Weather Variables and Soil Moisture Regime Influences on Stomatal Conductance and Leaf Water Potential of Oil Palm

Idris Sani[1,2*], Teh Christopher Boon Sung[1], Zaibon Syaharudin[1], Sim Choon Cheak[3]

[1]Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.
[2]Department of Soil Science, Faculty of Agriculture/Institute for Agricultural Research, Ahmadu Bello University, 1044 Samaru, Zaria, Nigeria.
[3]Sime Darby Plantation Research Sdn. Bhd., 42960 Carey Island, Kuala Langat, Selangor, Malaysia.

*Corresponding Author: saniidris@abu.edu.ng

Article history:
Received: 6 August 2025
Accepted: 23 November 2025
Published: 30 December 2025

Keywords: *Stomatal conductance, Soil texture, Vapor pressure deficit, Water stress, Leaf water potential.*

Abstract
Although oil palm (OP) is an important crop that occupies 10.7 million hectares in the South East-Asia, equivalent to 42.8% of the global OP coverage, information regarding weather relationship with OP gaseous exchange and photosynthetic characteristics remains scanty. This study investigated the empirical relationship between meteorological elements and stomatal conductance (STC) and leaf water potential (LWP) water stress indices in mature OP trees. The STC, LWP, meteorological elements and soil moisture content (SMC) were measured on-field and concurrently for 120 days. The best STC performance was when the relative humidity (RH) was between 98.3% to 82.6%. The STC became highest between 24.5°C to 27.6°C and lowest at 30.1°C – 32.7°C. For vapor pressure deficit (VPD), 0.06 to 1.09 kPa caused a positive response of STC, while 1.5 to 2.73 kPa limited it by 50.1%. Increased LWP was observed at 35.2°C - 37.0°C, VPD of 2.6 kPa, and RH below 58.3%. The OP on clay at 91.1% SMC was lower in STC than that under sandy clay at 86.2% SMC by 16.4%. Under the highest soil wetness (91.1% - clay and 86.2% - sandy clay), the LWP of the OP was still higher in palms under clay. The SMR curve showed the clay soil to have a higher SMC across all the potentials than the sandy clay. Correlation output indicated that STC positively correlated with RH (r=0.66) and negatively with VPD. The finding disentangled key actors involved in OP gaseous exchange and inferred that OP under clay has a higher proneness to water stress.

https://dx.doi.org/10.52951/dasj.25170211

Introduction

Oil palm (OP) occupies about 10.7 million hectares of land space in the Southeast Asian region, equivalent to 42.8% of total global OP production area, thus ranking it the 12th crop by cultivation area extent (Lewis *et al*., 2020). In Malaysia, OP production represents the central agricultural engagement of greatest economic value, both in terms of the country's Gross Domestic Product and job creation (MPOB, 2022). However, there has been concern of yield gap from climate change effects, notably due to water stress resulting from rainfall water deficits (Idris *et al.,* 2024; Abubakar *et al.,* 2021). Okon *et al.* (2021) established that water stress causes OP to wilt, stunt, and suffer root underdevelopment, through its effect on carbon dioxide intake and stomatal aperture response (Montoya *et al.,* 2024). High water demand and natural predisposition of OP to water stress (Pangaribuan *et al*., 2024) make studying its gaseous exchange characteristics and leaf water status crucial for sustainable production through a well-informed irrigation program (Payus *et al*., 2020). Moreover, the physiological characteristics in question (stomatal conductance and leaf water potential) are greatly weather-dependent (Konduri *et al*., 2020; Monzon *et al.,* 2021; Monzon *et al.,* 2022), hence the need to coopt monitoring of meteorological elements in the study, for a comprehensive understanding of the scenario.

Weather is a geographical term that denotes atmospheric state, specific to a short time and less extensive location coverage (Ahmed *et al.,* 2020). It is described through measured conditions of temperature, relative humidity, precipitation, and vapor pressure deficit among others. Li *et al.* (2023), and Paterson (2023) noted that certain physiological mechanisms and processes (e.g., gaseous exchange and photosynthesis) that govern crop growth and development are synergistically controlled by two or more variables. Oil palm like other plants synthesizes its photosynthates by combining atmospheric CO_2 with water. The CO_2 raw material gets into the crop systems through stomatal opening when water escapes through the stomatal conductance process (Jaafar and Anderson, 2024). In other words, as crop leaflets release water from the stomates, CO_2 is taken-in simultaneously for photosynthesis. According to Bayona-Rodriguez and Romero (2019), OP experiencing low leaf water exhibits a reduction/cessation of growth and yield as a result of low transpiration which lowers CO_2 intake. Therefore, stomatal conductance and leaf water condition provide an unambiguous indication of potential photosynthetic and yield performances in OP trees (Bayona-Rodriguez and Romero, 2019). However, Idris *et al.* (2024) stated that, OP possesses certain special features including well-lignified cuticle, and fibrous leaflets which make water stress symptoms physically less noticeable, leading to photosynthetic inefficiency and remarkable yield decline (Norizan *et al.,* 2021). As such, providing insights into these OP gaseous exchange variables is critically imperative in OP production enhancement, especially for location-specific decision-making and precision water management designs.

On a broader view, the challenge at hand suggests that, to satisfy global food demand by 2050, the current production output ought to be increased by 100%. Notwithstanding, temperature weather parameter alone potentially constrain this target since it has been projected to rise by about 3.2°C, over the 21st century across all the emission scenarios IPCC (2014). This means there is a high probability of heat increase both in terms of intensity and duration. Findings by Monzon *et al*. (2022) further underpin the importance of vapor pressure deficit (VPD) which strongly and negatively correlated with water use efficiency (WUE), bunch number, and bunch weight in many OP plantations in Indonesia. The authors attributed the outcome to the stomatal conductance reduction due to lowered leaf water content. To that extent predicting and enhancing the sustainability of OP as a critical food and energy commodity can be best done by relating crucial weather variables to these important physiological processes that drive the growth and development of the crop (Randall *et al.,* 2024; Konduri *et al.,* 2020). More and more, even within similar climatic zones, other endogenous factors notably soil textural difference accounts for variability in productive physiological performance which cascade to yield differences (Monzon *et al*., 2022). According to Idris (2020) soil textural role revolves around controlling soil moisture content and its energy state. Best known to us, no open-field research studied the trend of water stress indicators as weather variables and soil moisture levels change over the whole daytime hours. Most studies are non-recent and they were able to cover only a few hours of the daytime (Suresh *et al*., 2010; Kunjet *et al*., 2013; Apichatmeta *et al*., 2017). Middleby *et al.* (2024) stated that, although, meteorological elements like air temperature and VPD exert significant effect on crop physiological functions, their relationship is yet blunt. Filling this gap, therefore, this study aimed to unveil the behavioral pattern of stomatal conductance and leaf water potential water stress indicators in connection with weather and soil moisture variability throughout the daytime hours under different soil textures.

Materials and Methods

Experimental Site, Treatment, Weather and Moisture Monitoring

The study was executed between 2023 and 2024 at an oil palm site located in the Universiti Putra Malaysia, Seri Serdang, Selangor (2°59'20”N, 101°43'14”E). The plantation was planted with the dura crossed with *Pisifera* in 2012, is spaced in 8.8 × 8.8 × 8.8 under a good routine management system (ring weeding, inter-row slashing, pruning etc). Daily measurements of stomatal conductance and leaf water potential were recorded for four consecutive months (December to March) from six healthy, mature oil palm trees, with three on sandy clay (SCL) and three on clay (CLY) soils. The measurements were accordingly conducted on wet and dry days (24hrs after a wet day and 48hrs after a dry day, respectively), based on the theoretical basis that perfect drainage and runoff must have occurred after 48 hours. The weather variables of the study site were recorded using a portable WatchDog 2000 series station (Figure 1B). Hourly soil moisture content was recorded using the Aqua Pro sensor – AP – 204 model.

Determination of Water Stress Indices

Stomatal conductance and leaf water potential measurement

Stomatal conductance was measured using the leaf porometer SC-1 model, METER Group, Inc. USA. The meter was calibrated accurately using a calibration plate, filter paper, and desiccator granules as the User Guide prescribes. The oil palm leaflets on frond 17 were clipped to the porometer sensor head until the measurement indicator on the monitor reached the maximum.

The Plant Moisture System model SKYE SKPM 1400, Skye Instrument Ltd., United Kingdom, which consists of a pressure chamber and an N_2-gas-containing cylinder pressure source was used to measure the leaf water potential. To achieve that, healthy fresh leaves from frond 17 were cut off from the internode using secateurs. Scissors were used to expose the midrib by cutting off the leaf blades at both sides. A rubber washer with a 1.0 mm aperture that fits tightly to the midrib was selected for correct measurement. The lower part of the leaflet was carefully rolled and wrapped using sellotape and placed into the pressure chamber (Figure 1A). The PMS was calibrated using the zero knob. The flow rate knob was carefully adjusted to monitor the pressure flow rate into the chamber in which the leaflet was placed. The readings were recorded once the water was squeezed and bubbled out of the leaf midrib.

A B

Figure 1 (A). Prepared leaflets ready to be inserted into the PMS pressure chamber and (B) WatchDog 2000 weather station monitor interphase used for obtaining weather records of the study site

Laboratory Analyses

The soil particle distribution analysis was conducted using the Standard International Pipette method following the procedure outlined by Gee and Bauder (1986) as detailed by Sung and Talib (2006). Soil moisture retention at various potentials were determined using the pressure plate (Klute, 1986; Reynolds *et al.,* 2008).

Statistical Analyses

All obtained data were graphically and statistically analyzed using OriginPro 2024 learning edition software and R 4.2.3 2023 software, respectively. Two-factor analysis of variance was used to compare the different time scales and textures through library (readxl), fit <- lm (y~x1+x2, data = filename), anova (fit) and (lsd_trt<-LSD.test (fit, "factor")) codes. Correlation outputs for water stress indices, soil and meteorology data were generated using the library ("PerformanceAnalytics") and chart. Correlation (filename, Method ="round").

Results and Discussion

Graphs in Figure 2 presents a temporal pattern of the key meteorological variables and how they relate to the stomatal conductance (STC) and leaf water potential (LWP) water stress indices over the daytime hours during the wet and dry days. During the wet days, the relative humidity (RH) ranged from 98.3 to 58.8%. The best stomatal conductance performance was recorded when the RH was between 98.3 % to 82.6% and a considerable reduction occurred when the RH dropped to 69.5% until 58.8%. It can be drawn from the stomatal response to RH that 82.1% favored the best performance greater than the lowest value recorded fewer than 58.8% by 66.8%.

For the temperature effect, the stomatal conductance was highest between 24.5°C to 27.6°C and lowest at 30.1°C – 32.7°C. A temperature of 27.6°C resulted in the highest stomatal conductance in oil palm, which was significantly better than that recorded at 32.7°C by 66%. In respect of VPD, 0.06 to 1.09 kPa caused positive response of the stomatal conductance while 1.5 to 2.7 kPa reduced it hugely by more than 50%.

During the dry days, RH at 44.2 – 58.3% drastically lowered the stomatal conductance by 48.4% compared to 95.6 – 75.4% RH. Similarly, 35 - 37°C led to partial stomatal closure. The VPD shoots up during the afternoon hours compared to the morning time averaging 2.7 kPa leading to declined stomatal conductance. Equally, increased leaf water potentials were observed when temperature rose to 35°C up to 37.0°C, VPD of 2.6 kPa and below 58% RH implying water tolerance adaptability. In the final analysis, the result revealed that the stomatal conductance and leaf water potential trends of the oil palm both during the wet and dry days behaved in response to fluctuating weather variables. From the pooled results (Dry and wet day) 98% to 75% and 24.5°C to 27.6°C and 0.06 to 1.0 kPa suggest the most favorable meteorological condition for oil palm gaseous exchange and water status.

Middleby *et al.* (2024) report on six tree species has aligned with our findings indicating stomatal conductance inverse relationship with RH, temperature and VPD after exceeding the optimal range. Similarly, observations by Li *et al.* (2020) confirmed a profound decrease in leaf water status which in turn affects mesophyll conductance in wheat crop.

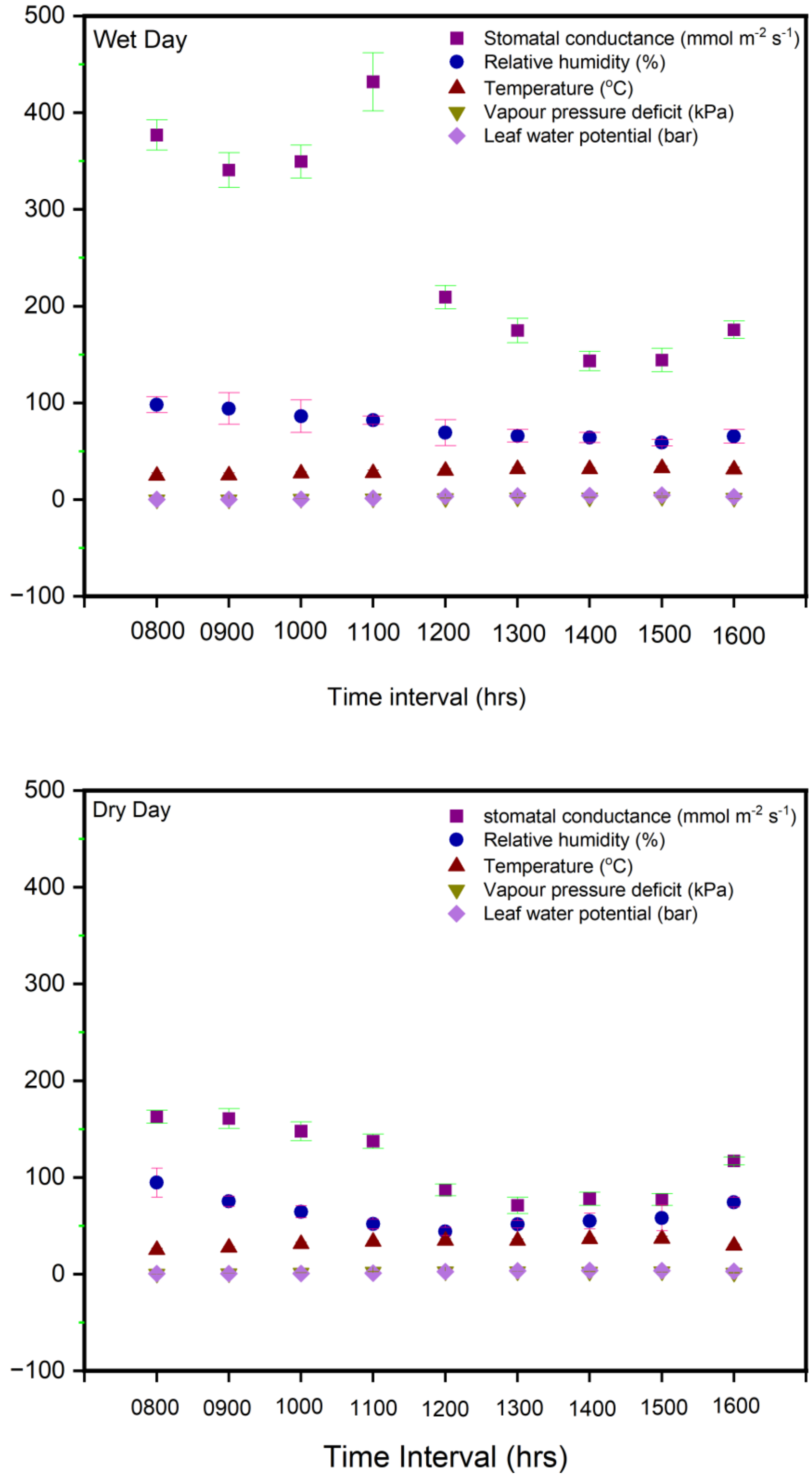
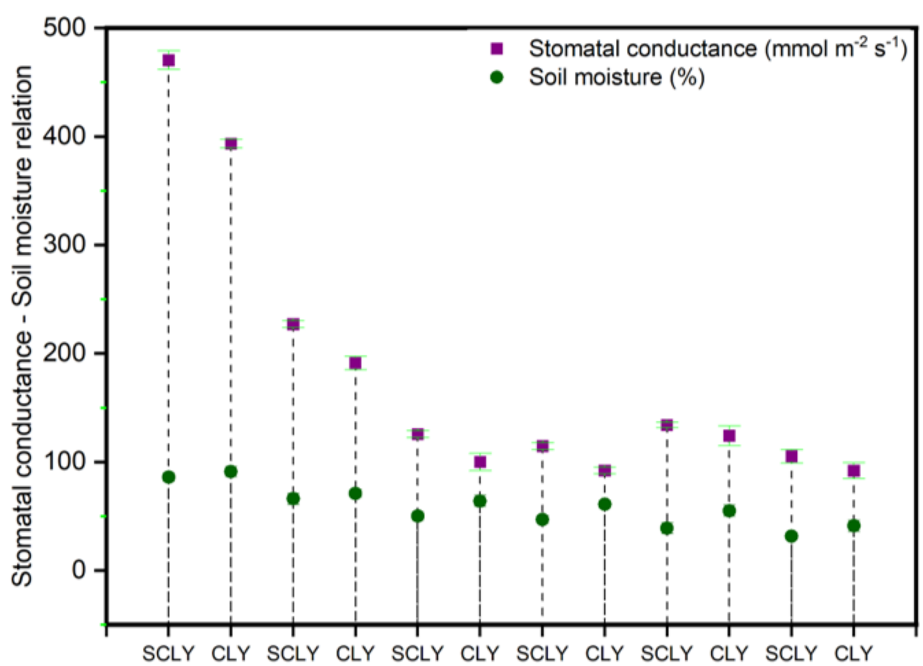


Figure 2. Diurnal pattern of the relative humidity, vapour pressure deficit and atmospheric temperature meteorological variables and stomatal conductance (STC) and leaf water potential (LWP) water stress indicators in wet and dry days

Soil Moisture - Water Stress Indices Relationship

Graphs in Figure 3 demonstrate the behavior of oil palm stomatal conductance and leaf water potential scenarios as soil moisture and textural class differ. According to the outcomes, although clay texture showed the highest percent of soil moisture content – SMC (91.1 – 41.3%), still its stomatal conductance (STC) was lower compared to that of sandy clay. For instance, oil palm under 91.1% SMC in clay textured soil had 16.4% lower STC compared to those under 86.2% SMC in sandy clay texture. Similarly, oil palm under 66.0% SMC in clay had 2.3 times lower STC than those under 64.3% SMC in clay texture. Still, the STC of oil palm under 55.2% SMC in clay (125.6 mmol m^{-2} s^{-1}) was statistically equal to those under 50.0% SMC in sandy clay (124.1 mmol m^{-2} s^{-1}).

As signified by the results, the pressure at which water is held in the oil palm leaves behaved distinctly under clay and sandy clay textures at different moisture levels. The pressure with which the water is retained in the oil palm leaflets was much greater in clay than in the sandy clay soil. Even under high soil moisture (91.2% clay and 86.2% sandy clay), the leaf water potential was still higher in clay (0.14 vs 0.16 bar, respectively). However, when soil moisture approached field capacity, the disparity reduced such that at 47.4% and 41.3% SMC the potentials were 4.1 and 3.7 bar in sandy clay and clay, respectively. A close look at the result revealed a lack of consistent relationship between the %SMC and leaf water potential. This is expected due to the role of several contributory factors ranging from weather, nutrition and hormones in water conservation mechanism (Lindh *et al*., 2022). Suresh *et al*. (2010) reported that although oil palm exhibits varying levels of cellular plasticity due to leaf hydraulic state, soil water status did not irreversibly influence gas-exchange characteristics particularly leaf water and its energy state.



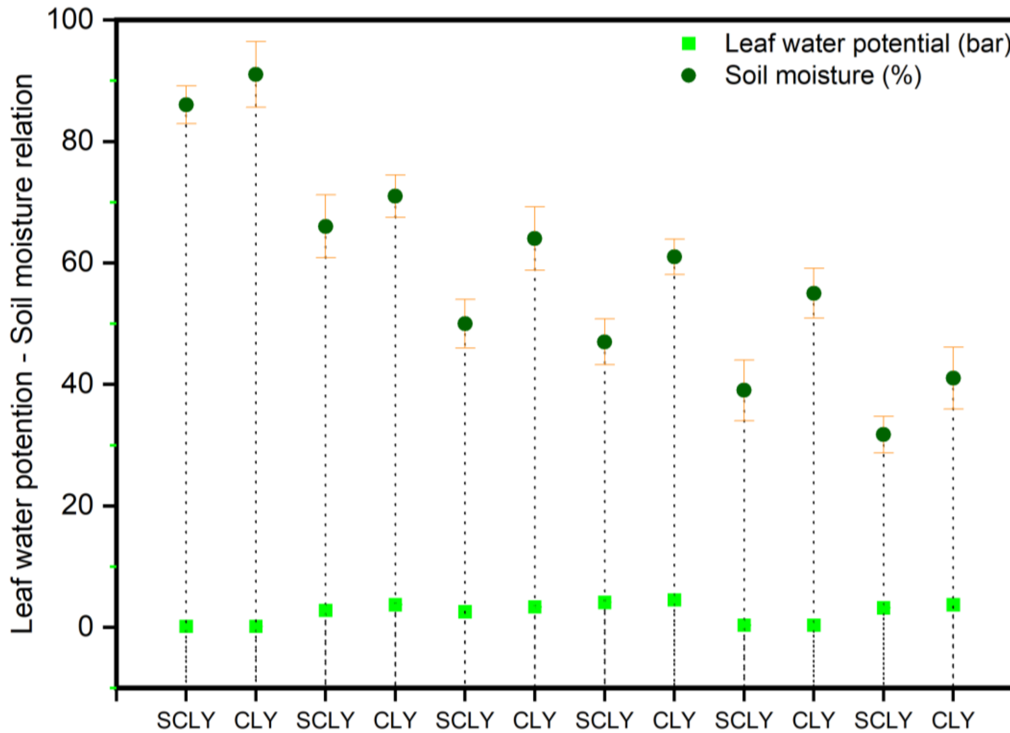


Figure 3. Relationship between soil moisture content and stomatal conductance and leaf water potential in oil palm tree in clay (CLY) and sandy clay (SCLY) textured soils

Soil Water Retention Curve

The Soil water retention curve (SWRC) which denotes the relationship between the matric potential of the soil water and its corresponding volumetric amount was plotted according to Eftekhari and Akhtarpour (2024). The curve (Figure 4) showed the clay soil to have a higher moisture level across all the potentials measured compared to the sandy clay. Idris (2020) stated that although water moves up higher in small-diameter capillaries, thereby favoring small-size pores retain more water but it is held more tightly than in large-size pores. The curve (Figure 4) suggests that the sandy clay may allow better water uptake, aeration and facilitate good drainage compared to the clay.

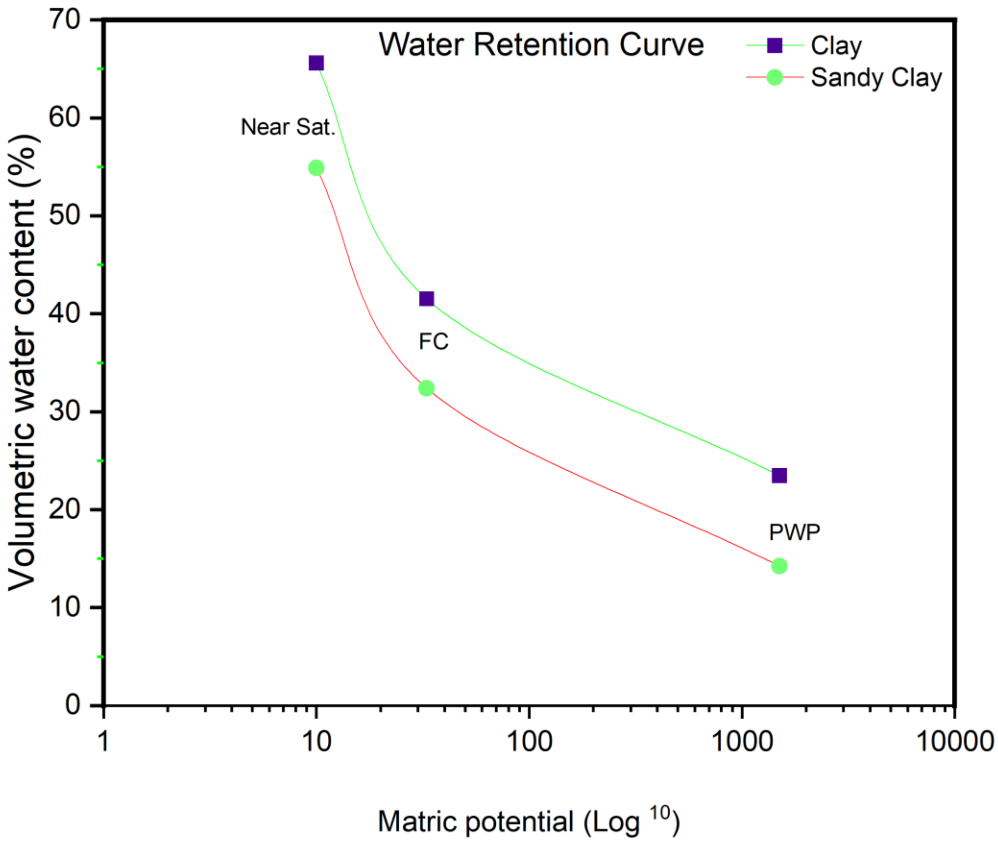


Figure 4. Soil retention characteristic curve for clay and sandy clay textured soils

Correlation Plot

The correlation analysis further defines the quantified relationship between the water stress indices and the meteorological variables. Here, stomatal conductance significantly depicted a strong positive correlation with RH (r = 0.66) while depicting a significantly strong negative correlation of about equal magnitude with temperature and VPD (r = -0.63 and -0.64, respectively). Expectedly, the leaf water potential demonstrated a significant and positive correlation with temperature and VPD. The output re-establishes the stomatal sensitivity to the two variables (temperature and VPD), and also signifies how oil palm responded swiftly by holding or retaining water more tightly hence the observed positive correlation between the LWP and temperature and VPD (see Figure 5).

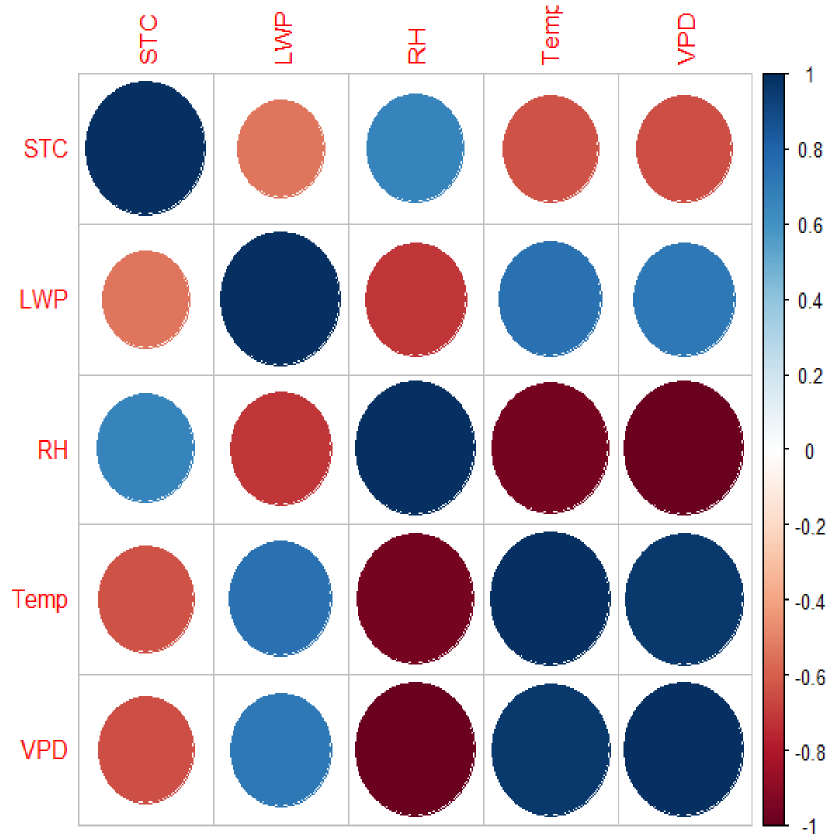


Figure 5. Correlation chart demonstrating strong positive relationship between water stress indices - STC and LWP (Stomatal conductance and leaf water potential) and weather variables (Temp = temperature, RH = relative humidity, VPD = vapor pressure deficit)

From the results presented, it was deduced that, although water was abundantly available to the oil palm trees in clay texture, the OP exhibited less gaseous exchange characteristics by recording lower stomatal conductance and higher leaf water potential. In harmony with our results, Monzon *et al*. (2022) reported highest moisture content in clay-rich soil, yet pointed out that palms under such high moisture conditions could manifest partial stomatal closure and decreased transpiration, possibly due to high suction effect. Equally, Kholová *et al*. (2021) suggested that while certain traits can provide better yield under low moisture, some show reduced yield even under high-watered conditions. Generally, from our results, the stomatal conductance has expressed a high sensitivity to water reduction for each of the soil textures. This has been found by Smith (1989) who recommended that oil palm genotypes with low stomatal sensitivity to soil water deficit should be best considered in rainfed production system compared to those with high sensitivity.

Conclusions

Results of this study inferred that, temperature between 24.5°C to 27.6°C best supported stomatal conductance of mature oil palm trees, while 30.1°C – 32.7°C caused its remarkable decline (↓66%). At an RH of 82.1% oil palm demonstrated highest stomatal conductance (↑66.8%) than 58.8% RH. Additionally, vapor pressure deficit of 0.06 to 1.09 kPa resulted in superior stomatal conductance, while 1.5 to 2.7 kPa reduced it by ½. It can be notably deduced from the results that, oil palm had better leaf water status and higher stomatal conductance under sandy clay soil, than under clay, despite soil moisture content was 5.0% higher in the clay soil. Our findings confirmed the sensitivity of STC and LWP to temperature, relative humidity and vapor pressure deficit in oil palm. It further indicated that, although clay soil retains higher water than sandy clay, oil palm under clay is more liable to water stress than in sandy clay. Stomatal conductance demonstrated a significant positive correlation with RH (r = 0.66) which was a sharp contrast as per its relationship with temperature and VPD (r = -0.63 and -0.64, respectively).

Acknowledgments

The authors acknowledge support from the Ministry of Higher Education, Malaysia and Ahmadu Bello University, Zaria Nigeria.

Conflict of Interest

We declare lack of conflict as per the content of this paper.

Funding Declaration

Fundamental Research Grant Scheme (FRGS) (No. FRGS/1/2022/WAB04/UPM/02/2, Ministry of Higher Education, Malaysia was the funding source of this research.

Author Contribution

All authors have contributed technically to the research and development of the manuscript.

Reference

Abubakar, A., Ishak, M. Y., and Makmom, A. A. (2021). Impacts of and adaptation to climate change on the oil palm in Malaysia: a systematic review. *Environmental Science and Pollution Research*, *28*(39), 54339-54361. https://doi.org/10.1007/s11356-021-15890-3

Ahmed, M. T., Imtiaz, M. N., and Mitu, N. S. (2020). Impact of weather on crops in few northern parts of bangladesh: Hci and machine learning based approach. *Australian Journal of Engineering and Innovative Technology*, *2*(1), 7-15. https://doi.org/10.34104/ajeit.020.07015

Apichatmeta, K., Sudsiri, C. J., and Ritchie, R. J. (2017). Photosynthesis of oil palm (Elaeis guineensis). *Scientia Horticulturae*, *214*, 34-40. https://doi.org/10.1016/j.scienta.2016.11.013

Bayona-Rodriguez, C. J., and Romero, H. M. (2019). Physiological and agronomic behavior of commercial cultivars of oil palm ('Elaeis guineensis') and OxG hybrids ('Elaeis oleifera'x'Elaeis guineensis') at rainy and dry seasons. *Australian Journal of Crop Science*, *13*(3), 424-432. https://doi.org/10.21475/ajcs.19.13.03.p1354

Eftekhari, R., and Akhtarpour, A. (2024). The Soil-Water Characteristic Curve and Determination Methods. In *3rd International Congress on Civil Engineering, Architecture, Building Materials and Environment*, 1-12. https://en.civilica.com/doc/1969786/

Gee, G. W., and Bauder, J. W. (1986). *Particle size analysis*. In: A. Klute, editor, Methods of soil analysis. Part 1.2nd ed. Agron.Monogr. 9. ASA and SSSA, Madison, WI. p. 383–411.

Idris, S. (2020). *Effect of long -term flooding and landuse under different soil types on selected soil and groundwater properties of Hadejia-Nguru wetland, Nigeria.* Thesis Submitted Faculty of Agriculture Ahmadu Bello University, Zaria, Nigeria.

Idris, S., Sung, C. T. B., Zaibon, S., and Cheak, S. C. (2024). Climate variability and water Stress effects on oil palm (*Elaeis guineensis* Jacq.) productivity in Malaysia. *Journal of Oil Palm Research*, 1-32. http://psasir.upm.edu.my/id/eprint/117485/1/117485.pdf

IPCC, (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *Cambridge; New York, NY: Cambridge University Press,* 485-533. https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-FrontMatterA_FINAL.pdf

Jaafar, L., and Anderson, C. T. (2024). Architecture and functions of stomatal cell walls in eudicots and grasses. *Annals of Botany*, *134*(2), 195-204. https://doi.org/10.1093/aob/mcae078

Kholová, J., Urban, M. O., Cock, J., Arcos, J., Arnaud, E., Aytekin, D., Azevedo, V., Barnes, A.P., Ceccarelli, S., Chavarriaga, P., Cobb, J.N., Connor, D., Cooper, M., Craufurd, P., Debouck, D., Fungo, R., Grando, S., Hammer, G.L., Jara, C.E., Messina, C., Mosquera, G., Nchanji, E., Ng, E.H., Prager, S., Sankaran, S., Selvaraj, M., Tardieu, F., Thornton, P., Valdes-Gutierrez, S.P., van Etten, J., Wenz, P., and Xu, Y. (2021). In pursuit of a better world: crop improvement and the CGIAR. *Journal of Experimental Botany*, *72*(14), 5158-5179. https://doi.org/10.1093/jxb/erab226

Klute, A. (1986). Water retention: laboratory methods. *Methods of soil analysis: part 1 Physical and Mineralogical Methods*, *5*, 635-662. https://doi.org/10.2136/sssabookser5.1.2ed.c26.

Konduri, V. S., Vandal, T. J., Ganguly, S., and Ganguly, A. R. (2020). Data science for weather impacts on crop yield. *Frontiers in Sustainable Food Systems*, *4*(52), 1-11. https://doi.org/10.3389/fsufs.2020.00052

Kunjet, S., Thaler, P., Gay, F., Chuntuma, P., Sangkhasila, K., and Kasemsap, P. (2013). Effects of drought and tapping for latex production on water relations of Hevea brasiliensis trees. *Agriculture and Natural Resources*, *47*(4), 506-515. https://li01.tci-thaijo.org/index.php/anres/article/view/243090

Lewis, K., Rumpang, E., Kho, L. K., McCalmont, J., Teh, Y. A., Gallego-Sala, A., and Hill, T. C. (2020). An assessment of oil palm plantation aboveground biomass stocks on tropical peat using destructive and non-destructive methods. *Scientific Reports*, *10*(1), 1-12. https://doi.org/10.1038/s41598-020-58982-9

Li, Y., Song, X., Li, S., Salter, W. T., and Barbour, M. M. (2020). The role of leaf water potential in the temperature response of mesophyll conductance. *New Phytologist*, *225*(3), 1193-1205. https://doi.org/10.1111/nph.16214

Li, Y. T., Gao, H. Y., and Zhang, Z. S. (2023). Effects of environmental and non-environmental factors on dynamic photosynthetic carbon assimilation in leaves under changing light. *Plants*, *12*(10), 1-14. https://doi.org/10.3390/plants12102015

Lindh, M., Hoeber, S., Weih, M., and Manzoni, S. (2022). Interactions of nutrient and water availability control growth and diversity effects in a Salix two-species mixture. *Ecohydrology*, *15*(5), 1-16. https://doi.org/10.1002/eco.2401

Middleby, K. B., Cheesman, A. W., and Cernusak, L. A. (2024). Impacts of elevated temperature and vapour pressure deficit on leaf gas exchange and plant growth across six tropical rainforest tree species. *New Phytologist*, *243*(2), 648-661. https://doi.org/10.1111/nph.19822

Montoya, C., Daza, E., Mejía-Alvarado, F. S., Caicedo-Zambrano, A. F., Ayala-Díaz, I., Ruiz-Romero, R., and Romero, H. M. (2024). Photosynthetic performance of oil palm genotypes under drought stress. *Plants*, *13*(19), 1-16. https://doi.org/10.3390/plants13192705

Monzon, J. P., Slingerland, M. A., Rahutomo, S., Agus, F., Oberthür, T., Andrade, J. F., and Grassini, P. (2021). Fostering a climate-smart intensification for oil palm. *Nature Sustainability*, *4*(7), 595-601. https://doi.org/10.1038/s41893-021-00700-y

Monzon, J. P., Jabloun, M., Cock, J., Caliman, J. P., Couëdel, A., Donough, C. R., and Grassini, P. (2022). Influence of weather and endogenous cycles on spatiotemporal yield variation in oil palm. *Agricultural and Forest Meteorology*, *314*, 1-10. https://doi.org/10.1016/j.agrformet.2021.108789

MPOB, (2022). *Malaysian Oil Palm Statistics 2021*. 41st edition. MPOB, Bangi. 214 pp. https://share.google/9dZkXpDMGkjQKLUBY

Norizan, M. S., Wayayok, A., Karim, Y. A., Abdullah, A. F., and Mahadi, M. R. (2021). Quantitative approach for irrigation requirement of oil palm: Case study in Chuping, Northern Malaysia. *Journal of Oil Palm Research*, *33*(2), 278-288. https://doi.org/10.21894/jopr.2020.0094

Okon, E. M., Falana, B. M., Solaja, S. O., Yakubu, S. O., Alabi, O. O., Okikiola, B. T., and Edeme, A. B. (2021). Systematic review of climate change impact research in Nigeria: implication for sustainable development. *Heliyon*, *7*(9), 1-21. https://doi.org/10.1016/j.heliyon.2021.e07941

Pangaribuan, I. F., Rahmawati, N., Akoeb, E. N., Yenni, Y., and Pangaribuan, Y. (2024). Reactions of Drought-Affected Oil Palm Variety Seedlings during the Nursery Phase: Bud and Root Responses. *IOP Conference Series: Earth and Environmental Science*, 1308(1), 1-8. https://doi.org/10.1088/1755-1315/1308/1/012034

Paterson, R. R. M. (2023). Future climate effects on yield and mortality of conventional versus modified oil palm in SE Asia. *Plants*, *12*(12), 1-11. https://doi.org/10.3390/plants12122236

Payus, C., Ann Huey, L., Adnan, F., Besse Rimba, A., Mohan, G., Kumar Chapagain, S., and Fukushi, K. (2020). Impact of extreme drought climate on water security in North Borneo: Case study of Sabah. *Water*, *12*(4), 1-19. https://doi.org/10.3390/w12041135

Randall, M., Schiller, K., Lewis, A., Montgomery, J., and Alam, M. S. (2024). A systematic review of crop planning optimisation under climate change. *Water Resources Management*, *38*(6), 1867-1881. https://doi.org/10.1007/s11269-024-03758-3

Reynolds, W. D., Drury, C. F., Yang, X. M., and Tan, C. S. (2008). Optimal soil physical quality inferred through structural regression and parameter interactions. *Geoderma*, *146*(3-4), 466-474. https://doi.org/10.1016/j.geoderma.2008.06.017

Smith, B. G. (1989). The effects of soil water and atmospheric vapour pressure deficit on stomatal behaviour and photosynthesis in the oil palm. *Journal of Experimental Botany*, *40*(6), 647-651. https://doi.org/10.1093/jxb/40.6.647

Suresh, K., Nagamani, C., Ramachandrudu, K., and Mathur, R. K. (2010). Gas-exchange characteristics, leaf water potential and chlorophyll a fluorescence in oil palm (*Elaeis guineensis* Jacq.) seedlings under water stress and recovery. *Photosynthetica*, *48*(3), 430-436. https://doi.org/10.1007/s11099-010-0056-x

Sung, C. T. B., and Talib, J. (2006). *Soil and Plant Analyses*. Vol. I Soil Physics Analyses, University Putra Malaysia Press. http://christopherteh.com/publications/resources/Soil-Physics-Analyses-Vol-I.pdf