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Original Research Article

Growth Performance of Coconut (*Cocos nucifera*) in a Tropical Rooftop Nursery: Analysis of Growth Response to Environmental Factors

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Abstract: This study investigates the intricate relationships between environmental factors and the growth performance of coconut plant (*Cocos nucifera*) in a rooftop nursery setting in the tropics. Coconut cultivation is of great economic and ecological importance, making it crucial to understand the environmental variables that influence growth. The coconut plant growth data and environmental parameters, including temperature (T), relative humidity (RH), light intensity (LI), height (H), leaf count (L), frond count (F), and stem diameter (D), were examined weekly over an extended period. Correlation analysis revealed interesting insights into the relationships between these variables. The week exhibited a positive correlation with temperature (r = 0.59 and light intensity (r = 0.35), suggesting that coconut growth is influenced by seasonal changes in temperature and sunlight exposure. Relative humidity showed a strong negative correlation with temperature (r = -0.75, indicating the interplay between these two critical factors. Notably, stem diameter (D) displayed a positive correlation with height (H) (r = 0.72, emphasizing the importance of vertical growth for overall coconut development. The findings underscore the significance of understanding how these environmental factors interact to influence coconut growth. The positive correlations between temperature, light intensity, and growth parameters highlight the need for optimal climate conditions in rooftop nurseries. Effective environmental management practices, such as shading to mitigate excessive light exposure and maintaining appropriate temperature and humidity levels, are essential for fostering healthy coconut growth.

Keywords: coconut growth; environmental factors; rooftop nursery; correlation analysis; sustainable cultivation

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1. Introduction

The coconut palm is widely grown in many tropical regions. Coconut (*Cocos nucifera L.*) is an eco-friendly smallholder palm native to the tropics that is grown across an area of 11.99 million hectares and yields 67.04 billion nuts per year at a productivity of 5592 nuts per hectare according to Hebbar (2022). Prades *et al*. (2016) suggest that the coconut plant have originated in the area that includes the Bismarck Archipelago, New Guinea, and the Malayan Peninsula and Archipelago from where it spreads throughout the tropics. At the beginning of coconut cultivation, it is not advisable to plant coconut seeds directly in planting pits. According to Rusitha (2014), only well-developed coconut seedlings, carefully chosen and approximately 7–8 months old, should be planted in adequately prepared pits. This approach enables farmers to choose robust and healthy coconut seedlings exhibiting strong growth, laying the foundation for uniform coconut plants with optimal growth performance, as outlined by Perera (2013).

Coconut cultivation currently faces numerous challenges, including palm senility, significant abiotic and biotic stressors, market instability for coconut products, and inadequate production of seedlings for replanting aging palms, as highlighted by Nguyen *et al*. (2015) and Salum *et al*. (2020). A crucial aspect is finding a suitable location for growing coconut seedlings. Coconut palms thrive in hot climates, requiring an annual mean air temperature ranging between 22–34°C and the absence of temperatures below 15°C. Additionally, they necessitate solar radiation incidence ranging from 300–900 W m^{-2}, relative air humidity between 60–90%, annual mean rainfall exceeding 1500 mm, which should be evenly distributed throughout the year, and an annual sunshine duration of 2000 hours, as outlined by Ohler (1999). The quantity and distribution of rainfall significantly impact fruit set and growth, underscoring their importance, as emphasized by Rajagopal *et al*. (1996).

By 2050, it is projected that 66% of the global population, up from the current 54%, will inhabit urban areas, as indicated by the United Nations (2014). Human activities have led to numerous challenges worldwide, including the rapid depletion of agricultural land. Addressing these issues, urban farming emerges as a promising solution, as suggested by

Smit *et al*. (2001). Rooftop farming offers several benefits such as mitigating the urban heat island effect by reducing roof and surrounding air temperatures, thus contributing to overall climate cooling, as highlighted by Hui (2011). Various techniques are employed for rooftop farming in urban areas, including green roofs, hydroponics, organic farming, aeroponics, and container gardens. However, a common challenge in rooftop crop cultivation is excessive exposure to direct sunlight, which can elevate temperatures within crop protection structures. Consequently, this increase in temperature can affect the quality of fertilizers and plant growth by altering factors such as electrical conductivity (EC) and pH levels.

Understanding the intricate relationship between coconut growth and environmental factors is essential for optimizing cultivation practices, increasing yield, and ensuring food security. Temperature directly affects photosynthesis, a critical physiological process in coconut palms. Studies by Das and Mohanty (2018) reveal that elevated temperatures can enhance photosynthesis rates, leading to better growth. However, excessively high temperatures can also induce heat stress, adversely affecting coconut growth. On the other end of the spectrum, coconut palms are sensitive to low temperatures. Research by Bakr *et al*. (2019) demonstrates that chilling stress, caused by temperatures below 15°C, can lead to reduced growth rates, especially in young coconut seedlings. This highlights the vulnerability of coconut palms to cold conditions.

Relative humidity (RH) is another critical environmental factor that significantly influences coconut growth. RH levels impact several aspects of coconut physiology and growth. Coconut palms exhibit high rates of transpiration due to their large surface area and high stomatal density. RH plays a crucial role in regulating transpiration. Research by Mohd *et al*. (2018) suggests that higher RH levels can reduce transpiration rates, conserving water and preventing water stress in coconut palms. Light intensity (LI), primarily in the form of solar radiation, is a key driver of photosynthesis in coconut palms. It plays a pivotal role in shaping various growth parameters. Coconut palms are heliophilous, meaning they require abundant sunlight for photosynthesis.

Conversely, inadequate light conditions, often due to shading by surrounding vegetation, can lead to shade stress in coconut palms. This inhibits photosynthesis and ultimately reduces growth. Research by Adnan *et al*. (2020) emphasizes the importance of managing LI to prevent shade stress. Light intensity is also linked to water availability. Drought conditions can reduce LI because of reduced soil moisture and cloud cover. This reduction in LI can negatively impact coconut growth by limiting photosynthesis. Proper irrigation and water management are essential to mitigate this effect. It is crucial to recognize that these environmental factors do not act in isolation; they often interact and can have synergistic or antagonistic effects on coconut growth. Temperature and RH are closely linked, as temperature influences the air's capacity to hold moisture. Studies by Siva *et al*. (2019) demonstrate that high temperatures combined with low RH can lead to water stress in coconut palms. Proper irrigation practices become essential under such conditions.

LI and temperature also interact significantly. This interaction can have both positive and negative effects on coconut growth, depending on the overall climatic conditions. Effective coconut cultivation requires a comprehensive approach to managing these environmental factors. Research by Prasad and Khan (2019) suggests that a well-planned irrigation schedule, considering temperature, RH, and LI, can optimize coconut growth and productivity. Temperature is a primary environmental factor influencing coconut growth and development. Numerous studies have highlighted the significant impact of temperature on various growth parameters of coconut palms. Research by Kumar *et al.* (2020) found that coconut palms thrive in regions with a mean annual temperature range of 27°C to 30°C. Within this range, they exhibit faster growth rates, including increased stem diameter and leaf production. The authors emphasize that temperature fluctuations beyond this range can lead to stress conditions, hindering coconut growth.

This study seeks to address several issues that pertain the productivity of coconut seedlings in nursey. Firstly, the cultivation of coconut aims to reach the maximum planting area in Malaysia to meet future demand, considering the long-term implications of decreasing agricultural land and the necessity to find or create new planting areas. Secondly, there is a current lack of infrastructure and technologies to support coconut production. Thirdly, the suitability of rooftop areas of buildings for coconut seedlings cultivation and the correlation of environmental parameters such as temperature, relative humidity, wind speed, and light intensity with crop growth performance are under consideration. The goal of this study is, therefore, to evaluate coconut growth performance under rain shelter nursery on a roof top garden in tropical area. The study also aims to achieve the following specific objectives: 1) To identify environmental parameters that significantly correlate with crop growth performance; 2) To obtain linear regression of variables related to the coconut growth parameters.

2. Materials and Methods

2.1. Rain Shelter Nursery Structure Development

The experiment was conducted under a rain shelter nursery structure, as shown in Figure 1, located at 3.0025° N latitude and 101.7071°E longitude on the rooftop area of Level 3, Faculty of Engineering, 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 50% cocopeat and 50% topsoil as the growing media. 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.

Figure 1. Rain shelter nursery in roof top area

2.3. Coconut Cultivation Layout

In this study, the coconut variety examined was the Matag F1 coconut, a hybrid coconut derived from the original coconut varieties in Malaysia, namely the Malaysia Yellow Dwarf (MYD) or Malaysia Red Dwarf (MRD), and the Tagnanan coconut from the Philippines. "Matag" serves as the abbreviated term or nickname for this new hybrid coconut. The primary focus of this study was on the young Matag coconut plants in their nursery stage. Figure 2 shows the arrangement of the coconut plants, where 5 rows of coconut plants were utilized, with each row comprising 12 young plants, resulting in a total of 60 plants under investigation. The rows were oriented in a North-South direction, ensuring uniform light exposure for all plants throughout the day. This layout was chosen to optimize sunlight distribution, particularly in tropical regions, where solar radiation plays a critical role in plant growth.

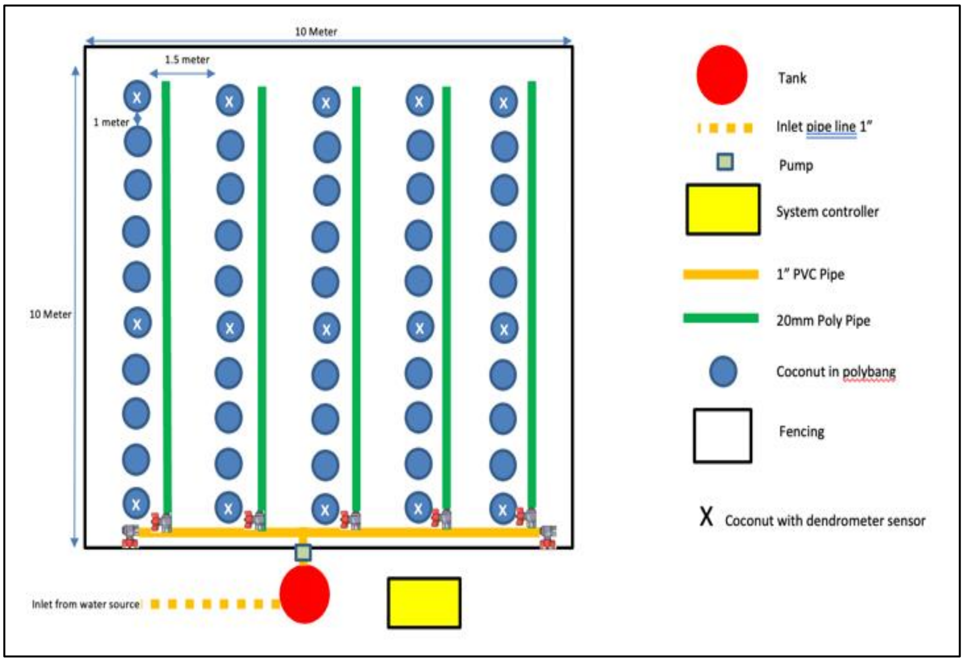

Figure 2. Coconut cultivation layout

The irrigation method employed was fertigation, specifically utilizing the drip irrigation technique. Fertigation involves the application of fertilizers through the irrigation system. In this study, drip irrigation was practiced, with each irrigation session lasting for 3 minutes, repeated 4 times a day. The irrigation rate was set at 2 liters per crop per day. Regarding fertilization, the following nutrient ranges were applied: nitrogen (N) between 100 to 200 grams per coconut per year, phosphorus (P) ranging from 30 to 60 grams per coconut per year, and potassium (K) between 100 to 200 grams per plant per year. These fertilization levels were maintained to ensure optimal growth and development of the coconut plants during their nursery stage.

2.4. Data Collection

Data collection was conducted on 60 trees of young coconut seedlings about 1 month age under a rain shelter nursery in roof top area for 12 weeks. The coconut seedlings were measured manually for its height, stem diameter, frond number and number of leaves. The data is recorded once a week for 12 weeks. Environment parameters such as ambient temperature, relative humidity, and light intensity were recorded using the data logger to see the correlation between crop growth performance parameters such as height, stem diameter and number of leaves; and environment parameters such as ambient temperatures, relative humidity %, and light intensity %.

2.4.1. Crop growth parameters measurement

A ruler and a thread were prepared as tools. The ruler was positioned on top of the soil until it reached the bottom of the last leaf. Subsequently, the data was measured and recorded, with the result being 30 cm. For the diameter measurement, the thread was wrapped around the coconut trunk at its base. After marking the thread, it was placed on the ruler, and the data was measured and recorded, resulting in 10 cm. The height and stem diameter measurement are shown in Figure 3.

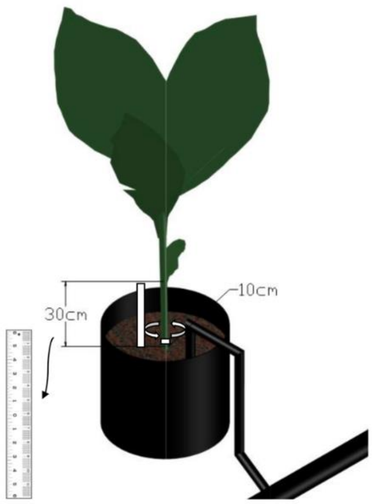

Figure 3. The height and stem diameter measurement

2.4.2. Environment parameters measurement

A weather station, watchdog weather station 2000 series have been installed in the centre of coconut nursery, to collect various meteorological data related to the weather conditions in the nursery area during the young coconut growth. It consists of several instruments and sensors that measure different weather parameters to provide comprehensive information about the climate. Typically, a weather station for a coconut nursery includes the following components temperature sensor, relative humidity sensor, wind speed sensor, rain gauge and light intensity sensor. These sensors are typically installed at a suitable height and location within the coconut nursery to ensure accurate measurements. The collected weather data is then recorded and analyzed to understand the environmental conditions and make informed decisions regarding irrigation scheduling, crop management, and other practices necessary for the successful growth of coconut plants.

2.5. Data Analysis

Randomized Complete Block Design (RCBD) and one way ANOVA were used to design the experiment for data collection. There is two hypothesis development for time, which is first the null hypothesis (H_0) where there is no significant difference for crop growth from week 1 to 12 and alternative hypothesis (H_a) where there is significant difference for crop growth parameter from week 1 to 12. Also, there is two hypothesis development for replication, which is first the null hypothesis (H_0) where there is no block effect between samples and alternative hypothesis (H_a) where there is block effect between samples. The data obtained were subjected to descriptive statistics, analysis of variance (ANOVA), correlation and linear regression analysis. All the statistical analysis was carried out using R-Studio statistical software (R-Studio Version 1.4.1564).

3. Results and Discussion

3.1. Analysis of Variance (ANOVA) Of Coconut Growth Parameters Response to Time (Week)

Table 1 presents the results of an analysis of variance (ANOVA) conducted to compare the mean coconut stem diameter growth over a period of 12 weeks. Based on table 1, the analysis reveals significant differences in mean coconut stem diameter growth among the 12 treatment conditions over the 12-week period. The treatments explain a substantial amount of the observed variation, as evidenced by the large F value which is 20.12 and extremely low p-value which is $< 2.2 \times 10^{-16}$. The findings of the study by Sudarmaji, (2020) revealed the growth characteristics of coconut palm stems during the nursery period where the stem diameter increased gradually over time, indicating the growth and development of the coconut seedlings. These parameters affect the physiological processes of coconut seedlings, including photosynthesis and transpiration. Research by Nambiar *et al*. (2021) highlighted the importance of maintaining optimal temperature, relative humidity, and sunlight exposure in coconut nurseries. Variations in these parameters can lead to stress conditions, affecting plant health and growth.

Table 1. ANOVA of mean comparison for coconut stem diameter growth

	Df	Sum sq	Mean Sq	F Value	Pr (>F)
Treatment	11	3599.7	327.25	20.122	$< 2.2^{-16}$
Residuals	228	3708	16.26		

The trend in stem diameter growth over the weeks was analyzed using regression analysis to better capture the progressive increase in growth, which is typical in the early stages of plant development. As shown in the regression line in Figure 3, stem diameter increased slowly during the initial weeks, particularly in weeks 1 and 2, which showed minimal growth. However, from week 3 onwards, a steady and significant upward trend was observed, continuing through to week 12. For instance, the stem diameter measurement in the 12th week (34.19) demonstrated the highest growth rate, marking a notable increase compared to earlier weeks. The regression analysis confirmed a significant growth trend over time, particularly after the 3rd week, highlighting the progressive nature of coconut stem diameter growth during this stage.

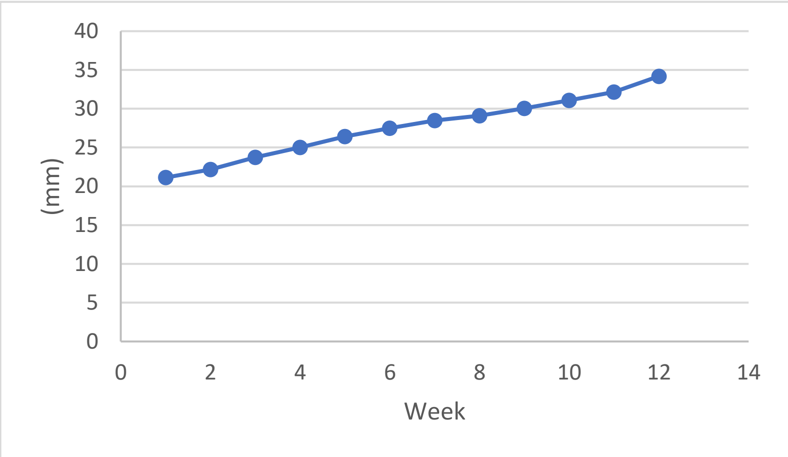

Figure 4. Linear regression for coconut stem diameter growth at different weeks

Table 2 presents the results of an analysis of variance (ANOVA) conducted to assess the significance of coconut height variation based on different treatments. The F value of 12.16 measures the significance of the differences among the treatment means for coconut height. The associated p-value is less than 2.2 x 10^{-16}, which indicates strong evidence against the null hypothesis. This suggests that there are significant differences in coconut height among the treatment groups. Understanding the genetic basis of height growth traits is crucial for coconut breeding programs and improving coconut varieties. These parameters affect the physiological processes of coconut seedlings, including photosynthesis and transpiration.

Table 2. ANOVA of mean comparison for coconut height

	Df	Sum sq	Mean Sq	F Value	Pr (>F)
Treatment	11	47700	4336.3	12.16	< 2.2^{-16}
Residuals	228	81307	356.6		

Figure 4 presents the linear regression analysis on coconut height across different weeks. Analyzing the regression line for the height of the coconut plants, it can be observed that the height steadily increases as the weeks progress, which aligns with general plant growth patterns. As expected, coconut palms in tropical climates exhibit continuous growth, with environmental factors like temperature playing a critical role. Studies by Sharma *et al*. (2021) have shown that coconut palms achieve optimal height increments when exposed to mean annual temperatures between 27°C and 30°C. Deviations from this range — whether towards higher or lower temperatures — tend to inhibit growth.

From the regression analysis, the height at week 12 was recorded at 103.60 cm, showing a significant increase in growth compared to earlier weeks. In contrast, the lowest height was observed during the 1st week, at 60.03 cm. The regression line illustrates a gradual increase in growth after the initial weeks, with a pronounced acceleration in height observed after week 2. This trend reflects that, while growth starts slowly, it becomes steady and eventually shows rapid improvement, particularly between weeks 11 and 12. Regression analysis confirms a strong positive correlation between time (weeks) and height increment, providing a clearer understanding of the growth dynamics compared to the earlier method of group comparison based on mean differences.

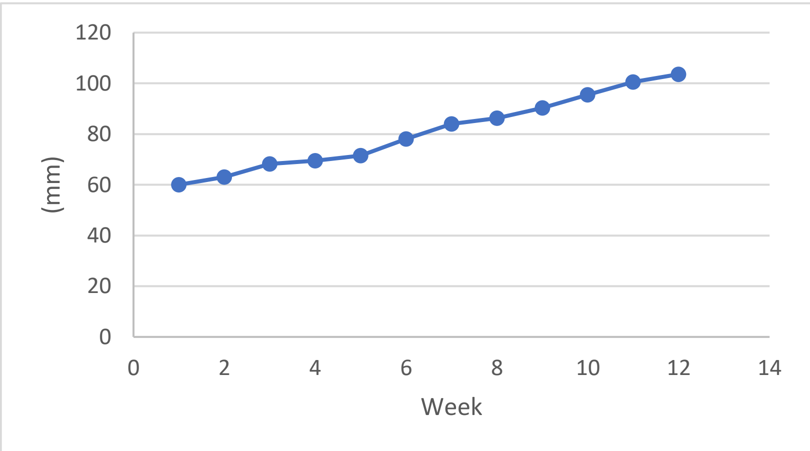

Figure 5. Linear regression analysis for coconut height at different weeks

Table 3 presents the results of an analysis of variance (ANOVA) conducted to compare the mean coconut leaf counts across different treatments. The F value of 14.07 measures the significance of the differences among the treatment means for coconut leaf counts. The associated p-value is less than 2.2×10^{-16}, which suggests strong evidence against the null hypothesis. This indicates that there are significant differences in coconut leaf counts among the treatment groups. There were significant differences observed among all coconut leaves number for 12 weeks. Alternative hypothesis (Ha) accepted shows that there is block effect, which means there is an effect of environmental parameters to coconut height. The Shapiro-Wilk normality test that have been conduct using R-studio software shows the p-value is 1.21 which is more than 0.05. Therefore, null hypothesis (H_0) is accepted, which means that the data is normally distributed.

Table 3. ANOVA of mean comparison for coconut leaves counts

	Df	Sum sq	Mean Sq	F Value	Pr (>F)
Treatment	11	439.93	39.99	14.07	$< 2.2^{-16}$
Residuals	228	648	2.842		

The regression analysis shows in Figure 6, that there was a gradual increase in the number of coconut leaves over the 12 weeks, with specific points of slower growth in weeks 3 and 4. There were no significant differences in leaf numbers between weeks 1 and 2, weeks 5 and 6, and weeks 7, 8, and 9. However, weeks 3 and 4 showed more deviation from the trend, suggesting variations in growth conditions or environmental factors during that period.

Leaf traits are vital for the overall growth and productivity of coconut palms. By applying regression analysis, the study provides clearer insights into how these traits evolve over time. Understanding the genetic control over leaf traits through this method offers valuable information for breeding and agricultural practices, helping to estimate genetic potential and heritability of leaf traits more effectively than simple mean comparisons.

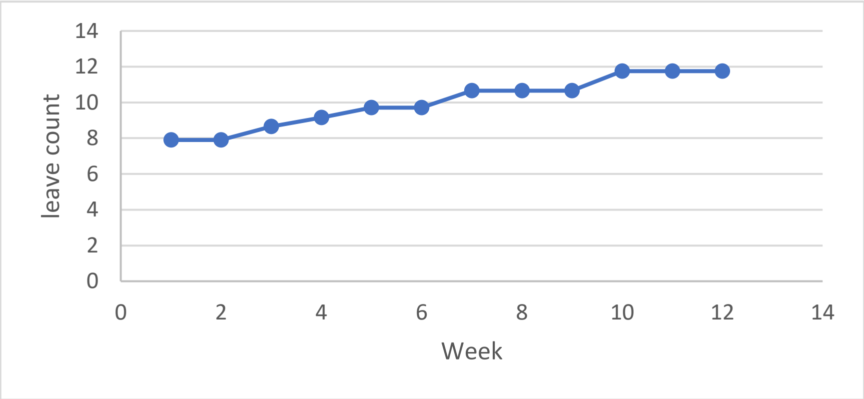

Figure 6. Linear regression analysis for coconut leaves counts at different weeks.

3.2. ANOVA and Linear Regression of Coconut Growth Parameters Data Response to Environment Parameters

Table 4 provides the results of an analysis of variance (ANOVA) conducted to examine the response of coconut stem diameter to environmental parameters. The p-values are provided to assess the statistical significance of each factor. In this case, the week factor demonstrates an extremely low p-value of less than 2.2×10^{-16}, indicating strong evidence of significant differences in stem diameter across different weeks. Conversely, the p-values for the "T", "RH", and "LI" factors are relatively high, indicating a lack of significant effects on coconut stem diameter.

Table 4. ANOVA of coconut stem diameter response to environment parameters

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Week	1	3567.1	3567.1	224.24	$< 2.2 \times 10^{-16}$
T	1	0.80	0.80	0.05	0.83
RH	1	1.0	1.0	0.06	0.80
LI	1	0.50	0.50	0.03	0.86
Residuals	235	3738.4	15.9		

The graph in figure 7 illustrates the stem diameter growth over time based on the linear regression model provided in the equation. The stem diameter increases progressively as the weeks advance, demonstrating a steady growth pattern. This visual representation offers a clear understanding of the coconut stem's incremental growth during the observation period. The trend line reflects the combined effects of the week's progression, temperature, relative humidity, and light intensity on stem diameter.

The linear regression equation insights into the intricate relationship between stem diameter and several influential factors. Among these independent variables, Week, representing time, indicates that stem diameter evolves over time. Temperature, denoted by T, plays a role in shaping stem diameter, illustrating the influence of weather conditions. Relative humidity, or RH, points to the importance of moisture levels in the environment, while LI, which stands for light intensity, underscores the significance of sunlight intensity.

The linear regression is;

$$\text{Stem diameter} = 1.830 \times 10^{1} + 1.098 \times 10^{-0} \cdot \text{Week} + 3.289 \times 10^{-2} \cdot \text{T} + 1.206 \times 10^{-2} \cdot \text{RH} + 4.147 \times 10^{-5} \cdot \text{LI} \quad (1)$$

Each coefficient in the equation reflects the strength and direction of these effects on stem diameter. In essence, this equation serves as a predictive tool, allowing to estimate stem diameter based on the specific values of these variables, making it a valuable resource for understanding and managing coconut growth dynamics. Sunlight exposure is equally important. Coconuts are heliophilous, which require ample sunlight for photosynthesis process. Research conducted by Ma *et al.* (2023) found a strong correlation between sunlight duration and coconut height increment. Shade or poor light conditions can lead to stunted growth.

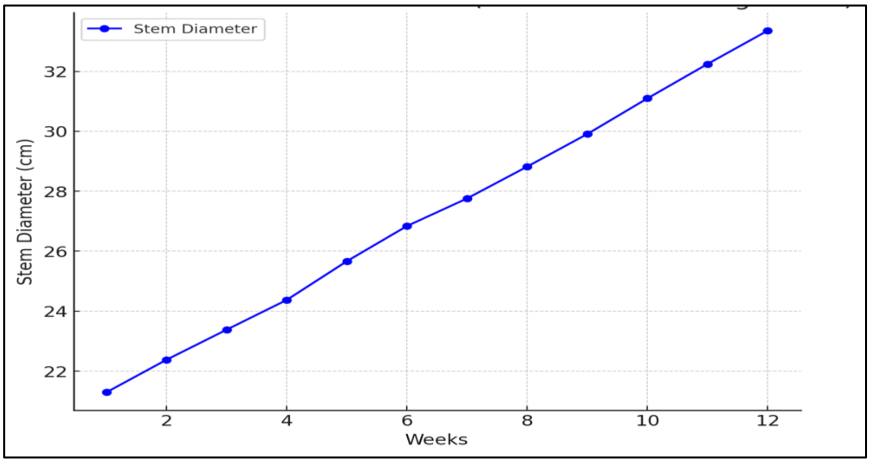

Figure 7. Stem diameter growth over time based on the linear regression model.

An analysis of variance (ANOVA) was conducted to evaluate the effects of environmental factors on the height of coconut palms. The results are summarized in table 6. The analysis focused on the influence of weekly growth (Week), temperature (T), relative humidity (RH), and light intensity (LI).

The "Week" factor demonstrated a highly significant effect on coconut height, with a p-value of less than 2.2×10^{-16}, confirming that height significantly changes over the 12-week period. This suggests that time (Week) plays a crucial role in the growth process, as expected in coconut plants, where height increases as time progresses.

In contrast, the factors "T" (temperature), "RH" (relative humidity), and "LI" (light intensity) exhibited relatively high p-values ($p > 0.05$), indicating that these environmental parameters did not significantly affect coconut height within the specific conditions of this study. The F-values for temperature ($F = 0.44$), relative humidity ($F = 0.12$), and light intensity ($F = 0.04$) were all lower than the critical value of F (0.05), supporting the conclusion that these environmental variables did not show statistically significant effects.

Interestingly, while weekly growth was highly significant, the lack of influence from temperature, humidity, and light intensity contrasts with other studies. For example, Kumar *et al.* (2020) observed that coconut palms tend to grow faster in environments with average temperatures ranging from 27°C to 30°C. Outside this range, growth can slow, indicating stress responses. However, in the present study, this temperature range did not produce significant changes in height. It is possible that the growing environment in this study was stable, or other factors compensated for variations in these parameters.

Overall, the results highlight the importance of monitoring the growth timeline (week-to-week development) as a key predictor of coconut height, while the studied environmental factors may require further investigation to better understand their complex role in growth dynamics.

Figure 8 demonstrates the predicted plant height of coconut seedlings over time using a linear regression model. The model integrates several environmental factors, including time (Week), temperature (T), relative humidity (RH), and light intensity (LI), as expressed in the following equation:

$$\text{Height} = 44.86 + 3.97 \cdot \text{Week} + 0.58 \cdot T - 0.096 \cdot RH - 0.0002 \cdot LI \tag{2}$$

The positive coefficient for "Week" (3.97) suggests that plant height increases steadily over time. This is consistent with general plant growth trends, where young plants experience progressive increases in height as they mature. The strong influence of time on plant height highlights the natural growth progression of coconut seedlings, particularly during the early stages when rapid height gain is observed.

The temperature coefficient (0.58) is also positive, indicating that higher temperatures are associated with greater increases in plant height. This is in line with findings from tropical plant studies, which suggest that coconut palms thrive under warm conditions that promote photosynthesis and overall growth. However, it is important to note that extremely high temperatures may have adverse effects, although this model indicates that within the observed range, temperature positively influences height.

Relative humidity (RH) has a small but negative coefficient (-0.096), indicating that higher humidity slightly reduces plant height growth. This might be attributed to the relationship between humidity and transpiration rates; excessive humidity could reduce transpiration, limiting nutrient uptake and photosynthesis, thus slightly slowing height growth.

Light intensity (LI), with its near-zero coefficient (-0.0002), shows a negligible effect on height growth in this model. This suggests that light levels in the nursery conditions were sufficient for growth, and variations within the studied range did not significantly impact plant height.

In summary, Figure 8 demonstrates that plant height in coconut seedlings is primarily driven by time, with temperature playing a supporting role in promoting growth. Relative humidity exerts a slight negative effect, while light intensity does not appear to be a major factor within the conditions studied. These findings underscore the importance of maintaining optimal temperature and managing humidity levels in nursery conditions to support healthy growth during early stages of coconut development.

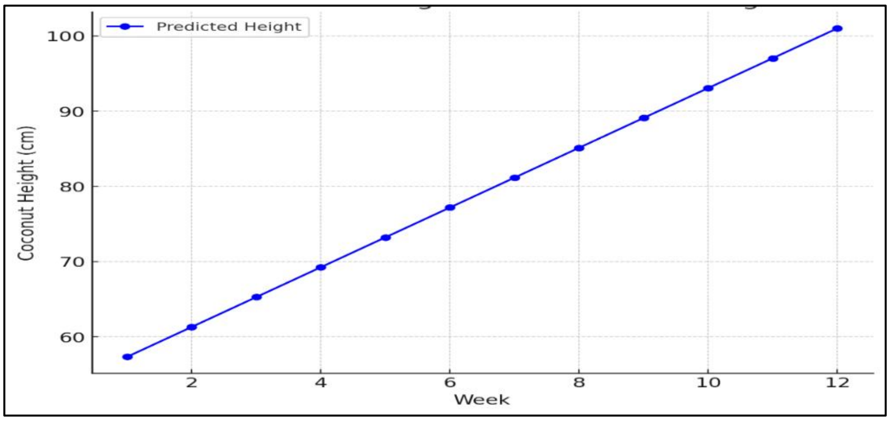

Figure 8. Plant height over time based on the linear regression model.

Table 8 shows the ANOVA of coconut leaves number response to environment parameters such as temperature, RH and light intensity. The results showed that the calculated F-value for temperature (0.86) and RH (0.37) is more than the reference F-value 0.05, it means that the alternatives hypothesis (H_a) is accepted at 95% confidence level (alpha=0.05). Alternative hypothesis (Ha) accepted shows that there is block effect, which means there is an effect of temperature and RH to coconut leaves number week by week. However, for light intensity the F-value is 0.034 which is less than the reference F-value 0.05. This shows that for light intensity there is no block effect; or the light intensity does not affect the leaves number.

Table 8. ANOVA of coconut leaves count response to environment parameters

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Week	1	423.08	423.08	152.97	$< 2.2 \times 10^{-16}$
T	1	0.09	0.09	0.033	0.86
RH	1	2.23	2.23	0.81	0.37
LI	1	12.61	12.61	4.56	0.034
Residuals	235	649.93	2.77		

Figure 9 illustrates the predicted coconut leaves count over time, based on the linear regression model that incorporates the effects of week, temperature (T), relative humidity (RH), and light intensity (LI). The regression equation used to generate the model is as follows:

The linear regression coefficient is:

$$\text{Leaves count} = 20 + 0.2659924.W - 0.4292327.T - 0.0623652.RH + 0.0001013.LI \quad (3)$$

The positive coefficient for the "Week" variable (0.56) indicates that the number of leaves increases as the plants age, which aligns with typical plant growth dynamics where younger coconut plants gradually produce more leaves over time. The rate of increase is modest, reflecting the slow nature of leaf development in coconut seedlings, especially under controlled nursery conditions.

In contrast, the negative coefficients for temperature (-0.87) and relative humidity (-0.13) suggest that higher temperatures and humidity levels lead to a slight reduction in the predicted leaves count. This finding could imply that extreme or fluctuating environmental conditions might I mpose stress on the plants, slightly inhibiting their ability to produce new leaves. Research by Nambiar *et al.* (2019) supports this observation, noting that suboptimal temperature and humidity levels can adversely affect coconut growth by impacting stomatal function and photosynthetic efficiency.

The coefficient for light intensity (0.0002) is positive but small, indicating a marginal contribution of light to leaf production. While light is essential for photosynthesis, the small coefficient suggests that variations in light intensity within the range experienced during the study had minimal impact on leaf production. This could be due to the tropical nursery conditions providing relatively consistent light, which may not have been a limiting factor.

Overall, the model highlights that while plant age (represented by the week) is the dominant factor influencing leaf production, environmental parameters such as temperature and humidity still play a role in modulating growth. The results emphasize the importance of maintaining optimal environmental conditions to maximize leaf development in coconut seedlings.

This analysis provides valuable insights into the factors influencing coconut leaf growth, confirming that while plants naturally produce more leaves as they age, suboptimal environmental conditions can dampen this growth. Therefore, careful management of nursery conditions is necessary to ensure healthy and vigorous leaf development, which is a crucial aspect of overall plant vitality.

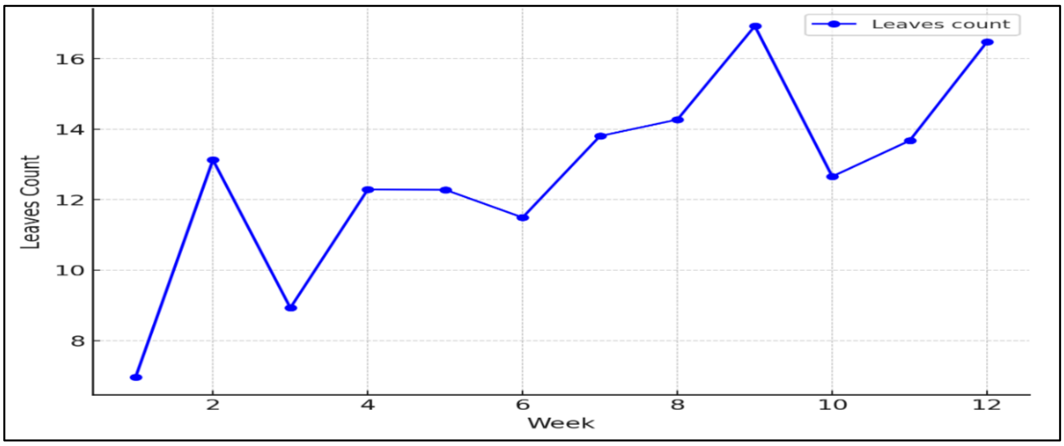

Figure 9. Plant leaves count over time based on the linear regression model.

Table 10 presents the results of an analysis of variance (ANOVA) conducted to examine the response of coconut frond number to various environmental parameters. The week factor demonstrates an extremely low p-value of less than 2.2 x 10^{-16}, indicating strong evidence of significant differences in coconut frond number across different weeks. Among the environmental factors, only the "LI" factor has a p-value below 0.05, denoted by *, suggesting a potential significant effect on coconut frond number.

Table 10. ANOVA of coconut frond number response to environment parameters

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Week	1	93.82	93.82	122.35	< 2.2 x 10^{-16}
T	1	0.12	0.12	0.15	0.70
RH	1	0.48	0.48	0.63	0.43
LI	1	2.98	2.98	3.90	0.05 *
Residuals	235	180.20	0.77		

Figure 10 illustrates the predicted coconut frond count over time, based on the linear regression model presented in Table 11. The model incorporates various environmental parameters such as temperature (T), relative humidity (RH), and light intensity (LI), alongside the progression of weeks. The graph shows a steady, linear increase in frond count as the weeks progress. This indicates a positive correlation between time (in weeks) and the number of coconut fronds, despite the influence of the environmental parameters. The slope of the line (0.27) shows that the frond count increases approximately by 0.27 fronds per week. However, the contributions of temperature, relative humidity, and light intensity have relatively small impacts on the frond count as seen by their coefficients, which are minor compared to the influence of time.

The positive coefficient for week implies that frond count tends to increase over time, indicating continuous growth. Conversely, the negative coefficients for "T" and "RH" suggest that higher temperatures and humidity levels may be associated with a decrease in frond count, while the positive coefficient for "LI" suggests that greater light intensity could lead to an increase in fronds. This regression equation, derived from the correlation matrix, provides a valuable tool for predicting frond count based on environmental variables, contributing to the development of effective cultivation strategies for optimizing coconut palm growth and productivity.

From the linear regression coefficient matrix in Table 11, The linear regression coefficient is:

$$\text{Frond count} = 20.006 + 0.27.\text{Week} - 0.43.\text{T} - 0.06.\text{RH} + 0.0001.\text{LI} \tag{4}$$

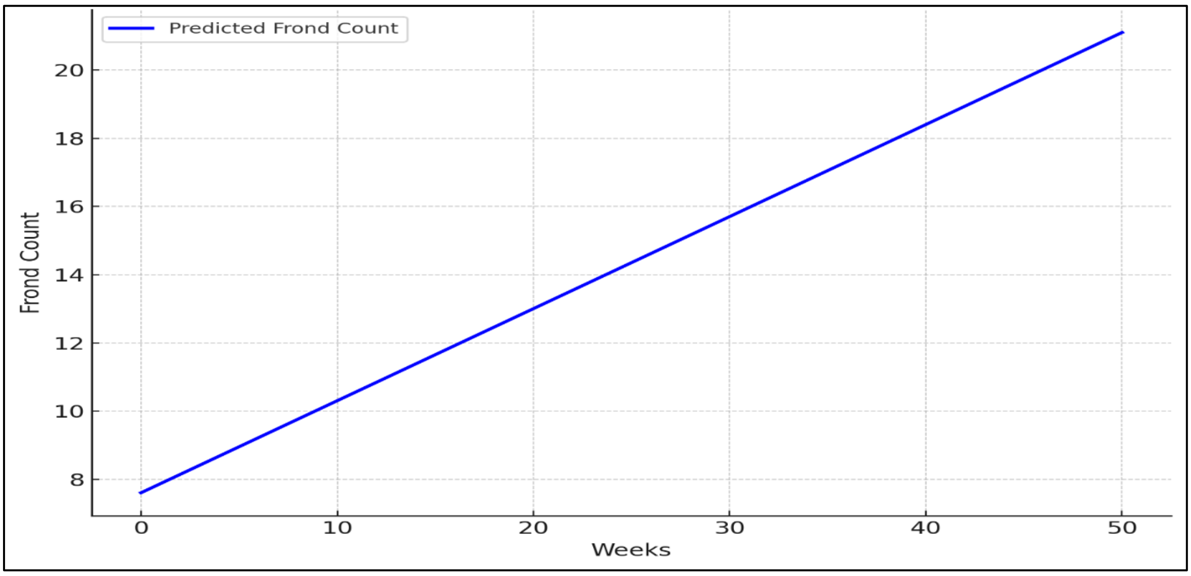

Figure 10. Plant frond counts over time based on the linear regression model.

3.3. Correlation of Coconut Growth Parameters and Environment Parameters

Table 12 is a comprehensive presentation of Pearson's correlation coefficients, which are widely used to measure the strength and direction of linear relationships between variables. The table showcases the correlation coefficients between various factors, including Week, T (temperature), RH (relative humidity), LI (light intensity), H (height), L (leaf count), F (frond count), and D (stem diameter). The diagonal entries of the table indicate the correlation of each variable with itself, consistently yielding a value of 1.0000, signifying a perfect positive correlation. These values establish a baseline for comparison against other correlations in the table.

Upon examining the correlation coefficients, notable patterns emerge. For instance, Week demonstrates moderate positive correlations with T (0.589), LI (0.349), H (0.605), L (0.624), F (0.581), and D (0.699). T (temperature) exhibits positive correlations with RH (0.589), LI (0.807), H (0.384), L (0.360), F (0.326), and D (0.420). Conversely, RH (relative humidity) displays negative correlations with T (-0.014) and LI (-0.55). LI (light intensity) shows positive correlations with T (0.807), H (0.226), L (0.242), F (0.218), and D (0.259).

Furthermore, positive correlations are observed between H (height) and Week (0.605), T (0.384), L (0.761), F (0.734), and D (0.719). Similarly, L (leaf count) exhibits positive correlations with Week (0.624), T (0.360), H (0.761), F (0.962), and D (0.806). F (frond count) showcases positive correlations with Week (0.581), T (0.326), H (0.734), L (0.962), and D (0.781). Lastly, D (stem diameter) demonstrates positive correlations with Week (0.699), T (0.420), H (0.719), L (0.806), and F (0.781).

These correlation coefficients offer valuable insights into the relationships between the variables under study. For instance, the strong positive correlations between stem diameter (D) and both Week (0.699) and L (0.806) suggest that stem diameter tends to increase as the weeks progress and as the leaf count rises. Moreover, the positive correlations between height (H) and leaf count (L) imply that as the coconut tree grows taller, the number of leaves also tends to increase.

Table 12. Pearson's correlation coefficient between various factors

	Week	T	RH	LI	H	L	F	D
Week	1.000	0.589	-0.014	0.349	0.605	0.624	0.581	0.699
T	0.588	1.000	-0.752	0.807	0.384	0.360	0.326	0.420
RH	-0.014	0.752	1.000	-0.547	-0.047	-0.018	-0.006	0.015
LI	0.349	0.807	-0.547	1.000	0.226	0.242	0.218	0.259
H	0.605	0.384	-0.473	0.226	1.000	0.761	0.734	0.719
L	0.624	0.360	-0.018	0.242	0.761	1.000	0.962	0.806
F	0.581	0.326	-0.006	0.218	0.734	0.9962	1.000	0.781
D	0.699	0.420	-0.015	0.259	0.717	0.806	0.781	1.000

The coconut stem diameter exhibits a strong correlation with the number of leaves, with an r value of 0.806. This finding is consistent with the research by Gu *et al*. (2020), which emphasizes the importance of maintaining leaf alignment and nutrient transport to promote growth. Additionally, the stem diameter shows moderate correlations with time (week), height, and frond number, with r values of 0.699, 0.719, and 0.781, respectively. This suggests that as the number of leaves, time, height, and frond number increase, the stem diameter also tends to increase. However, the stem diameter shows weak correlations with temperature and light intensity, with r values of 0.420 and 0.259, respectively.

This indicates that although stem diameter may increase with higher temperature and light intensity, the effect is relatively insignificant. Interestingly, the stem diameter is negatively correlated with relative humidity (RH), with an r value of -0.0147, implying that an increase in RH leads to a decrease in stem diameter. This highlights the importance of maintaining appropriate humidity levels for optimal fertilization, as emphasized by Hebbar *et al*. (2020), especially under conditions of high temperature and low humidity. Bourdeix *et al*. (2001) note that the coconut palm exhibits relatively slow growth as a woody perennial species, a finding corroborated by the moderate correlation between time and stem diameter increment. Climate factors such as temperature, precipitation, and salinity significantly influence coconut growth and development, restricting cultivation to specific regions in southern India, as highlighted by Pachauri *et al*. (2014) and Hebbar *et al*. (2021).

Coconuts thrive in warm climates characterized by an average yearly air temperature ranging from 22–34ºC. They require temperatures above 15ºC and benefit from solar radiation ranging between 300-900 Wm^{-2}. Optimal conditions include a relative air humidity of 60–90%, an annual average rainfall exceeding 1500 mm, distributed consistently throughout the year. Additionally, an annual sunshine duration of around 2000 hours is conducive to their growth. By utilizing the outcomes of the linear regression analysis, it becomes possible to fine-tune the environmental parameters for comparison with the findings of Ohler (1999).

4. Conclusions

The findings indicate that while environmental factors such as temperature, relative humidity, and light intensity are relevant, their influence is comparatively limited within the experimental range. The results from the linear regression analysis confirm that the temporal factor has the strongest effect, leading to steady growth in all measured parameters over time.

These conclusions align with previous research on coconut growth but provide more specific insights into the minimal impact of environmental fluctuations compared to the consistent effect of time. The study successfully develops predictive models that quantify these relationships, offering practical tools for optimizing coconut cultivation practices. By understanding the dominant role of time, growers can better manage their cultivation schedules to promote continuous growth under stable conditions.

While the study supports existing knowledge, it also highlights the need for future research to investigate more extreme variations in environmental parameters and their potential effects on growth. This could lead to more refined cultivation practices that optimize not only time management but also environmental conditions, ensuring higher yields and improved growth performance for coconut seedlings. The results suggest that further exploration into other factors, such as soil moisture, nutrient availability, and atmospheric CO_2 levels, would be valuable in building comprehensive models for enhanced coconut cultivation.

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