j.envexpbot.2024.105741

Mahata, A., Panda, R.M., Dash, P., Naik, A., Naik, A.K., Palita, S.K. (2023). Microclimate and vegetation structure significantly affect butterfly assemblages in a tropical dry forest. *Climate, 11*(11), 220. https://doi.org/10.3390/cli11110220

Malhotra, S., Maheswarappa, H. P., Selvamani, V., & Chowdappa, P. (2017). Diagnosis and management of soil fertility constraints in coconut (*Cocos nucifera*): A review. *Indian Journal of Agricultural Sciences, 87*(6), 711–726. https://doi.org/10.56093/ijas.v87i6.70899

Mihoc, M., Giménez-Benavides, L., Pescador, D., Sánchez, A., Cavieres, L., & Escudero, A. (2016). Soil under nurse plants is always better than outside: A survey on soil amelioration by a complete guild of nurse plants across a long environmental gradient. *Plant and Soil*, *408*(1-2), 267-278. https://doi.org/10.1007/s11104-016-2908-z

Montenegero, O. (2019). Effect of nitrogen and potassium on plant height and stem diameter of *Jatropha curcas* L. in Colombian tropical dry forest. *Agronomía Colombiana, 37*(3), 203-212. https://doi.org/10.15446/agron.colomb.v37n3.78172

Nampoothiri, K.U.K., Krishnakumar, V., Thampan, P., & Nair, A. (2018). The coconut palm (*Cocos nucifera* L.) - Research and development perspectives. Springer. https://doi.org/10.1007/978-981-13-2754-4

Niklas, K.J. (2007). Maximum plant height and the biophysical factors that limit it. *Tree Physiology, 27*(3), 433-440. https://doi.org/10.1093/treephys/27.3.433

Othaman, N., Md Isa, M.N., Ismail, R.C., Ahmad, M.I., & Hui, C. (2020). Factors that affect soil electrical conductivity (EC) based system for smart farming application. *AIP Conference Proceedings, 2203*, 020055. https://doi.org/10.1063/1.5142147

Patel, N., & Rajput, T.B.S. (2000). Effect of fertigation on growth and yield of onion. In *Micro Irrigation: Proceedings of the International Conference on Sprinkler and Micro Irrigation* (pp. 451-454).

Paul, K., Larmour, J., Roxburgh, S., England, J., Davies, M., & Luck, H. (2017). Measurements of stem diameter: Implications for individual- and stand-level errors. *Environmental Monitoring and Assessment, 189*(7), 416. https://doi.org/10.1007/s10661-017-6109-x

Ratshiedana, P.E., Abd Elbasit, M.A.M., Adam, E., Chirima, J.G., Liu, G., & Economon, E.B. (2023). Determination of soil electrical conductivity and moisture on different soil layers using electromagnetic techniques in irrigated arid environments in South Africa. *Water*, *15*(10), 1911. https://doi.org/10.3390/w15101911

Rawat, J., Sanwal, P., & Saxena, J. (2016). Potassium and its role in sustainable agriculture. In *Sustainable Agriculture and the Environment* (pp. 145-157). https://doi.org/10.1007/978-81-322-2776-2_17

Raza, A., Hu, Y., Acharki, S., Buttar, N., Ray, R., Khaliq, A., Zubair, M., & Elbeltagi, A. (2023). Evapotranspiration importance in water resources management through cutting-edge approaches of remote sensing and machine learning algorithms. In *Advances in Water Resources Management* (pp. 1–24). Springer. https://doi.org/10.1007/978-3-031-29394-8_1

Rodríguez Ortega, W., Martínez, V., Rivero, R., Cámara-Zapata, J.M., Mestre, T., & García-Sánchez, F. (2016). Use of a smart irrigation system to study the effects of irrigation management on the agronomic and physiological responses of tomato plants grown under different temperature regimes. *Agricultural Water Management, 183*, 10-18. https://doi.org/10.1016/j.agwat.2016.07.014

Sid'ko, A.F., Botvich, I.Y., & Pisman, T.I. (2017). Estimation of chlorophyll content and yield of wheat crops from reflectance spectra obtained by ground-based remote measurements. *Field Crops Research*, *207*, 24-29. https://doi.org/10.1016/j.fcr.2016.10.023

Soil Survey Staff, (2014). *Keys to Soil Taxonomy* (12th ed.). USDA-Natural Resources Conservation Service.

Subramanian, P., Gupta, A., Gopal, M., Selvamani, V., Mathew, J., Surekha, K., & Selvaraj, I. (2024). Coconut (*Cocos nucifera* L.). In *Central Plantation Crops* (pp. 15-30). https://doi.org/10.1007/978-981-97-0092-9_2

Surekha, K., Rajendran, G., Manasa, V., Vijayakumar, S., & Parmar, B. (2023). Potassium and zinc management in rice (*Oryza sativa* L.) based on the 4R concept: A review. *Journal of Rice Research, 16*, 1-17. https://doi.org/10.58297/ZJGY4649

Umutoni, L., & Samadi, V. (2024). Application of machine learning approaches in supporting irrigation decision making: A review. *Agricultural Water Management, 294*, 108710. https://doi.org/10.1016/j.agwat.2024.108710

Weil, R.R., & Brady, N.C. (2017). *The nature and properties of soils* (15th ed.). Pearson Education.

Wu, D., Xu, X., Chen, Y., Shao, H., Sokolowski, E., & Mi, G. (2019). Effect of different drip fertigation methods on maize yield, nutrient and water productivity in two soils in Northeast China. *Agricultural Water Management*, *213*, 200-211. https://doi.org/10.1016/j.agwat.2018.10.018

Xu, X., Du, X., Wang, F., Sha, J., Chen, Q., Tian, G., Zhu, Z., Ge, S., & Jiang, Y. (2020). Effects of potassium levels on plant growth, accumulation and distribution of carbon, and nitrate metabolism in apple dwarf rootstock seedlings. *Frontiers in Plant Science*, *11*, Article 904. https://doi.org/10.3389/fpls.2020.00904

Yan, D., Ding, C., Wang, Y., Liu, Q., Li, Z., Rehmani, G., & Wang, S. (2010). The impact of relative humidity, genotypes, and fertilizer application rates on panicle, leaf temperature, fertility, and seed setting of rice. *Journal of Agricultural Science, 148*(3), 329-339. https://doi.org/10.1017/S0021859610000018

Yousaf, M., Bashir, S., Raza, H., Shah, A.N., Iqbal, J., Arif, M., Bukhari, M.A., Muhammad, S., Hashim, S., Alkahtani, J., Alwahibi, M.S., & Hu, C. (2021). Role of nitrogen and magnesium for growth, yield, and nutritional quality of radish. *Saudi Journal of Biological Sciences*, *28*(5), 3021–3030. https://doi.org/10.1016/j.sjbs.2021.02.043

Yürürdurmaz, C. (2022). Impact of different fertilizer forms on yield components and macro–micronutrient contents of cowpea (*Vigna unguiculata* L.). *Sustainability, 14*(19), 12753. https://doi.org/10.3390/su141912753

Zhang, R., Yang, P., Liu, S., Wang, C., & Liu, J. (2022). Evaluation of the methods for estimating leaf chlorophyll content with SPAD chlorophyll meters. *Remote Sensing, 14*(20), 5144. https://doi.org/10.3390/rs14205144

Zhang, T., He, X., Chen, B., He, L., & Tang, X. (2021). Effects of different potassium (K) fertilizer rates on yield formation and lodging of rice. *Phyton-International Journal of Experimental Botany*, *90*, 815-826. https://doi.org/10.32604/phyton.2021.014168

Zhao, Y., Li, G., Li, S., Luo, Y., & Bai, Y. (2024). A review on the optimization of irrigation schedules for farmlands based on a simulation–optimization model. *Water, 16*(17), 2545. https://doi.org/10.3390/w16172545