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

The highest intercellular $CO_2$ was 90 g NPm 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 $CO_2$ concentration during photosynthesis and transpiration.

TABLE VI
INTERCELLULAR CO2 OF OIL PALM SEEDLINGS AGED 80, 110, 140 DAT TREATED WITH NPK 12:12:17:2+TE AND COCONUT HUSK ASH

| Treatment | Intercellular $CO_2$ | | |
|---|---|---|---|
| | **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

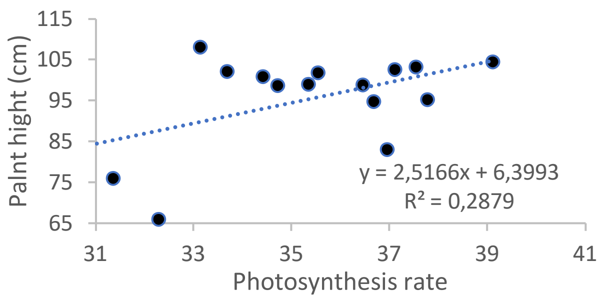
| Treatment | Chlorophyll content | | |
|---|---|---|---|
| | **80 DAT** | **110 DAT** | **140 DAT** |
| Control | 41.00 ± 3.90 efg | 42.57±5.15 cd | 43.25±2.51 d |
| Control + 40 g Coconut Husk Ash/plant | 43.53 ± 8.30 def | 32.60±7.00 d | 41.16±0.55d |
| Control + 80 g Coconut Husk Ash/plant | 47.63 ± 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.

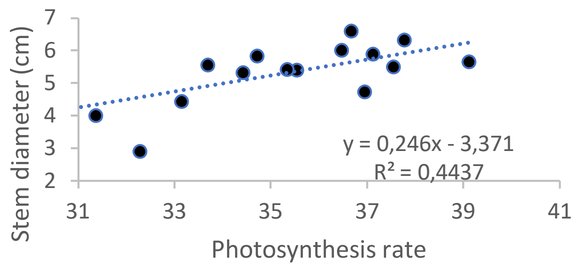
### *I. Correlation between Photosynthetic Rate, Stomatal Conductance, Transpiration Rate, and Intercellular CO2 to the Height and Diameter of Oil Palm Seedlings Aged 140 DAT*

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.

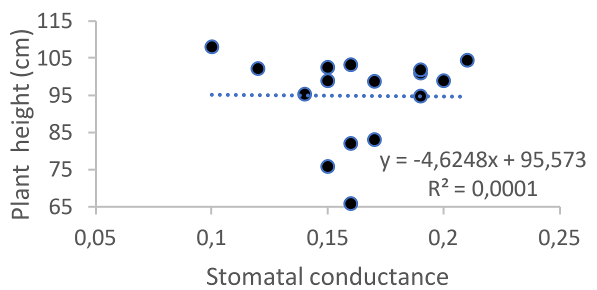
Furthermore, the rate correlated with the diameter ofthe seedling stems, with an R of 0.44, as presented in Figure 2B. An increased rate boosted growth in the seedling stem diameter, and a higher R-value was obtained. The rate was found to vary as the plant aged, which could be attributed to changes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



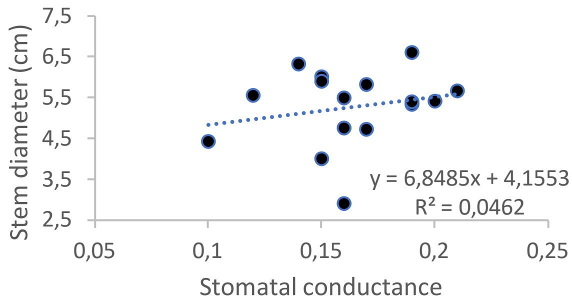

a




b




c




d

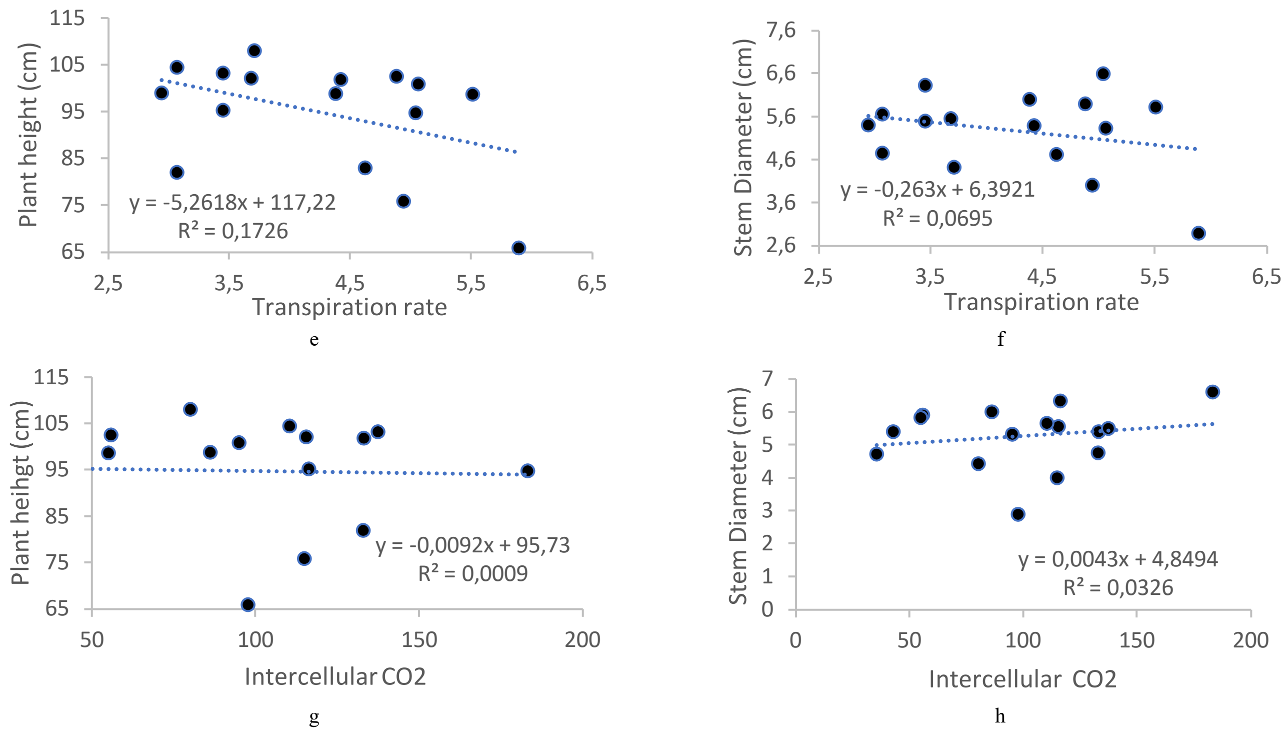



Fig. 2 Relationship between growth and physiological traits; A. Photosynthesis and seedling height, B. Photosynthesis and stem diameter, C. Stomatal conductance and height, D. Stomatal conductance and stem diameter, E. Transpiration rate and seedling height, F. Transpiration rate and stem diameter, G. Intercellular $CO_2$ and height, H. Intercellular $CO_2$ 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 $CO_2$ 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 $CO_2$ content negatively correlated to height with an R of 0.0009. A higher $CO_2$ 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 $CO_2$, 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 $CO_2$ 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 $CO_2$ 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.


## Acknowledgment

The authors thank Universitas Islam Riau and all those who have contributed to this research.

## References


[1] F. Nurfatriani, R. Ramawati, G. K. Sari, W. Saputra, and H. Komarudin, "Oil Palm Economic Benefit Distribution to Regions for Environmental Sustainability: Indonesia's Revenue-Sharing Scheme," *Land*, vol. 11, no. 9, p. 1452, Sep. 2022, doi: 10.3390/land11091452.

[2] K. Zhang et al., "Biochar Coating Is a Sustainable and Economical Approach to Promote Seed Coating Technology, Seed Germination, Plant Performance, and Soil Health," *Plants*, vol. 11, no. 21, p. 2864, Oct. 2022, doi: 10.3390/plants11212864.

[3] T. W. Yuwati et al., "Restoration of Degraded Tropical Peatland in Indonesia: A Review," *Land*, vol. 10, no. 11, p. 1170, Nov. 2021, doi:10.3390/land10111170.

[4] P. Cockson et al., "The Impacts of Micronutrient Fertility on the Mineral Uptake and Growth of Brassica carinata," *Agriculture*, vol. 11, no. 3, p. 221, Mar. 2021, doi: 10.3390/agriculture11030221.

[5] L. N. L. K. Choo, O. H. Ahmed, N. A. Razak, and S. Sekot, "Improving Nitrogen Availability and Ananas comosus L. Merr var. Moris Productivity in a Tropical Peat Soil Using Clinoptilolite Zeolite," *Agronomy*, vol. 12, no. 11, p. 2750, Nov. 2022, doi:10.3390/agronomy12112750.

[6] S. S. Shareef, H. A. J. Qasim, and O. M. Omar, "Effect of (N.P.K) Nano and Mineral Fertilizer on Some Growth Characteristics of Pinus Brutia Ten. Seedlings by Foliar Application," *IOP Conference Series: Earth and Environmental Science*, vol. 910, no. 1, p. 012012, Nov. 2021, doi: 10.1088/1755-1315/910/1/012012.

[7] M. Balk, P. Sofia, A. T. Neffe, and N. Tirelli, "Lignin, the Lignification Process, and Advanced, Lignin-Based Materials," *International Journal of Molecular Sciences*, vol. 24, no. 14, p. 11668, Jul. 2023, doi: 10.3390/ijms241411668.

[8] S. H. Kamarudin et al., "A Review on Natural Fiber Reinforced Polymer Composites (NFRPC) for Sustainable Industrial Applications," *Polymers*, vol. 14, no. 17, p. 3698, Sep. 2022, doi:10.3390/polym14173698.

[9] E. Windiastuti, Suprihatin, Y. Bindar, and U. Hasanudin, "Identification of potential application of oil palm empty fruit bunches (EFB): a review," *IOP Conference Series: Earth and Environmental Science*, vol. 1063, no. 1, p. 012024, Jul. 2022, doi: 10.1088/1755-1315/1063/1/012024.

[10] X. Bonneau, I. Haryanto, and T. Karsiwan, "Coconut Husk Ash as A Fertilizer for Coconut Palms on Peat," *Experimental Agriculture*, vol. 46, no. 3, pp. 401–414, Apr. 2010, doi: 10.1017/s0014479710000025.

[11] F. Fathurrahman, S. Zahrah, E. Ernita, H. Heriyanto, and I. Mahadi, "The Effects of the Growth Regulator Paclobutrazol on Physiological Characteristics of Rain Tree (*Albizia saman* Jacq. Merr.)," *Journal of Ecological Engineering*, vol. 24, no. 12, pp. 346–355, Dec. 2023, doi:10.12911/22998993/173396.

[12] F. Fathurrahman, "Effects of Carbon Dioxide Concentration on the Growth and Physiology of Albizia saman (Jacq.) Merr," *Journal of Ecological Engineering*, vol. 24, no. 9, pp. 302–311, Sep. 2023, doi: 10.12911/22998993/169145.

[13] IPCC, Climate Change, "The Physical science basis," contribution of working group 1 to the Sixth Assessment Report on 6 August, 2021.

[14] A. Alhasan, M. Abbas, and D. Al-Ameri, "Influence of Applying Seaweed Extracts and NPK Fertilizer on Vegetative Growth, Flowering Traits and Seed Yield of Borage (Borage officinalis L.)," *Asian Journal of Plant Sciences*, vol. 22, no. 1, pp. 206–214, Jan. 2023, doi: 10.3923/ajps.2023.206.214.

[15] X. Li et al., "Effects of Two Kinds of Commercial Organic Fertilizers on Growth and Rhizosphere Soil Properties of Corn on New Reclamation Land," *Plants*, vol. 11, no. 19, p. 2553, Sep. 2022, doi: 10.3390/plants11192553.

[16] A. W. Purnama, E. Purwanto, and Solichatun, "Growth, carbohydrate accumulation, and productivity of local glutinous corn Bimapulut (Zea mays var. ceratina Kuleshov) after seed priming and coconut coir ash fertilizer application," *IOP Conference Series: Earth and Environmental Science*, vol. 905, no. 1, p. 012008, Nov. 2021, doi:10.1088/1755-1315/905/1/012008.

[17] B. A. Sirait, A. Imelda Man, O. M. Samosir, R. G. Marpaung, . N., and C. Manalu, "Growth Palm Oil Seedling (Elaeis guineensis Jacq.) via NPK Fertilization and Different Frequency of Watering," *Journal of Agronomy*, vol. 20, no. 1, pp. 1–8, Dec. 2020, doi:10.3923/ja.2021.1.8.

[18] V. T. H. Nguyen, T. Kraska, W. Winkler, S. Aydinlik, B. E. Jackson, and R. Pude, "Primary Mechanical Modification to Improve Performance of Miscanthus as Stand-Alone Growing Substrates," *Agronomy*, vol. 12, no. 2, p. 420, Feb. 2022, doi:10.3390/agronomy12020420.

[19] O. O. Aluko, C. Li, Q. Wang, and H. Liu, "Sucrose Utilization for Improved Crop Yields: A Review Article," *International Journal of Molecular Sciences,* vol. 22, no. 9, p. 4704, Apr. 2021, doi: 10.3390/ijms22094704.

[20] M. Moosavi-Nezhad, B. Alibeigi, A. Estaji, N. S. Gruda, and S. Aliniaeifard, "Growth, Biomass Partitioning, and Photosynthetic Performance of Chrysanthemum Cuttings in Response to Different Light Spectra," *Plants*, vol. 11, no. 23, p. 3337, Dec. 2022, doi:10.3390/plants11233337.

[21] G. Izydorczyk, K. Mikula, D. Skrzypczak, A. Witek-Krowiak, and K. Chojnacka, "Granulation as the method of rational fertilizer application," *Smart Agrochemicals for Sustainable Agriculture*, pp. 163–184, 2022, doi: 10.1016/b978-0-12-817036-6.00003-0.

[22] S. Dayer et al., "Nighttime transpiration represents a negligible part of water loss and does not increase the risk of water stress in grapevine," *Plant, Cell Environment*, vol. 44, no. 2, pp. 387–398, Nov. 2020, doi:10.1111/pce.13923.

[23] G. Ievinsh, "Water Content of Plant Tissues: So Simple That Almost Forgotten?," *Plants*, vol. 12, no. 6, p. 1238, Mar. 2023, doi:10.3390/plants12061238.

[24] H. M. Romero, S. Guataquira, and D. C. Forero, "Light Interception, Photosynthetic Performance, and Yield of Oil Palm Interspecific OxG Hybrid (*Elaeis oleifera* (Kunth) *Cortés* x *Elaeis guineensis* Jacq.) under Three Planting Densities," *Plants*, vol. 11, no. 9, p. 1166, Apr. 2022, doi: 10.3390/plants11091166.

[25] I. F. Pangaribuan and E. N. Akoeb, "Analysis of morphological responses of drought stress oil palm in nursery phase," *IOP Conference Series: Earth and Environmental Science*, vol. 977, no. 1, p. 012013, Jun. 2022, doi: 10.1088/1755-1315/977/1/012013.

[26] A. K. Shanker et al., "Elevated CO2 and Water Stress in Combination in Plants: Brothers in Arms or Partners in Crime?," *Biology*, vol. 11, no. 9, p. 1330, Sep. 2022, doi: 10.3390/biology11091330.

[27] M. Chtouki, F. Laaziz, R. Naciri, S. Garré, F. Nguyen, and A. Oukarroum, "Interactive effect of soil moisture content and phosphorus fertilizer form on chickpea growth, photosynthesis, and nutrient uptake," *Scientific Reports*, vol. 12, no. 1, Apr. 2022, doi:10.1038/s41598-022-10703-0.

[28] S. Leveau, B. Parent, S. Zaka, and P. Martre, "Differential sensitivity to temperature and evaporative demand in wheat relatives," *Journal of Experimental Botany*, Sep. 2021, doi: 10.1093/jxb/erab431.