

## The Effects of NPK Fertilizer and Coconut Husk Ash as Ameliorant on Growth and Photosynthetic Rate of Oil Palm Seedlings in Peat Media

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**Abstract**—This study aimed to investigate the effects of NPK fertilizer and coconut husk ash as an ameliorant on growth and photosynthetic levels of oil palm seedlings in peat soil growth media. A Completely Randomized Design (CRD) was used with two factors, NPK 12:12:17:2+TE including control, 30 g, 60 g, and 90 g per plant. Coconut husk ash includes control, 40 g, 80 g, and 120 g per plant. The data were statistically analyzed using ANOVA, and any observed significant difference led to Duncan's test at  $p < 0.05$ . The combination of 90 g of fertilizer dose and 80 g of coconut husk ash produced the tallest plant height of 104.53 cm. The highest increase in stem girth was 6.01 cm. The photosynthetic rate was  $39.11 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ , and the highest stomatal conductance was  $0.21 \text{ H}_2\text{O m}^{-2} \text{ s}^{-1}$ . The highest internal  $\text{CO}_2$  and Water Use Efficiency was  $177 \mu\text{mol CO}_2 \text{ mol}^{-1}$  and 16.15, respectively, while the best transpiration rate was  $2.94 \text{ mM H}_2\text{O m}^{-2} \text{ s}^{-1}$ . Additionally, the photosynthetic rate positively correlated with seedling height and stem diameter, with a  $R^2$  0.25 and 0.44 coefficient, respectively. Stomatal conductance was positively correlated with stem diameter, namely  $R^2$  0.04. Meanwhile, transpiration rate was negatively correlated with seedling height ( $R^2$  17%) and seedling stem diameter ( $R^2$  6.9%). Intracellular  $\text{CO}_2$  was negatively correlated with plant height but positively correlated with stem diameter. The results of this study are expected to be used in increased growth and photosynthesis.

**Keywords**— Oil palm; fertilizer; ameliorant; elevated; growth; physiological.

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### I. INTRODUCTION

Oil palm is a strategic crop commodity that has high economic value and occupies a crucial position in the plantation industry for both domestic and export needs. Furthermore, it is currently the largest vegetable oil crop in the world. According to [1], the estimated area of Indonesian oil palm plantations reached 16.18 million ha in 2021, showing an increase of 0.24% compared to 14.59 million ha in 2020. This trend suggests a tendency for further expansion despite the 60.11% increase recorded over the last decade, precisely from 2011 to 2021. The private sector owns most of the plantations, accounting for 6.03 million ha, and the remaining 550,333 h belongs to the state. The most significant part of the cultivated land, which covers 2.86 million ha, is found in Riau, among other provinces.

To cater to the increasing oil palm area and replace old plants, large amounts of healthy seeds with strong vigor need to be raised in a growing medium rich in organic matter [2]. Coconut husk ash is an example of organic material waste processed into ameliorant to achieve this objective. In Riau, the soil conditions present are dominated by nutrient-poor dry fields. Moreover, swamp land covers up to 51.06% or 4,827,972 ha of the province area [3]. The land surface includes peat, a mass of semi-decomposed organic matter, which is divided into three stages of maturity, namely capric (ripe), hemic (half-ripe), and fabric (raw). Sapric peat is characterized by a matured color, ranging from dark brown to black, and retains a fiber content of  $<15\%$  when pressed by hand. The fertility level is low [4] due to its insufficient macro and micronutrient content, as well as its acidic nature with  $\text{pH} < 4$  ([5]).

The adequate addition of NPK 12:12:17:2+TE is one potential solution to the challenges of employing peat soil as a nursery medium. This compound fertilizer contains several macro and micronutrients commonly used for nurseries and young plants. Although the nitrogen and phosphate content is relatively low, the high potassium content supports plant growth during the vegetative phase. The composition of NPK 12:12:17:2+TE is 12% nitrogen, 12% phosphate, 17% potassium, 2% magnesium, and 0.04-0.07% micronutrients, including Boron, Zn, and Cu. Applying NPKMg fertilizer (12:12:17:2) at a dose of 30 g/plant significantly affected all parameters in coconut seedlings. [6] reported that applying 50 g/seedling of NPK fertilizer promoted better growth than doses of 35 g/seedling, 15 g/seedling, and the control. Other organic fertilizers can also increase soil fertility and plant growth. The air temperature factor affecting plant growth can have positive and negative impacts.

Coconut production in Riau province is estimated at 400,000 tons per year, and the weight of coconut fiber is 35%. Annual coconut fiber production in Riau Province is estimated at around 140,000 tons annually. This large capacity can be used as the main ingredient to produce potassium. Coconut husk waste can be used as an ameliorant to enhance soil quality by burning to obtain ash containing a high pH (11.77%) and total K content (21.87%), as well as low C-Organic (0.01%), total N (0.03%), and total P (2.31%), with good cation exchange capacity value of 13.29 me/100g.

Furthermore, its main components are lignin and cellulose, which require a long time to be naturally decomposed along with hemicellulose and pectin by microbes [7]. The production of 1 kg each of coconut husk and cocopeat requires five coconuts, while 1 kg of husk dust requires 16 [8]. Coconut husk ash treatment increased soil available K for up to 4 months after planting (MAP). The application of 39.25g of coconut husk ash led to the highest K uptake and sustained availability of K in the soil till 4 MAP. Furthermore, [9] stated that a dose of 100 g/plant of oil palm shoot ash significantly increased the diameter of seedling humps. An application of coconut husk waste can increase the production of oil palm [10], shallots, and all cultivated plants

Oil palm has gained worldwide recognition for its positive health implications, discovered through studies conducted with its leaf extract. The plant growth and physiological aspects, including photosynthesis, stomata conductance, internal CO<sub>2</sub>, and transpiration, are often affected by fertilizer, ameliorant, and weather. Several factors, such as atmospheric CO<sub>2</sub>, environmental nutrient reserve, temperature, and light, influence these. Increased atmospheric CO<sub>2</sub> due to climate change can directly impact plant physiology [11], [12]. The concentration of CO<sub>2</sub> in the atmosphere has increased from 280 ppm in pre-industrial times to 400 ± 50 ppm currently, with a projection to reach 530-970 ppm by the end of the 21<sup>st</sup> century [13]. Therefore, this study aimed to investigate the effects of NPK 12:12:17:2+TE fertilizer and coconut husk ash on oil palm seedlings raised in peat soil growth media.

## II. MATERIALS AND METHODS

This study was conducted from January to June 2022 in the Experimental Garden of the Faculty of Agriculture, Universitas Islam Riau. The materials used were DxP Sain 2

Ekona (Tenera) variety of oil palm seedlings, coconut husk ash from self-made, and NPK 12:12:17:2+TE fertilizer from the farm shop of Pekanbaru, Riau. Meanwhile, the equipment employed included the LI-COR 6400XT Portable Photosynthesis System and the SPAD 502 chlorophyll meter.

A CRD was applied in a factorial manner consisting of two factors: coconut husk ash and NPK 12:12:17:2+TE. The factors comprised four levels each, making 16 treatment combinations with three replications for 48 experimental plots. Each plot contained six plants, from which three were used as observation samples, amounting to 288 plants. Doses of the treatment factors were controlled, 40, 80, and 120 g/plant for coconut husk ash, and control, 30, 60, and 90 g/plant for fertilizer.

The land used was 18 m long and 9 m wide, totaling 162 m<sup>2</sup>, cleared of trash, grass, and wood. Oil palm seeds nursed for the experimental process were four months old, each with four to five leaves and a 15-30 cm height. The NPK 12:12:17:2+TE treatment was administered in nine stages with an interval of 15 days after the first application during planting. Sapric peat soil was extracted from the soil surface at 0-20 cm. This was filled into polybags measuring 30 cm x 35 cm to reach a 2 cm level from the edges, weighing 10 kg soil. The polybags were arranged parallel to one another with a spacing of 90 cm x 90 cm. They were labeled with a zinc plate three weeks before planting. Coconut husk ash of 160 kg was collected, of which only 18 kg was required for this study. This was applied once 14 days before planting and mixed with peat soil until evenly distributed. Then, the mixture was transferred back into the polybags.

A 10 cm pipette stake was installed during seed planting to measure plant height by inserting it into the polybags at the stem base. Daily watering began after filling the polybags as required. Moreover, pests such as grasshoppers, night beetles, and caterpillars attack oil palm seedlings aged 2, 7, and 12 weeks by boring holes into the surface and base of the young leaves. They were controlled by spraying Decis insecticide containing deltamethrin at a dose of 2 ml<sup>-1</sup> of water and repeated every 1-2 weeks. Anthracnose and leaf spot diseases attacking the seedlings at the age of four weeks after planting were controlled by spraying Antracol fungicide with Propineb, an active ingredient, at a dose of 2 g<sup>-1</sup> of water every 7-10 days.

Growth in each experimental plot was evaluated with plant height, hump diameter, and chlorophyll content. Meanwhile, physiological observations included net photosynthesis, stomatal conductance, intercellular CO<sub>2</sub>, transpiration rate, WUE, and chlorophyll content. The measurements were conducted with matured leaves on the fifth branch from the growing point using the LI-COR 6400XT Portable Photosynthesis System (LI-COR Inc., Lincoln, Nebraska, USA) at 1000 mol PAR (Photosynthetically Active Radiation) and 1000 μmol m<sup>-2</sup> s<sup>-1</sup>. Photosynthetic observations were carried out from 8.00 - 11.00 am on sunny days. The girth size was measured at 5 cm from the planting medium using a digital Vernier caliper. The chlorophyll content of leaf blades from the third frond with a visually green color at the midrib was measured with a SPAD-502 chlorophyll meter (Minolta Camera Co., Osaka, Japan). The leaf sample was placed in the chlorophyll meter head slot and pressed down during the process. After closing the head above

the leaf, the meter sounded, and the automatic measurement results that appeared on the screen were stored in the tool.

The research used was a randomized block design and data on growth morphology were statistically analyzed using Analysis of Variance (ANOVA) with SAS 9.1.3 software. When the treatment had a significant effect, it was continued with the Duncan Multiple Range Test (DMRT) at  $p < 0.05$ . The linear model is as follows:

$$Y_{cf} = \mu + C_c + F_f + \sum(cfn) \quad (1)$$

where:

$Y_{cf}$ : The observed variable from colchicine the  $f$  level and the immersion time of the  $c$  level

$\mu$ : The effect of the mean value

$C_c$ : effect of the  $T$  factor on the  $t$  level

$F_f$ : Effect of factor  $F$  on level  $f$

$C_c F_f$ : effect of interaction between the  $C$  factor at the level to  $-c$  and the  $F$  factor to the  $f$  level  $\sum(cfn)$ : Error effect of factor  $C$  at the  $c$  level and the  $F$  factor at the  $f$  level and repetition up to  $n$

C: 0, 1, 2, 3 (coconut husk ash)

F: 0, 1, 2, 3 (NPK 12:12:17:2+TE Fertilier)

N: 1, 2, 3 (Repeat)

### III. RESULTS AND DISCUSSION

#### A. Plant Height

The analysis of variance (ANOVA) results showed that the height of oil palm seedlings aged 80, 110, and 140 DAT (days after transplant) was significantly different among the treatments. The post-hoc DMRT test at  $p < 0.05$  indicated that the combination treatment of 90 g NPK/plant + 120 g coconut husk ash/plant produced the tallest seedlings with a height of 79.20 cm compared to other treatment combinations and the control. The increase in height growth was 66.66% at the sample doses of 90 g NPK + 120 g coconut husk ash compared to the control sample. The shortest height of 47.52 cm was found in the control sample due to a lack of nutrients in the peat soil, and the average plant height can be seen in Table 1.

TABLE I  
PLANT HEIGHT OF OIL PALM SEEDS AGED 80, 110, 140 DAT WITH NPK 12:12:17:2+TE AND COCONUT HUSK ASH TREATMENT

Treatment	Plant height		
	80 DAT	110 DAT	140 DAT
Control	47.52± 0.27 f	57.66± 0.21 e	65.90± 1.18 b
Control + 40 g Coconut Husk Ash/plant	49.23± 0.35 e	70.56± 0.44 d	75.93± 0.18 b
Control + 80 g Coconut Husk Ash/plant	58.06± 1.18 de	67.53± 0.66 cd	83.06± 1.86 b
Control + 120 g Coconut Husk Ash/plant	59.70± 0.76 c-e	72.03± 0.57 b-d	82.03± 0.15 b
30 g NPK/plant + Control	63.53± 0.87 b-e	80.21± 1.46 a-c	108.06± 1.11 a
30 g NPK/plant + 40 g Coconut Husk Ash/plant	73.73± 0.91 a-c	86.23± 1.00 ab	98.90± 0.38 a
30 g NPK/plant + 80 g Coconut Husk Ash/plant	68.04± 0.50 a-d	84.70± 0.77 ab	102.63± 0.86 a
30 g NPK/plant + 120 g Coconut Husk Ash/plant	74.73± 0.47 a-c	87.06± 0.78 ab	98.76± 0.46 a
60 g NPK/plant + Control	62.96± 0.35 b-e	77.63± 0.34 a-c	100.96± 0.60 a
60 g NPK/plant + 40 g Coconut Husk Ash/plant	64.43± 0.52 a-d	81.10± 1.02 a-c	101.86± 0.67 a
60 g NPK/plant + 80 g Coconut Husk Ash/plant	73.90± 0.30 a-c	85.90± 1.16 ab	95.30± 0.50 a
60 g NPK/plant + 120 g Coconut Husk Ash/plant	77.46± 0.06 ab	80.13± 1.34 a-c	94.83± 0.85 a
90 g NPK/plant + Control	67.46± 0.99 a-d	88.40± 0.17 ab	102.16± 0.96 a
90 g NPK/plant + 40 g Coconut Husk Ash/plant	76.90± 0.19 ab	80.36± 0.38 a-c	98.96± 0.32 a
90 g NPK/plant + 80 g Coconut Husk Ash/plant	73.23± 0.63 a-c	89.16± 0.46 ab	103.23± 0.81 a
90 g NPK/plant + 120 g Coconut Husk Ash/plant	79.20± 1.56 a	90.46± 0.77 a	104.53± 0.96 a

Note: Mean ± standard error (SE) followed by different letter of the same day of treatment is significant tested using Duncan multiple range test at  $p < 0.05$ . DAT = Days After Transplanting.

Observations of the analyzed height of the seedlings at 110 DAT showed a significant increase. The combination treatment of 90 g NPK/plant + 120 g coconut husk ash/plant produced the tallest highest of 90.46 cm compared to the control, which was 57.66 cm. The increase in growth of the treated sample at 110 DAT was 56.88% higher than the control. Furthermore, the ANOVA results showed a significant effect on the observation of plant height at 140 DAT. Increasing the doses to the highest level of 90 g NPK/plant + 120 g coconut husk ash/plant produced the tallest seedlings with a height of 104.53 cm. Growth increased by 58.61% in the sample aged 140 DAT at the highest dose combination compared to the control. The other treatment combinations at 80, 110, and 140 DAT showed differences, but the height of the seedlings was still below the value found at the highest dose, as indicated in Figure 1. NPK fertilizer application was discovered to influence growth of seedlings [14]. The high growth rate of oil palm plants observed in this study (Figure 1) was consistent with other results reported by [15] that the addition of NPK fertilizer (16:16:16) increased

plant height. Also, NPK fertilizer was suspected to be capable of providing nutrients quickly for plant growth. The use of coconut husk ash for oil palm nurseries is not yet investigated, but it has been shown to be important in increasing growth of other plants. For example, [16] stated that coconut husk ash fertilizer could increase the productivity of local Bimapolut corn.



Fig. 1 Differences in growth of oil palm seedlings aged 140 DAT A) control, B) combination doses of 90 g NPK + 120 g coconut husk ash per plant.

### B. Stem Diameter

The ANOVA results for the stem diameter of seedlings aged 80, 110, and 140 DAT showed a significant difference among the different treatments. The post-hoc DMRT test at  $p < 0.05$  indicated that the treatment combination of 60 g NPK/plant + 120 g coconut husk ash/plant produced the largest stem diameter of 5.01 cm compared to other treatment combinations and the control treated. The average stem diameter for each treatment combination can be found in Table 2. The increase in stem diameter growth was 135.21% in the treated sample plants compared to the control. The smallest stem diameter of 2.13 cm found in the control sample was partly due to the low pH factor and the lack of essential nutrients in the peat soil.

The ANOVA results for the stem diameter of the seedlings aged 110 DAT showed a significant increase. The combination treatment of 60 g NPK/plant + 120 g coconut husk ash/plant yielded the best growth in stem diameter, namely 5.53 cm compared to the 2.46 cm recorded in the control. A stem diameter of 117.88% was observed in the treated sample aged 110 DAT compared to the control. Additionally, the results showed a significant effect on the stem diameter at 140 DAT, where the treatment combination of 60 g NPK/plant + 120 g coconut husk ash/plant produced the largest stem diameter of 6.60 cm. The increase in growth of the treated sample aged 140 DAT was 127.58% compared

to the control. The combination of treatments at the age of 80, 110, and 140 DAT with an NPK fertilizer dose of 60 g/plant was the most effective in stimulating seedling stem growth. An increase in the dose led to a decrease in the stem diameter growth as presented in Table 2.

The dose of coconut husk ash ameliorant had a positive correlation with the stem diameter growth as indicated in Figure 1. Meanwhile, the NPK fertilizer dose, according to [17], did not have a significant effect on stem diameter. The elevating the dose of NPK had no significant effect on the stem diameter of the seedlings, even though the diameter increased numerically. The combined dose of coconut husk ash and NPK showed a substantial effect on the size of the seedling stem. This occurred because the high k content (42.86%) of coconut husk ash could improve the structure of peat soils by enhancing the water absorption capacity [18]. Water is needed in the process of absorbing nutrients, specifically K, which plays a critical role in plant cell development. Also, K acts as a regulator of plant physiological processes such as photosynthesis, accumulation, translocation, carbohydrate transportation, and opening and closing of stomata [19]. [20] stated that the amount of time between watering significantly affected the plant height, stem diameter, root volume, as well as the number of leaves, roots, and major branches, while genetic variations and age influenced the height of oil palm seedlings.

TABLE II  
STEM DIAMETER OF OIL PALM SEEDLINGS AGED 80, 110, 140 DAT TREATED WITH NPK 12:12:17:2+TE AND COCONUT HUSK ASH

Treatment	Stem diameter		
	80 DAT	110 DAT	140 DAT
Control	2.13±0.20 g	2.46±0.01 i	2.90±0.20 g
Control + 40 g Coconut Husk Ash/plant	3.30±0.01 ef	3.63±0.20 hi	4.01±0.01 f
Control + 80 g Coconut Husk Ash/plant	3.46±0.05 d-f	3.70±0.30 hi	4.73±0.25 de
Control + 120 g Coconut Husk Ash/plant	3.83±0.05 c-e	4.06±0.01 gh	4.76 ±0.45 de
30 g NPK/plant + Control	2.90±0.01 f	3.76 ±0.45 hi	4.43±0.60 ef
30 g NPK/plant + 40 g Coconut Husk Ash/plant	4.63 ±0.40 ab	5.16± 0.50 a-c	6.01± 0.20 a-c
30 g NPK/plant + 80 g Coconut Husk Ash/plant	4.43±0.20 a-c	5.03 ± 0.40 a-d	5.90±0.01 bc
30 g NPK/plant + 120 g Coconut Husk Ash/plant	4.20± 0.20 bc	5.36±0.15 ab	5.83±0.10 bc
60 g NPK/plant + Control	3.96±0.05 cd	4.63±0.05 c-g	5.33± 0.35 cd
60 g NPK/plant + 40 g Coconut Husk Ash/plant	4.01 ± 0.25 b-d	4.41± 0.10 e-g	5.40±0.45 cd
60 g NPK/plant + 80 g Coconut Husk Ash/plant	4.260.20 bc	4.96±0.20 a-e	6.33±0.40 ab
60 g NPK/plant + 120 g Coconut Husk Ash/plant	5.01±0.25 a	5.53±0.10 a	6.60±0.15 a
90 g NPK/plant + Control	3.86±0.05 c-e	4.46±0.05 d-g	5.56± 0.10 c
90 g NPK/plant + 40 g Coconut Husk Ash/plant	3.86±0.20 c-e	4.36±0.10 fg	5.41±0.25 cd
90 g NPK/plant + 80 g Coconut Husk Ash/plant	4.13±0.20 bc	4.70±0.01 c-f	5.50±0.05 c
90 g NPK/plant + 120 g Coconut Husk Ash/plant	4.23± 0.10 bc	4.86±0.10 b-f	5.66±0.15 bc

Note: Mean ± standard error (SE) followed by different letter of the same days of treatment is significant tested using Duncan multiple range test at  $p < 0.05$ . DAT = Days After Transplanting

Based on the results, an increase in the dose of the combination treatment produced different responses for two of the observed growth parameters. Increasing the dose boosted the elevation in plant height, while it led to a slower stem diameter growth.

### C. Photosynthetic Rate

The ANOVA results for the photosynthetic rate of the seedlings aged 80, 110, and 140 DAT showed a significant difference. The post-hoc DMRT test at  $p < 0.05$  indicated that the highest photosynthetic rate of  $35.48 \mu\text{M CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  was obtained with 90 g NPK/plant + 80 g Coconut Husk Ash/plant compared to other treatment combinations. In contrast, the control sample had a non-significant value of  $34.41 \mu\text{M CO}_2$

$\text{m}^{-2} \text{ s}^{-1}$  and the average can be seen in Table 3. The lowest value of  $31.0 \mu\text{M CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  was found in the Control + 40 g coconut husk ash /plant, and increasing the dose of fertilizer and ameliorant was observed to affect the photosynthetic rate.

The ANOVA at 110 DAT showed a significant difference, where the higher age of the seedlings and elevation in the treatment doses led to the highest increase in photosynthetic rate. The combination of 90 g NPK/plant + 120 g coconut husk ash/plant produced  $37.62 \mu\text{M CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ . The lowest rate was observed at a dose of 40 g coconut husk ash/plant, while the control sample had a higher rate. At 140 DAT, the greatest value of  $39.11 \mu\text{M CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  was recorded from the highest treatment combination, namely 90 g NPK/plant + 120 g coconut husk ash/plant. The smallest rate of  $30.07 \mu\text{M CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  was obtained with the Control + 120 g coconut husk

ash/plants. This combination initiated the greatest rate decrease, while other treatments showed an increase in photosynthesis. The decrease in photosynthetic rate, which was observed in both coconut husk ash and control treatments,

was also evident in some other treatment combinations. This could be attributed to the limited nutrients present in the control sample and coconut husk ash.

TABLE III  
PHOTOSYNTHETIC RATE OF OIL PALM SEEDLINGS AGED 80, 110, 140 DAT TREATED WITH NPK 12:12:17:2+TE AND COCONUT HUSK ASH

Treatment	Photosynthetic rate		
	80 DAT	110 DAT	140 DAT
Control	34.41± 0.27 ab	34.64±0.21 b-d	32.28±1.18 hi
Control + 40 g Coconut Husk Ash/plant	31.69± 0.87 f	33.42±1.46 d	31.36±1.12 ij
Control + 80 g Coconut Husk Ash/plant	32.69±0.35 d-f	37.01±0.34 ab	36.95±0.60 a-d
Control + 120 g Coconut Husk Ash/plant	33.21±0.99 b-f	35.65±1.18 a-d	30.07±0.97 j
30 g NPK/plant + Control	34.19±0.35 a-e	37.36±0.45 a	33.14±0.19 g-i
30 g NPK/plant + 40 g Coconut Husk Ash/plant	32.58±0.91 ef	33.99±1.01 cd	36.46±0.39 b-e
30 g NPK/plant + 80 g Coconut Husk Ash/plant	34.32±0.52 a-d	35.55±1.03 a-d	37.11±0.67 a-c
30 g NPK/plant + 120 g Coconut Husk Ash/plant	32.69±0.19 d-f	36.68±0.38 ab	34.71±0.33 d-g
60 g NPK/plant + Control	33.10±1.18 b-f	35.61±0.66 a-d	34.42±1.86 e-h
60 g NPK/plant + 40 g Coconut Husk Ash/plant	32.93±0.50 b-f	36.38±0.77 a-c	35.54±0.86 b-f
60 g NPK/plant + 80 g Coconut Husk Ash/plant	34.35±0.31 a-c	37.11± 1.16 ab	37.77±0.50 ab
60 g NPK/plant + 120 g Coconut Husk Ash/plant	32.68±0.63 d-f	36.71±0.46 ab	36.67±0.82 b-e
90 g NPK/plant + Control	34.04±0.76 a-e	35.61±0.57 a-d	33.68±0.16 f-h
90 g NPK/plant + 40 g Coconut Husk Ash/plant	33.55±0.47 b-e	35.22±0.78 a-d	35.34±0.46 c-g
90 g NPK/plant + 80 g Coconut Husk Ash/plant	35.48±0.06 a	37.56±1.34 a	37.54±0.85 a-c
90 g NPK/plant + 120 g Coconut Husk Ash/plant	32.73±1.56 c-f	37.62±0.78 a	39.11±0.93 a

Note: Mean ± standard error (SE) followed by different letter of the same days of treatment is significant tested using Duncan multiple range test at  $p < 0.05$ . DAT = Days After Transplanting.

A 19.48% increase was observed in the photosynthetic rate of seedlings aged 80 to 140 DAT treated with the combination of 90 g NPK + 120 g coconut husk ash. The nutrients of N, P, and K were sufficient to increase the seedling height. According to [21], adequate N levels can accelerate the growth of stems and leaves, P supports cell growth, and K is needed for enzyme activation, which promotes photosynthesis from leaves to other plant organs.

#### D. Stomatal Conductance

A significant effect was also found on the stomatal conductance of seedlings aged 80, 110, and 140 DAT. The combination of 30 g NPK/plant + 120 g coconut husk ash/plant yielded the highest stomatal conductance of  $0.21 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$  compared to other treatments. However, the control produced a significant value of  $0.17 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$ , and the average can be seen in Table 4. Not all fertilizer and ameliorant doses yielded a higher value than the control. Some were even lower. For example, 30 g NPK + 80 g coconut husk ash produced  $0.09 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$ .

At 110 DAT, 60 g NPK/plant + Control produced the highest value of  $0.24 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$  compared to other treatment combinations, while the control yielded a non-significant value. The lowest value of  $0.15 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$  was obtained from 30 g NPK/plant + Control. Different increases in stomatal conductance were found at ages 80 DAT and 120 DAT, indicating that the measurement results did not depend on the variable. These were evident by the higher values discovered from the control sample.

The combination of 90 g NPK/plant + 120 g coconut husk ash/plant yielded the highest stomatal conductance value of  $0.21 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$  at 110 DAT. The lowest value of  $0.10 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$  was found in the 30 g NPK/plant + Control treatment. The analysis results at the three observation times showed that the values fluctuated and varied, making it difficult to determine the best treatment. Stomatal conductance is a crucial process for gas exchange in plants.

At 110 DAT, 60 g NPK/plant + Control produced the highest value of  $0.24 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$  compared to other treatment combinations, while the control yielded a non-significant value. The lowest value of  $0.15 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$  was obtained from 30 g NPK/plant + Control. Different increases in stomatal conductance were found at ages 80 DAT and 120 DAT, indicating that the measurement results did not depend on the variable. These were evident by the higher values discovered from the control sample.

The combination of 90 g NPK/plant + 120 g coconut husk ash/plant yielded the highest stomatal conductance value of  $0.21 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$  at 110 DAT. The lowest value of  $0.10 \text{ mol H}_2\text{O m}^{-2} \text{ s}^{-1}$  was found in the 30 g NPK/plant + Control treatment. The analysis results at the three observation times showed that the values fluctuated and varied, making it difficult to determine the best treatment. Stomatal conductance is a crucial process for gas exchange in plants. During the day, stomata are usually open to enable the entry of  $\text{CO}_2$  for photosynthesis and oxygen for respiration. Stomata play a vital role in regulating water flow between plants and the atmosphere. They also control plant growth and mass, as well as energy cycles.

TABLE IV  
STOMATAL CONDUCTANCE OF OIL PALM SEEDLINGS AGED 80, 110, 140 DAT TREATED WITH NPK 12:12:17:2+TE AND COCONUT HUSK ASH

Treatment	Stomatal conductance		
	80 DAT	110 DAT	140 DAT
Control	0.17± 0.018 bc	0.19± 0.024 a-e	0.16 ± 0.010 b-d
Control + 40 g Coconut Husk Ash/plant	0.11±0.001 de	0.19± 0.016 a-e	0.15 ± 0.023 c-e
Control + 80 g Coconut Husk Ash/plant	0.12±0.020 de	0.18±0.006 b-e	0.17 ± 0.012 a-d
Control + 120 g Coconut Husk Ash/plant	0.13±0.017 cd	0.17± 0.006 c-e	0.16 ± 0.021 b-e
30 g NPK/plant + Control	0.13±0.024 cd	0.15± 0.006 e	0.10 ± 0.027 f
30 g NPK/plant + 40 g Coconut Husk Ash/plant	0.16±0.006 bc	0.20± 0.026 a-d	0.15 ± 0.013 c-e
30 g NPK/plant + 80 g Coconut Husk Ash/plant	0.09±0.001 e	0.21± 0.001a-d	0.15 ± 0.019 c-e
30 g NPK/plant + 120 g Coconut Husk Ash/plant	0.21±0.005 a	0.19± 0.017 a-e	0.17 ± 0.006 a-d
60 g NPK/plant + Control	0.18±0.011 ab	0.24± 0.012 a	0.19 ± 0.002 a-c
60 g NPK/plant + 40 g Coconut Husk Ash/plant	0.18±0.011 ab	0.19± 0.015 a-e	0.19 ± 0.015 a-c
60 g NPK/plant + 80 g Coconut Husk Ash/plant	0.16±0.004 bc	0.21± 0.004 a-d	0.14 ± 0.011 d-f
60 g NPK/plant + 120 g Coconut Husk Ash/plant	0.17±0.009 bc	0.22± 0.006 a-c	0.19 ± 0.005 a-c
90 g NPK/plant + Control	0.18±0.011 ab	0.17± 0.009 de	0.12 ± 0.010 ef
90 g NPK/plant + 40 g Coconut Husk Ash/plant	0.19±0.001 ab	0.20± 0.003 a-d	0.20 ± 0.015 ab
90 g NPK/plant + 80 g Coconut Husk Ash/plant	0.15±0.006 bc	0.23± 0.013 ab	0.16 ± 0.008 b-e
90 g NPK/plant + 120 g Coconut Husk Ash/plant	0.19±0.005 ab	0.21± 0.010 a-d	0.21 ± 0.003 a

Note: Mean ± standard error (SE) followed by different letter of the same days of treatment is significant tested using Duncan multiple range test at  $p < 0.05$ . DAT = Days After Transplanting.

### E. Transpiration Rate

The transpiration rate of seedlings aged 80, 110, and 140 DAT showed significant results. The lowest and best rate, namely 2.59 mM H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup>, was produced by the combination of 60 g NPK/plant + 40 g coconut husk ash/plant. However, 3.59 mM H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup> was obtained from the control

sample, and the average can be seen in Table 5. The transpiration rate decreased with the increase of fertilizer and ameliorant dose, and a smaller value appeared to be better. The Control positive 80 g coconut husk ash/plant yielded the highest value of 4.86 mM H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup> and the energy released in this process was wasted.

TABLE V  
TRANSPIRATION RATE OF OIL PALM SEEDLINGS AGED 80, 110, 140 DAT TREATED WITH NPK 12:12:17:2+TE AND COCONUT HUSK ASH

Treatment	Transpiration rate		
	80 DAT	110 DAT	140 DAT
Control	3.59±0.40 b-e	6.51±0.59 g	5.89± 0.48 f
Control + 40 g Coconut Husk Ash/plant	4.86 ±0.52 f	5.93±0.61 fg	4.94±0.69 ef
Control + 80 g Coconut Husk Ash/plant	3.82 ±0.11 de	5.48±0.28 c-f	4.62±0.07 de
Control + 120 g Coconut Husk Ash/plant	3.87±0.19 de	4.23±0.05 ab	3.07±0.31 ab
30 g NPK/plant + Control	4.79± 0.08 c-e	5.21±0.44 d-f	3.71± 0.52 cd
30 g NPK/plant + 40 g Coconut Husk Ash/plant	3.69±0.20 b-e	5.01± 0.33 b-d	4.38± 0.55 c-e
30 g NPK/plant + 80 g Coconut Husk Ash/plant	4.33±0.16 ef	5.07±0.05 b-d	4.88±0.22 ef
30 g NPK/plant + 120 g Coconut Husk Ash/plant	4.32±0.04 ef	5.42±0.06 b-e	5.51±0.29 f
60 g NPK/plant + Control	3.11±0.47 b-d	5.56±0.17 c-f	5.06±0.16 ef
60 g NPK/plant + 40 g Coconut Husk Ash/plant	2.59±0.55 a	5.49±0.03 c-f	4.42±0.43 b-e
60 g NPK/plant + 80 g Coconut Husk Ash/plant	3.86±0.05 c-e	5.48±0.28 c-f	3.45±0.05 ab
60 g NPK/plant + 120 g Coconut Husk Ash/plant	3.52±0.28 b-e	5.38±0.26 b-e	5.04±0.18 ef
90 g NPK/plant + Control	2.92±0.28 b-ef	4.52± 0.39 ab	3.68±0.35 ab
90 g NPK/plant + 40 g Coconut Husk Ash/plant	3.73±0.05 c-e	4.44±0.26 ab	2.94±0.24 a
90 g NPK/plant + 80 g Coconut Husk Ash/plant	3.38±0.10 b-d	3.99±0.16 a	3.45±0.11 ab
90 g NPK/plant + 120 g Coconut Husk Ash/plant	2.77±0.33 ab	4.52±0.33 ab	3.07±0.19 a

Note: Mean ± standard error (SE) followed by different letter of the same days of treatment is significant tested using Duncan multiple range test at  $p < 0.05$ . DAT = Days After Transplanting

At 110 DAT, an increase in the age of seedlings yielded the highest transpiration rate of 6.51 mM H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup> in the control sample. The lowest and best rate, namely 3.99 mM H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup>, was observed in the combination of 90 g NPK + 80 g coconut husk ash, while other treatments still produced high. The average results of the combined treatment showed a better transpiration rate at 80 DAT than at 110 DAT. At 140 DAT, the lowest and best value of 2.94 mM H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup> was achieved with 90 g NPK/plant + 40 g coconut husk ash/plant. Meanwhile, the highest value in the control sample, namely 5.89 mM H<sub>2</sub>O m<sup>-2</sup> s<sup>-1</sup>, was categorized as not good due to being high rate compared to other treatments. According to

[22], transpiration increases from early morning until late in the evening, then returns to normal at night until just before sunrise. A greater amount of water is often absorbed by the roots at higher transpiration rates [23].

### F. Intercellular CO<sub>2</sub>

Significant effects were observed on the intercellular CO<sub>2</sub> of seedlings aged 80, 110, and 140 DAT, where the highest content was found in the treatment of 40 g coconut husk ash/plant 181.42 ppm compared to other combinations, as presented in Table 6. Meanwhile, the lowest was 39.28 ppm detected in 60 g NPK/plant + 80 g coconut husk ash/plant, which was lower than the 92.81 ppm in the control sample. At

80 DAT, the control and treated samples showed no significant difference

The highest intercellular CO<sub>2</sub> was 90 g NPK observed at 110 DAT, while the 149.93 ppm found in the control sample was higher than the other combinations. The lowest content of 35.41 ppm was obtained with 40 g coconut husk ash/plant.

Moreover, at 140 DAT, ANOVA showed a significant difference between the highest content of 183.14 ppm obtained at 60 g NPK + 120 g coconut husk ash and 97.63 ppm yielded by the control. Some other treatments produced lower values probably due to the change in CO<sub>2</sub> concentration during photosynthesis and transpiration.

TABLE VI  
INTERCELLULAR CO<sub>2</sub> OF OIL PALM SEEDLINGS AGED 80, 110, 140 DAT TREATED WITH NPK 12:12:17:2+TE AND COCONUT HUSK ASH

Treatment	Intercellular CO <sub>2</sub>		
	80 DAT	80 DAT	80 DAT
Control	92.81 ±4.28 c	149.93±15.17 ab	97.63±11.57 bc
Control + 40 g Coconut Husk Ash/plant	181.42 ±48.34 a	35.41±85.27 cd	114.83±19.61 a-c
Control + 80 g Coconut Husk Ash/plant	98.58 ±16.99 c	87.64±0.88 b-d	35.61±12.62 c
Control + 120 g Coconut Husk Ash/plant	75.15±7.26 cd	59.37±10.52 cd	132.85±42.32 ab
30 g NPK/plant + Control	103.11±6.09 c	74.82±5.11 b-d	80.14. ±56.78
30 g NPK/plant + 40 g Coconut Husk Ash/plant	70.94±2.34 cd	80.87±7.94 b-d	86.07±19.18 bc
30 g NPK/plant + 80 g Coconut Husk Ash/plant	45.36 ±14.16 d	53.69±9.10 cd	55.84±4.49 bc
30 g NPK/plant + 120 g Coconut Husk Ash/plant	106.36± 1.67 bc	60.01± 4.23 cd	55.01±13.22 bc
60 g NPK/plant + Control	150.10± 62.78 ab	49.02±6.46 cd	95.01±17.08 bc
60 g NPK/plant + 40 g Coconut Husk Ash/plant	73.97 ±7.63 d	104.24±9.46 b-d	133.09±17.97 ab
60 g NPK/plant + 80 g Coconut Husk Ash/plant	39.28±15.71 b	68.68±26.41 b-d	116.17±12.31 a-c
60 g NPK/plant + 120 g Coconut Husk Ash/plant	45.20±11.92 d	72.39±11.86 b-d	183.14±18.90 a
90 g NPK/plant + Control	108.31±22.63 bc	27.88±15.71 d	115.49±29.55 a-c
90 g NPK/plant + 40 g Coconut Husk Ash/plant	83.16±2.66 cd	177.95±10.17 a	42.83±11.79 c
90 g NPK/plant + 80 g Coconut Husk Ash/plant	64.73±12.31 cd	75.08±4.87 b-d	137.35±7.70 ab
90 g NPK/plant + 120 g Coconut Husk Ash/plant	92.58 ±8.79 c	52.61±9.22 cd	110.38±33.62 a-c

Note: Mean ± standard error (SE) followed by different letter of the same days of treatment is significant tested using Duncan multiple range test at p<0.05. DAT = Days After Transplanting

#### G. WUE

WUE was also significantly affected, with the highest WUE of 15.50 observed at 80 DAT in the combined treatment of 60 g NPK + 120 g, as presented in Table 7. Meanwhile, the lowest WUE of 6.95 was obtained with 40 g coconut husk ash. The observation at 110 DAT showed the highest WUE at 60 g NPK/plant + 80 g coconut husk ash/plant, while the lowest

of 5.61 was in the control. At 140 DAT, the ANOVA results indicated a significant difference between the highest value of 16.15 obtained with 90 g NPK + 120 g coconut husk ash) and 9.65 found in the control sample. However, some other treated combinations produced lower values than the control due to the intermittent changes in metabolism occurring during photosynthesis and transpiration, which could affect WUE.

TABLE VII  
WATER USE EFFICIENCY (WUE) OF OIL PALM SEEDLINGS AGED 80, 110, 140 DAT TREATED WITH NPK 12:12:17:2+TE AND COCONUT HUSK ASH

Treatment	Water use efficiency		
	80 DAT	110 DAT	140 DAT
Control	12.12± 1.30 bc	5.61±1.78 e	9.65±1.49 b-e
Control + 40 g Coconut Husk Ash/plant	6.95±1.90 bc	6.97±1.42 c-e	7.36±3.15 b-e
Control + 80 g Coconut Husk Ash/plant	8.80±0.10 a	7.02±0.20 c-e	8.33±0.70 b-e
Control + 120 g Coconut Husk Ash/plant	8.47±0.19 de	8.44±0.37 a-c	10.90±1.43 b-d
30 g NPK/plant + Control	12.21±0.49 bc	7.51±0.50 b-e	6.34±2.31 e
30 g NPK/plant + 40 g Coconut Husk Ash/plant	10.59±0.89 cd	7.14±0.69 c-e	9.94± 1.62b-e
30 g NPK/plant + 80 g Coconut Husk Ash/plant	7.34±0.15 e	6.99±0.13 c-e	7.70±0.27 b-e
30 g NPK/plant + 120 g Coconut Husk Ash/plant	7.56±0.12 e	6.77± 0.07 c-e	6.97±0.42 c-e
60 g NPK/plant + Control	14.17±1.80 ab	6.44±0.23 c-e	6.34±0.50 e
60 g NPK/plant + 40 g Coconut Husk Ash/plant	8.59±0.45 de	6.99±0.58 c-e	9.12±1.15 b-e
60 g NPK/plant + 80 g Coconut Husk Ash/plant	8.96±0.19 de	9.96±0.48 a	10.93±0.21 bc
60 g NPK/plant + 120 g Coconut Husk Ash/plant	15.50±0.49 a	5.80±0.18 e	11.58±0.38 b
90 g NPK/plant + Control	11.91±0.93 bc	8.36±0.71 a-d	9.81±0.90 b-e
90 g NPK/plant + 40 g Coconut Husk Ash/plant	8.67±0.21 ab	8.08±0.35 a-d	9.74±0.78 b-e
90 g NPK/plant + 80 g Coconut Husk Ash/plant	9.79±0.25 c-e	9.55±0.13 ab	16.15±0.10 a
90 g NPK/plant + 120 g Coconut Husk Ash/plant	12.34±0.28 bc	6.22±0.23 de	10.94±0.21 bc

Note: Mean ± standard error (SE) followed by different letter of the same days of treatment is significant tested using Duncan multiple range test at p<0.05. DAT = Days After Transplanting.

#### H. Chlorophyll Content

The combination of 60 g NPK/plant + 120 g coconut husk ash/plant produced the highest chlorophyll of 63.59 as presented in Table 8. Meanwhile, the lowest content of 30.57 ppm was obtained at 30 g NPK/plant, lower than 41.00 found

in the control. The observational data at 80 DAT showed that the control and treated samples did not have significant effects.

At 110 DAT, the highest chlorophyll was observed in the treatment combination dose of 90 g NPK + 120 g coconut husk ash, while the lowest of 35.54 was obtained with 30 g

NPK/plant chlorophyll, which was lower than 42.57 in the control sample. At 140 DAT, the highest combination dose of 90 g NPK/plant + 120 g coconut husk ash/plant produced 62.17, while the lowest was also 35.54 obtained with 30 g NPK/plant, compared to 43.25 in the control. A linear

response was discovered between the chlorophyll and the diameter/height of the different plant patterns. Observations showed that higher chlorophyll content led to a greater growth in terms of the diameter or height of the seedlings.

TABLE VIII  
CHLOROPHYLL CONTENT OF OIL PALM SEEDLINGS AGED 80, 110, 140 DAT TREATED WITH NPK 12:12:17:2+TE AND COCONUT HUSK ASH

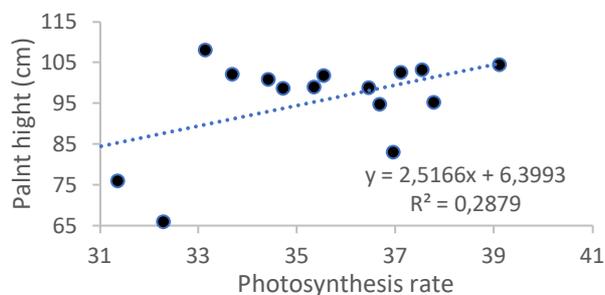
Treatment	Chlorophyll content		
	80 DAT	110 DAT	140 DAT
Control	41.00 ± 3.90 efg	42.57±5.15 cd	43.25±2.51 d
Control + 40 g Coconut Husk Ash/plant	43.53 ± 8.30 def	32.60±7.00 d	41.16±0.55d
Control + 80 g Coconut Husk Ash/plant	47.63 ± 8.05 cdef	42.70± 0.95 cd	43.26±0.97 d
Control + 120 g Coconut Husk Ash/plant	60.47 ± 2.10 ab	42.03± 7.32 cd	46.54±0.68 d
30 g NPK/plant + Control	30.57 ± 4.30 fg	46.56± 5.05 bc	35.54±4.42 e
30 g NPK/plant + 40 g Coconut Husk Ash/plant	54.83 ± 0.05 abc	54.23 ± 2.60 a-c	55.80±2.02 bc
30 g NPK/plant + 80 g Coconut Husk Ash/plant	51.10 ± 8.25 bcde	53.43± 3.50 a-c	61.66±2.11 a
30 g NPK/plant + 120 g Coconut Husk Ash/plant	60.37 ± 2.35 ab	54.10± 1.75 a-c	58.88±1.58 a-c
60 g NPK/plant + Control	37.53 ± 1.20 fg	55.36 ± 11.35 ab	42.14±0.06 d
60 g NPK/plant + 40 g Coconut Husk Ash/plant	54.70 ± 0.95 abc	53.43± 2.85 a-c	60.66±1.50 a-c
60 g NPK/plant + 80 g Coconut Husk Ash/plant	55.93 ± 9.00 abc	60.40± 9.50 a	55.32±1.09 c
60 g NPK/plant + 120 g Coconut Husk Ash/plant	63.59 ± 1.77 a	56.507±5.05 ab	58.06±0.58 a-c
90 g NPK/plant + Control	42.03 ± 2.70 fg	58.06± 5.15 ab	42.05±3.95 d
90 g NPK/plant + 40 g Coconut Husk Ash/plant	53.40 ± 1.40 abcd	54.10± 2.75 a-c	61.23±1.54 ab
90 g NPK/plant + 80 g Coconut Husk Ash/plant	55.47 ± 0.25 abc	57.55±2.30 a	58.88±1.94 a-c
90 g NPK/plant + 120 g Coconut Husk Ash/plant	61.07 ± 2.80 ab	62.24±3.65 a	62.17±1.01 a

Note: Mean ± standard error (SE) followed by different letters of the same treatment days is significantly tested using the Duncan multiple range test at p<0.05. DAT = Days After Transplanting.

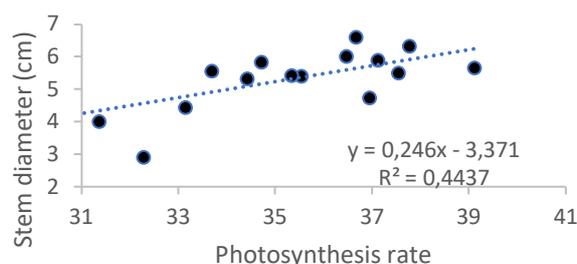
### I. Correlation between Photosynthetic Rate, Stomatal Conductance, Transpiration Rate, and Intercellular CO<sub>2</sub> to the Height and Diameter of Oil Palm Seedlings Aged 140 DAT

As indicated in Figure 2A, the photosynthetic rate and height of the seedlings were positively correlated, with a correlation coefficient (R) of 0.25. The increase in the photosynthetic rate was found to accelerate height.

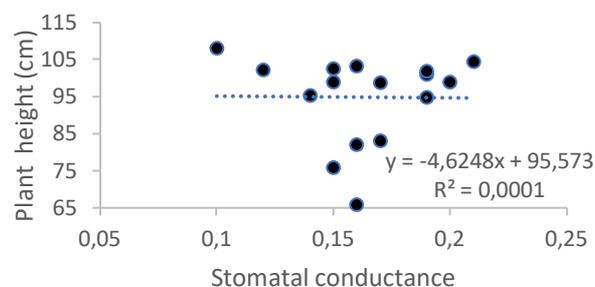
Furthermore, the rate correlated with the diameter of the seedling stems, with an R of 0.44, as presented in Figure 2B. An increased rate boosted growth in the seedling stem diameter, and a higher R-value was obtained. The rate was found to vary as the plant aged, which could be attributed to changes in metabolism and physiological responses due to plant senescence [24]. Additionally, photosynthesis was observed to be more active in older leaf tissues [25].



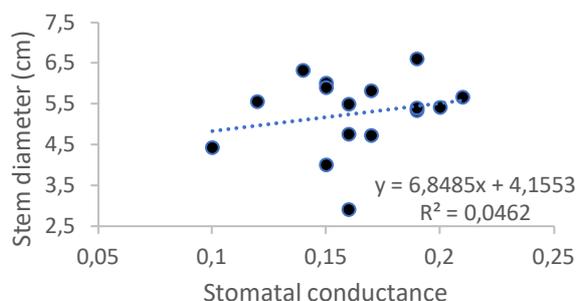
a



b



c



d

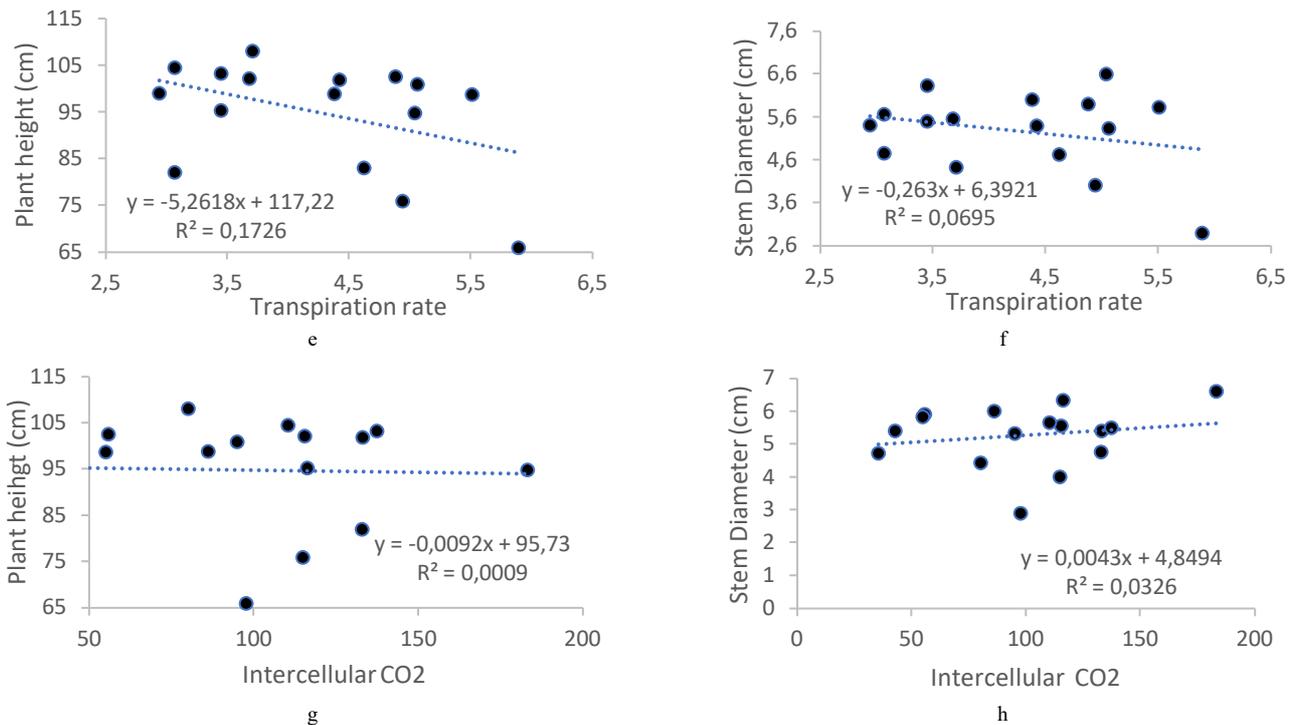


Fig. 2 Relationship between growth and physiological traits; A. Photosynthesis and seedling height, B. Photosynthesis and stem diameter, C. Stomatal conductance and height, D. Stomatal conductance and stem diameter, E. Transpiration rate and seedling height, F. Transpiration rate and stem diameter, G. Inter-cellular CO<sub>2</sub> and height, H. Inter-cellular CO<sub>2</sub> and stem diameter.

Stomatal conductance negatively correlated with height and a small R of 0.0001 as indicated in Figure 2C. A higher stomatal conductance had a lesser impact on height. However, it showed a positive correlation with stem diameter with an R-value of 0.046. A higher value had a more prominent role in increasing the size of the stem diameter as indicated in Figure 2D. This was consistent with the statement by [26] that increased CO<sub>2</sub> led to higher WUE as the reduction in stoma opening and Stomatal density decreased stomatal conductance (gs), followed by transpiration rate. The number of active stomata was suspected to be unaffected by the applied doses of fertilizer and ameliorant, leading to carbon accumulation for the enlargement of stems and shoots [27].

According to Figure 2E, the transpiration rate negatively correlated with height and an R-value of 0.17. A higher rate inhibited growth in the height of seedlings, while a lower rate tended to initiate an increase. As shown in Figure 2F, the rate was negatively correlated with the diameter of the seedlings with an R of 0.06. The transpiration rate followed changes in evaporative demand. Hence, it negatively affected the leaf elongation and expansion rates [28]. Based on Figure 2G, intercellular CO<sub>2</sub> content negatively correlated to height with an R of 0.0009. A higher CO<sub>2</sub> inhibited the growth of seedlings, while a lower content triggered the height, although it might slow down. The content positively correlated with stem diameter and an R of 0.03, as indicated in Figure 2H. A higher content boosted the diameter expansion, and a higher R-value was recorded.

#### IV. CONCLUSION

In conclusion, applying NPK 12:12:17:2+TE fertilizer and coconut husk ash as an ameliorant on growth and photosynthesis of oil palm seedlings in peat media yielded

significant increase in height and diameter of the samples at 80, 110, and 140 DAT. The highest dose variable produced the fastest growth rate. Additionally, significant observations in photosynthetic rate, stomatal conductance, transpiration rate, intercellular CO<sub>2</sub> and WUE were recorded at the best combination treatments, and these fluctuated across the plant ages. However, the single treatment showed a worse value than the combinations. The chlorophyll content was significantly higher at 80, 110, and 140 DAT, with the most significant values observed at the highest combination treatment dose. The control value was higher than the single treatment of NPK fertilizer.

Analysis of the relationship between photosynthetic rate, stomatal conductance, transpiration rate, and intercellular CO<sub>2</sub> with the height and diameter of oil palm seedlings aged 140 DAT showed diversity in growth rates, with some plants growing fast, moderate, and even slow. Higher photosynthetic rates were associated with a faster height and stem diameter elevation of the seedlings, while the transpiration rate decreased. Increasing stomatal conductance and intercellular CO<sub>2</sub> led to expanded diameter, but reduced height. This research is still limited to analysis; therefore, it is necessary to observe more deeply the impact of treatment on the physical, chemical, and biological properties of the soil. Abundant raw materials such as coconut fiber, which are considered waste, can be an essential source of nutrients for environmentally friendly plant growth and can replace chemically synthesized nutrients.

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