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Impact of Climate Change on Oil Palm Productivity

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ABSTRACT

This study aims to analyze the influence of climate elements on oil palm productivity at the Pamukan Plantation in Kotabaru Regency, South Kalimantan. The observed climate elements include rainfall, air temperature, and air humidity. This study was conducted using an agronomic survey method and statistical analysis with regression and correlation, using secondary and primary data collected over the past six years (2015–2020). The results show that rainfall, temperature, and air humidity have a significant relationship with fluctuations in oil palm production. Increased rainfall beyond the optimal threshold actually reduces productivity, which is thought to be related to the hilly topography and the dominance of ultisol soils with low infiltration and water retention capacity. High water deficits, such as those experienced in 2015, negatively impact production the following year. Furthermore, increases in temperature and air humidity also show a negative relationship with production, due to disruptions in photosynthesis and plant transpiration. This study indicates that climate change could significantly affect oil palm productivity at the Pamukan Plantation. Therefore, adaptation strategies and plantation management are needed that are more responsive to changing climate conditions to maintain sustainable production.

Keywords: Climate change; Crop productivity; *Elaeis guineensis;* Environmental stress; Plantation management

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INTRODUCTION

The oil palm *(Elaeis guineensis* Jacq.) is a strategic plantation commodity that plays a vital role in the Indonesian economy. In addition to contributing significantly to national income through exports, oil palm also plays a role in provides employment and helps developing rural areas (Ajonina and Okanyene 2021; Tabe-Ojong et al. 2023). Indonesia is the world's largest palm oil producer, with plantations covering over 16 million hectares and crude palm oil (CPO) production reaching over 47 million tons per year (Indonesian Ministry of Agriculture 2023). Palm oil products are used not only for food, such as cooking oil, but also for industrial products, cosmetics, pharmaceuticals, and bioenergy. Consequently, global demand for palm oil continues to increase with population growth and the need for renewable energy (Nuryawan et al. 2022; Chaparro et al. 2023).

However, oil palm productivity is significantly influenced by various factors, both internal and external. Internal factors include planting material (genetics) and cultivation techniques, while the most dominant external factor is climate conditions (Abubakar et al. 2021; Castañeda-Garzón et al. 2021). Climatic elements that influence oil palm growth and development include rainfall, solar radiation, temperature, and humidity (Rajakal et al. 2021). Oil palm plants thrive in tropical regions with temperatures of 24–28°C, 5–7 hours of sunlight per day, and rainfall of 2,500–3,000 mm per year, evenly distributed throughout the year (Tani et al. 2020). The tropical climate and soil in Southeast Asian countries are ideal for growing oil palms (Uning et al. 2020; Xu et al. 2021). In general, water shortages in oil palm plantations can cause delayed ripening of fruit bunches, reduce fruit bunch weight, and decrease CPO extraction yields. The number of fruit bunches decreases nine months later, and the number of male flowers increases while the number of female flowers decreases (Tarwaca and Putra 2015).

Oil palm plants require at least 4 hours of sunlight per day. Sunlight exposure of less than 4 hours per day will reduce the plant's assimilation process for carbohydrate production and female flowers. The effect of solar radiation will be more optimal if rainfall is also optimal. In addition to sunlight exposure, the intensity of solar radiation, particularly in the 0.4-0.7 micron wavelength range, also affects the rate of photosynthesis. If solar radiation intensity decreases by 20%, the rate of photosynthesis decreases by up to 50%. Air

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temperature, to a certain extent, affects the metabolism and cells in plant organs, ultimately affecting growth and production (Sharma et al. 2024). The average optimal temperature required for oil palms is 24–28°C. Temperature is closely related to altitude. Therefore, a suitable altitude is 0–400 m above sea level, as at this altitude the air temperature is estimated to be 27–32°C. Low air temperatures in certain months will inhibit flower pollination, thus disrupting fruit formation (Tarwaca and Putra 2015).

The rate of photosynthesis is also determined by the level of humidity, represented by the VPD (Vapor Pressure Deficit), often referred to as vapor pressure deficit. The rate of photosynthesis tends to decrease when the VPD increases. Increased VPD causes a decrease in stomatal conductance, disrupting carbon dioxide diffusion, which inhibits the rate of photosynthesis (Inoue et al. 2021). The novelty of this research lies in the quantitative analysis of the specific effects of climate elements such as rainfall, air temperature, and humidity on oil palm productivity at the field scale, based on actual company data. Unlike some previous studies, which were more simulation- or model-based, this study uses observational data and actual productivity at the plantation level. Therefore, the results are expected to provide more applicable and relevant information for plantation managers and smallholders in developing climate change adaptation and mitigation strategies.

MATERIALS AND METHODS

External factors, such as climate, are the most important factors influencing oil palm cultivation (Pulighe 2023). Oil palm cultivation in a region must refer to factors determining productivity, including land suitability, climate patterns, and plant maintenance. The suitability and capability of the land, as well as the climatic conditions of the region, are important to avoid production failures or minimize potential damage. One climatic element that can be used to determine climate patterns is rainfall (Gonzales and Gonzales 2024). The study location is a palm oil plantation company consisting of five divisions with a total area of 2,971.57 ha (Table 1).

Table 1. Area of oil palm plantations in Pamukan

Division	Total area	Year	Soil class	Soil Type	Seedlings Source
I	815.25	2008/ 2009	S2	Mineral	Dami Mas
II	416.36	2008/ 2009	S2	Mineral	Dami Mas
III	509.75	2008/ 2009	S2	Mineral	Dami Mas
IV	642.59	2008/ 2009	S2	Mineral	Dami Mas
V	587.62	2008/ 2009	S2	Mineral	Dami Mas
Total	**2,971.57**				

Based on Table 2 and Table **3**, it is known that the Pamukan plantation in the period from 2015 to 2020 had 55 wet months, 8 humid months, and 9 dry months. Based on the results of the Q value calculation of 16.36%, the Pamukan plantation is included in the climate type group B, namely wet areas Table 4. After knowing the climate type, the next step is to calculate the amount of annual water deficit from 2015 to 2020. This aims to determine the amount of water shortage in that time period. According to Santosa et al. (2016), oil palm plants require quite high rainfall every year, which is between 2000 - 2500 mm / year and evenly distributed throughout the year. Rainfall will accelerate the rate of leaf flush in succession which will then spur the rate of flower flush.

Table 2. Number of wet, humid, and dry months at the research location

2015 - 2020	Wet Months	Humid Months	Dry Months
Oil Palm Companies in Pamukan	55	8	9

$$Q = \frac{9}{55} \times 100\ \% = 16{,}36\ \%$$

Table 3. Number of wet, humid, and dry months in Pamukan Plantation in period 2015-2020 in Pamukan Plantation

Year	Wet Months	Humid Months	Dry Months
2015	6	2	4
2016	11	1	0
2017	12	0	0
2018	10	0	2
2019	7	2	3
2020	9	3	0
TOTAL	**55**	**8**	**9**
Average	**9.17**	**1.33**	**1.50**

Table 4. Classification of climate types based on q value

Type Climates	Nilai Q (%)	Area Description
A	0.0 - 14.3	Very wet
B	14.3 - 33.3	Wet
C	33.3 - 60.0	Rather wet
D	60.0 - 100.0	Medium
E	100.0 - 167.0	Rather dry
F	167.0 - 300.0	Dry
G	300.0 - 700.0	Very dry
H	>700.0	Extreme Dry

Climatological data (Table 5) show that the yearly average of air temperature in Pamukan oil palm plantations during the 2015–2020 period ranged from 26.50 to 27.45 ℃. This condition is influenced by the duration of sunshine and the topography of the area. According to Tarwaca and Putra (2015), climatic elements, including rainfall, solar radiation, air temperature, and humidity, significantly influence the growth and production of oil palm bunches. These climatic factors must be at their optimum to meet the criteria for oil palm growth and development. This is in line with the opinions of Etman et al. (2024) and Pradiko (2022), who stated that temperature, rainfall, solar radiation, and humidity are important factors that must be at their optimum to support oil palm production. This can be seen from the Table 5 of climate condition data at the research location over the last 6 years.

Table 5. BMKG Gusti Syamsir Alam station data for 2015 – 2020

Weather Elements	2015	2016	2017	2018	2019	2020
Temperature (℃)	27.13	27.39	26.68	26.50	26.98	27.45
Rh (%)	79.92	85.01	85.98	85.34	82.31	84.07
Sunshine Duration (h)	6.72	5.34	4.32	5.04	5.56	4.57

Based on the results of observations conducted at the Pamukan oil palm plantation, production data for the last six years can be seen in the following Table 5. Based on Figure 1, it can be seen that palm oil production from 2015 to 2020 was 6,685.97 tons/year in 2015, 5,540.05 tons/year in 2016, 5,948.46 t.year^{-1} in 2017, 9,318.11 t.year^{-1} in 2018, 10,094.90 tons/year in 2019 and 7,616.68 tons/year in 2020. The highest production was in 2019 with a total of 10,094.90 t.year^{-1} while the lowest production was in 2016 with 5,540.05 t.year^{-1}. The graph also shows that production decreased from 2015 to 2016, but production increased significantly from 2017 to 2019. Production then declined again in 2020. This indicates fluctuations in production at the Pamukan plantation between 2015 and 2020. This fluctuation is suspected to be influenced by rainfall from 2015 to 2020, as seen in Figure 2. There is a direct relationship between rainfall in the previous 12 months and current production. Previous research by Suharyanti et al. (2020) showed that unstable rainfall over an annual period can directly impact flower formation and the number of harvested bunches. Furthermore, research by Paterson (2021) explains that rainfall has a long-term effect on oil palm growth and production. This means that if rainfall increases, production in the following 12 months will increase. Rainfall and Rainy Day Data at the Pamukan plantation based on the results of observations carried out at the Pamukan plantation, rainfall data for the last 6 years is presented in the following Table 7.

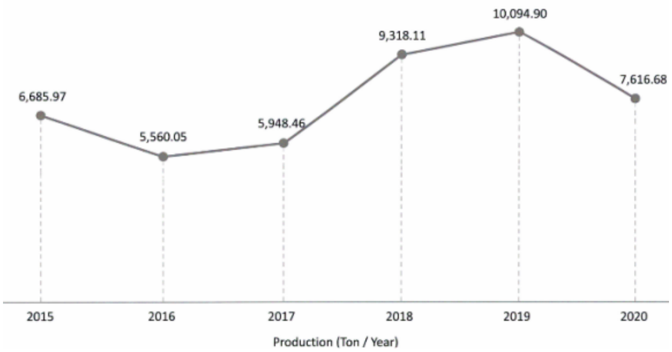

Figure 1. Production of oil palm in Pamukan pantation in the period 2015-2020.

Table 6.

Table 6. Data on oil palm plantation production in Pamukan 2015-2020

Month	Production (t)					
	2015	2016	2017	2018	2019	2020
January	855,810	908,220	352,570	631,030	418,930	727,250
February	779,590	537,410	370,670	836,850	501,150	604,460
March	846,580	363,420	501,590	1,375,200	755,690	450,810
April	715,320	204,390	745,340	1,301,890	914,640	481,860
May	543,010	226,760	830,670	1,059,060	1,048,580	349,060
Juny	492,020	212,530	573,220	720,110	910,500	422,520
July	380,550	247,280	793,510	736,470	1,013,280	349,590
August	246,380	319,440	778,160	915,560	751,890	343,780
September	297,990	474,600	427,220	539,110	721,060	512,360
October	361,110	773,140	193,730	350,020	1,308,460	844,150
November	494,870	674,720	159,180	397,830	954,260	1,285,660
December	672,740	598,140	222,600	454,950	796,460	1,244,880
TOTAL	6,685,970	5,540,050	5,948,460	9,318,080	10,094,900	7,616,380
Average	557,164	461,671	495,705	776,507	841,242	634,698
MAX	855,810	908,220	830,670	1,375,200	1,308,460	1,285,660
MIN	246,380	204,390	159,180	350,020	418,930	343,780
STDEV	204,635	228,333	236,091	322,524	230,868	318,079
CV (%)	36.73	49.46	47.63	41.54	27.44	50.12

Table 7. Rainfall data for the period 2015 - 2020

Month/Year	Rainfall (mm)						Average
	2015	2016	2017	2018	2019	2020	
January	362	83	294	341	367	93	256.67
February	234	166	200	358	282	316	259.33
Mart	234	186	225	518	172	217	258.67
April	214	192	367	219	135	115	207.00
Mey	62	239	306	223	126	106	177.00
Juny	178	108	140	221	585	262	249.00
July	35	196	200	106	21	202	126.67
August	-	102	151	49	5	130	72.83
September	-	150	114	54	21	263	100.33
October	7	163	180	112	109	186	126.17
November	96	194	249	259	79	80	159.50
December	188	356	182	176	64	69	172.50
TOTAL	1,610	2,135	2,608	2,636	1,966	2,039	2,165.67
Wet Months	6	11	12	10	7	9	11
Humid Months	2	1	-	-	2	3	1
Dry Months	4	-	-	2	3	-	-

Based on Figure 2, it can be seen that rainfall in Pamukan plantation in the period of 2015 to 2020 was 1,610 mm in 2015, 2,135 mm in 2016, 2,608 mm in 2017, 2,636 mm in 2018, 1,966 mm in 2019, and 2,039 mm in 2020. Meanwhile, the rainy days in the period of 2015 to 2020 were 97 days in 2015, 115 days in 2016, 157 days in 2017, 146 days in 2018, 103 days in 2019, and 138 days in 2020. From the graph, it can also be seen that the highest rainfall was in 2018, namely, the highest rainfall was 2,636 mm, and the lowest rainfall was 1,610 mm in 2015. The highest number of rainy days occurred in 2017, with 157 rainy days in one year, while the lowest number of rainy days was in 2015, with 97 rainy days. This generally illustrates that rainfall and rainy days in the Pamukan plantation between 2015 and 2020 fluctuated. This is in line with research by Gunawan et al. (2021), which found that annual rainfall significantly influences the dynamics of oil palm growth and production. This is also supported by Idris (2024), who emphasized the importance of climate stability for oil palm plantation productivity. After understanding the results of rainfall data from 2015 to 2020, the climate classification of the Pamukan Plantation area can be determined using the Schmidth and Ferguson method (Table 4).

Water deficit in Pamukan plantation from 2015 – 2020 presents in Table 8. Figure 3 shows that an increase in water deficit will impact production in the following 12-24 months. In 2015, a water deficit of 472 mm resulted in a 17.14% decrease in production in 2016. There was no water deficit from 2016 to 2017. In 2018, a 79 mm water deficit occurred, but this did not affect production in 2019. This is thought to be due to other factors not yet studied, such as fertilization, plant age, and the plant's ability to adapt to drought stress. In 2019, a 401 mm water deficit resulted in a 24.55% decrease in production in 2020.

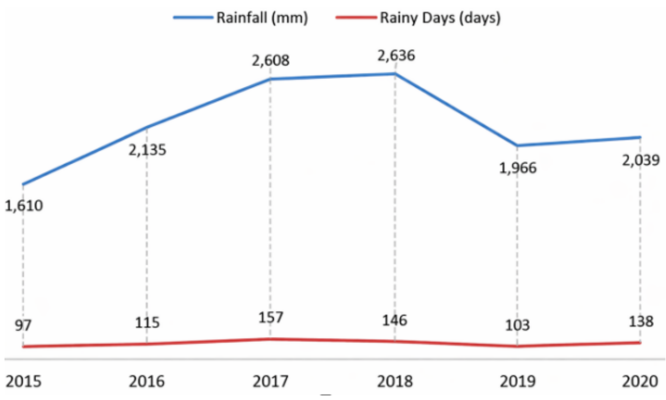

Figure 2. Graph of the Relationship between Rainfall and Rainy Days in the period 2015-2020

Table 8. Water deficit in Pamukan plantation from 2015 – 2020

Year	Rainfall (mm)	Water Deficit
2015	1,610	472
2016	2,135	-
2017	2,608	-
2018	2,636	79
2019	1,966	401
2020	2,039	57

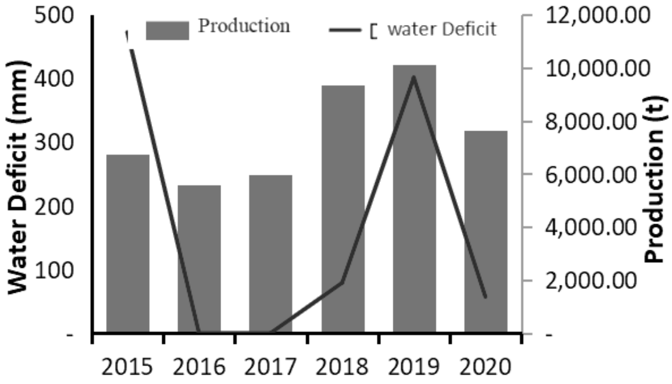

Figure 3. Analysis of water deficit on production

Analysis of the relationship between rainfall and production

This analysis of the relationship between rainfall and production aims to determine the close relationship between climate elements, namely rainfall, and production over the past six years. To determine the relationship between rainfall and palm oil production at the Pamukan plantation, regression and correlation analyses were conducted on rainfall and production data over the past six years. The results of the regression and correlation analyses on this data can be seen in the following figure (Figure 4).

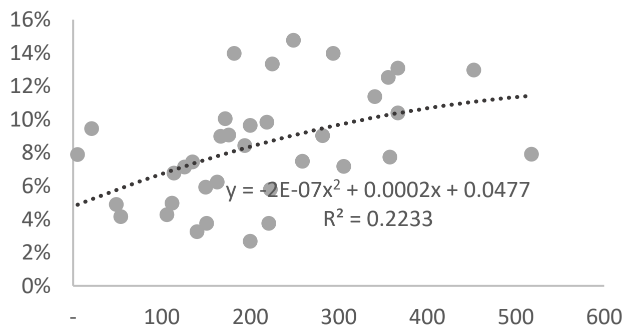

Figure 4. The relationship between rainfall and production on Pamukan plantations

The regression analysis of rainfall on production at the Pamukan plantation reveals a negative standard coefficient (-2E-07x2 + 0.0002x + 0.0477), which has the opposite meaning (Figure 4) Any increase in rainfall will reduce oil palm production. This is suspected to be due to the topography of the Pamukan Plantation, which is largely hilly and partly low-lying, directly adjacent to the tidal sea. The soil type at the Pamukan Plantation is ultisol. Ultisols are generally brownish-yellow to red in color and are formed from acid sulfate parent material, sandstone, and quartz sediment, making them very acidic and nutrient-poor (Pan et al. 2020). The physical properties of ultisols that interfere with plant growth and production include soil porosity, low infiltration rates and permeability, soil aggregate stability, and low water retention capacity (Alibasyah 2016). This is suspected to be the reason why increased rainfall will reduce oil palm production.

Furthermore, the *R* Square or R^2 value is 0.2233. This means that the effect of rainfall on production is 22.33%, while the other 77.67% is influenced by variables not studied, both agronomic and non-agronomic, which are related to palm oil production at the Pamukan Plantation. Meanwhile, the correlation coefficient of rainfall on production is 0.4647, which means that there is a moderate or sufficient relationship between rainfall and production. This study is in line with Anwar and Rahman (2024), who stated that rainfall contributes to palm oil production. Thus, it is important to consider other variables to obtain a more complete picture of the factors that influence palm oil production.

Analysis of the relationship between temperature and production

This analysis was conducted to determine the level of closeness of the relationship between climate elements, particularly temperature, and palm oil production over the past six years. For this purpose, regression and correlation methods were used on temperature and production data obtained during that time period. The results of the regression and correlation analyses are presented in the following Figure 5.

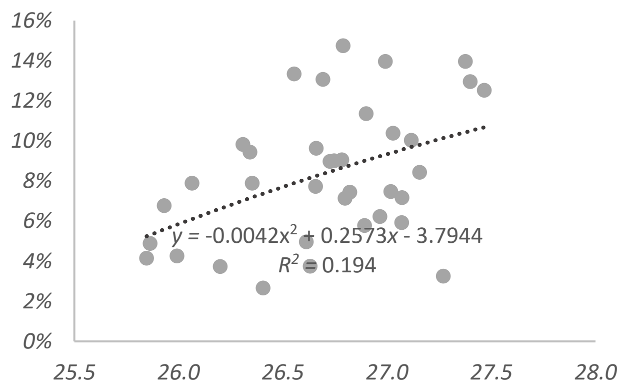

Figure 5. The relationship between temperature and production at Pamuka Plantation

The results of the temperature regression analysis on production at the Pamukan Plantation (Figure 5) show that the standard coefficient value is negative (-0.0042x2 + 0.2573x + 3.7944) which has the opposite meaning. Any increase in temperature to the maximum limit will reduce oil palm production. This is thought to be due to the topography and soil type at the Pamukan Plantation, which is mostly hilly land and some of it is lowland. The soil type at the Pamukan Plantation is ultisol. The physical properties of ultisol that interfere with plant growth and production are soil porosity, low soil infiltration and permeability rates, soil aggregate stability, and low water retention capacity (Alibasyah 2016). This is thought to cause each increase in temperature to increase the evaporation rate. Even though annual rainfall at the Pamukan Plantation is sufficient for optimum growth and development of oil palm plants, the low infiltration rate and water retention capacity mean that water does not remain in the soil pores for long. Therefore, physical environmental conditions play a crucial role in supporting optimal palm oil production (Ovwigho et al. 2024).

Furthermore, high temperatures are suspected to have a negative or opposite effect on the percentage of intercropping. Intercropping is an oil palm planted after the nucleus planting. Intercropping is intended to replace the main tree that dies or is attacked by pests and diseases and then be replaced with new plants. Intercropping is carried out on oil palms from one year after planting until just before the first harvest (TM 0). The response of transpiration rates at different plant ages directly affects the plant's photosynthesis process. Furthermore, the *R* Square (R^2) value is 0.194. This indicates that temperature influences production by 19.4%, while the remaining 80.6% is influenced by unexamined variables, both agronomic and non-agronomic, related to palm oil production at the Pamukan Plantation. Meanwhile, the correlation coefficient between temperature and production was 0.439612642, indicating a moderate or sufficient relationship between temperature and production. This finding aligns with research by Abubakar et al. (2022), which states that climate influences coconut production. Furthermore, research by Anwar and Rahman (2024) explains that environmental variables such as temperature, humidity, and rainfall contribute differently depending on the agronomic factors applied in the plantation.

Analysis of the relationship between humidity and production

This analysis was conducted to examine the relationship between climate factors, such as air humidity, and palm oil production over the past six years at the Pamukan Plantation. To this end, regression and correlation methods were applied to humidity and production data for that period. The results of this analysis are shown in the following Figure 6:

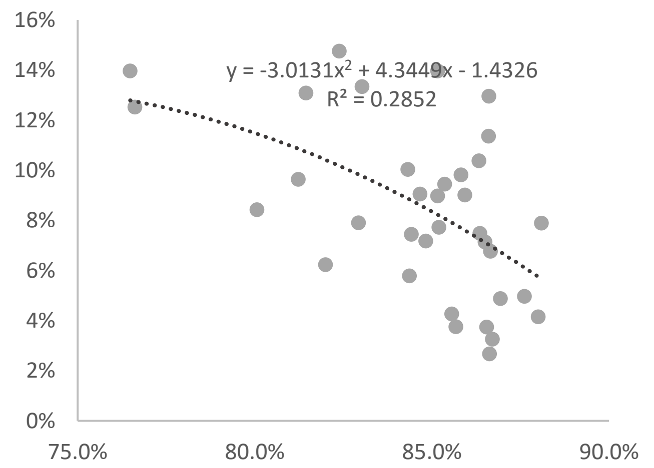

Figure 6. The relationship between humidity and palm oil production at the Pamukan Plantation

The results of the regression analysis of humidity on production at the Pamukan Plantation show that the standard coefficient value is negative (-3.0131x2 + 4.3449x + 1.4326), which has the opposite meaning. Any increase in humidity will reduce oil palm production. This is thought to be because high rainfall causes a decrease in air temperature due to reduced intensity and length of daily sunlight (Liu et al. 2022). Lower intensity and length of daily sunlight inhibit the transpiration rate (Granda et al. 2020). Low plant transpiration rates result in decreased humidity around the plant canopy (Al-Salman et al. 2023). Conversely, with low daily rainfall, the intensity and length of daily sunlight are quite high. High intensity and length of daily sunlight trigger the transpiration rate. High plant transpiration rates increase the concentration of water vapor in the atmosphere located close to the canopy or plant crown (Alam et al. 2021). This condition results in higher humidity around the canopy or plant crown. The low intensity and length of light reaching the canopy of oil palm plantations as a result of high rainfall also directly affect the relatively low air temperature around the canopy of oil palm plantations. Conversely, the high intensity and length of light reaching the canopy of oil palm plantations as a result of relatively low rainfall directly affect the high air temperature around the canopy of oil palm plantations, it is suspected that the increase and decrease in production are more determined by rainfall compared to other climate elements including humidity and air temperature (Tarwaca and Putra 2015n). Furthermore, the R Square or R2 value is 0.2852. This means that the effect of temperature on production is 28.52% while the other 71.48% is influenced by variables not studied, both from agronomic and non-agronomic aspects that are related to oil palm production at Pamukan Plantation. Meanwhile, the correlation coefficient between temperature and production is (-0.526417871), which means that there is a very weak relationship between temperature and production.

CONCLUSIONS AND SUGGESTIONS

Based on the study conducted at the Pamukan Plantation from 2015 to 2020, climatic factors such as rainfall, temperature, and humidity were found to influence oil palm productivity. Rainfall showed a negative correlation with production, where excessive levels reduced yields, particularly due to hilly terrain and ultisol soils with low water retention. A high water deficit in 2015 (472 mm) led to a 17.14% production decline in 2016, indicating its impact on productivity. Temperature also had a negative effect, contributing 19.4% to production variability, as higher temperatures increased evaporation and intensified drought conditions. Additionally, high humidity reduced productivity by lowering temperature and light intensity, thereby disrupting photosynthesis. Overall, climatic factors contributed 28.52% to production, although their influence was moderate, suggesting that other factors such as agronomic practices and socio-economic conditions also play important roles.

REFERENCES

Abubakar A, Ishak MY, Makmom AA. 2021. Impacts of and adaptation to climate change on the oil palm in Malaysia: A systematic review. Environ Sci Pollut Res. 28(39):54339–54361. https://doi.org/10.1007/s11356-021-15890-3.

Abubakar A, Ishak MY, Uddin MK, Bakar AA, Mohammed MU. 2022. What does modelling tells us on the influence of certain weather parameters on oil palm production in Peninsular Malaysia. Indian J Agric Res. https://doi.org/10.18805/IJARe.AF-715.

Ajonina UP, Okanyene BB. 2021. Impact of oil palm (*Elaeis guineensis*) cultivation on soil physico-chemical properties and food security of rural households within Mundemba sub-division, Cameroon. J Agric Ecol Res Int. 22(3):32–46. https://doi.org/10.9734/jaeri/2021/v22i330190.

Al-Salman Y, Ghannoum O, Cano FJ. 2023. Midday water use efficiency in sorghum is linked to faster stomatal closure rate, lower stomatal aperture and higher stomatal density. Plant J. 115(6):1661–1676. https://doi.org/10.1111/tpj.16346.

Alam MS, Lamb DW, Warwick NWM. 2021. A canopy transpiration model based on scaling up stomatal conductance and radiation interception as affected by leaf area index. Water. 13(3):252. https://doi.org/10.33089/w13030252.

Alibasyah MR. 2016. Perubahan beberapa sifat fisika dan kimia ultisol akibat pemberian pupuk kompos dan kapur dolomit pada lahan berteras. J Floratek. 11(1):75–87.

Anwar R, Rahman A. 2024. The impact of rainfall on oil palm production: A case study in Berau Regency, East Borneo, Indonesia. Asian J Adv Agric Res. 24(5):1–9. https://doi.org/10.9734/ajaar/2024/v24i5502.

Castañeda-Garzón SL, Argüelles Cárdenas JH, Hernández DR, Castro Navarro OM. 2021. Interacción genotipo x ambiente en *Elaeis guineensis* e Híbridos OxG de palma de aceite en Colombia. Acta Agronómica. 70(2). https://doi.org/10.15446/acag.v70n2.91874.

Chaparro LM, Neira LF, Molina D, Rivera-Barrera D, Castañeda M, López-Giraldo LJ, Escobar P. 2023. Biowaxes from palm oil as promising candidates for cosmetic matrices and pharmaceuticals for human use. Materials (Basel). 16(12):4402. https://doi.org/10.33090/ma16124402.

Etman HM, AbdelHameed IM, Desouki EE. 2024. Impact of temperature, rainfall and floods on oil palm production in Malaysia - A review. Zagazig J Agric Res. 51(6):2051–2064. https://doi.org/10.21608/zjar.2024.403408.

Gonzales E, Gonzales K. 2024. Analysis of climate indices to determine global climate patterns: Techniques for summarizing complex climate data. https://doi.org/10.5772/intechopen.114389.

Granda E, Baumgarten F, Gessler A, Gil-Pelegrin E, Peguero-Pina JJ, Sancho-Knapik D, Zimmermann NE, Dios V. 2020. Day length regulates seasonal patterns of stomatal conductance in *Quercus* species. Plant Cell Environ. 43(1):28–39. https://doi.org/10.1111/pce.13665.

Gunawan S, Sri Budiastuti MT, Sutrisno J, Wirianata H. 2021. The performance of oil palm productivity and management of organic materials at various rain intensity in sandy soil. Vol. 709. p. 12088.

Idris S. 2024. Climate variability and water stress effects on oil palm (*Elaeis guineensis* Jacq.) productivity in Malaysia. J Oil Palm Res. https://doi.org/10.21894/jopr.2024.0054.

Indonesian Ministry of Agriculture. 2023. Statistics of estate crops volume I volume 2022-2024. Jakarta (ID): Directorate General of Plantations, Ministry of Agriculture Republic of Indonesia.

Inoue T, Sunaga M, Ito M, Yuchen Q, Matsushima Y, Sakoda K, Yamori W. 2021. Minimizing VPD fluctuations maintains higher stomatal conductance and photosynthesis, resulting in improvement of plant growth in lettuce. Front Plant Sci. 12. https://doi.org/10.3389/fpls.2021.646144.

Liu W, Dong S, Zheng J, Liu C, Wang C, Shangguan W, Zhang Y, Zhang Y. 2022. Quantifying the rainfall cooling effect: The importance of relative humidity in Guangdong, South China. J Hydrometeorol. 23(6):875–889. https://doi.org/10.1175/JHM-D-21-0155.1.

Nuryawan A, Sutiawan J, Rahmawaty, Masruchin N, Bekhta P. 2022. Panel products made of oil palm trunk: A review of potency, environmental aspect, and comparison with wood-based composites. Polymers (Basel). 14(9):1758. https://doi.org/10.3390/polym14091758.

Ovwigho AC, Otunaruke EP, Joseph OO. 2024. Efficiency of oil palm production in Nigeria: A review-pathway. World J Adv Res Rev. 21(1):2558–2585. https://doi.org/10.30574/wjarr.2024.21.1.2736.

Pan X, Baquy MA-A, Guan P, Yan J, Wang R, Xu R, Xie L. 2020. Effect of soil acidification on the growth and nitrogen use efficiency of maize in Ultisols. J Soils Sediments. 20(3):1435–1445. https://doi.org/10.1007/s11368-019-02515-z.

Paterson RRM. 2021. Longitudinal trends of future climate change and oil palm growth: Empirical evidence for tropical Africa. Environ Sci Pollut Res. 28(17):21193–21203. https://doi.org/10.1007/s11356-020-12072-5.

Pradiko I. 2022. Transpiration of oil palm (*Elaeis guineensis* Jacq.) based on sap flow measurement: The relation to soil and climate variables. J Oil Palm Res. https://doi.org/10.21894/jopr.2022.0035.

Pulighe G. 2023. Navigating the path to sustainable oil palm cultivation: Addressing nexus challenges and solutions. Res World Agric Econ. 4(2):13–17. https://doi.org/10.36956/rwae.v4i2.835.

Rajakal JP, Andiappan V, Wan YK. 2021. Mathematical approach to forecast oil palm plantation yield under climate change uncertainties. Chem Eng Trans. 83:115–120. https://doi.org/10.3303/CET2183020.

Santosa EE, Santosa TNB, Astuti YTM. 2016. Kajian curah hujan dan pemupukan terhadap produktivitas kelapa sawit (*Elaeis guineensis* Jacq) di PT Liman Agro. Agromast. 1(1).

Sharma P, Janaagal M, Sheoran AR, Luhach A, Sharma D, Sharma C. 2024. Multifaceted responses to heat stress in plants: A review of the morpho-physiological, biochemical and anatomical changes. Asian Res J Agric. 17(4):1059–1071. https://doi.org/10.9734/arja/2024/v17i4620.

Suharyanti NA, Mizuno K, Sodri A. 2020. The effect of water deficit on inflorescence period at palm oil productivity on peatland. E3S Web Conf. 211:5005. https://doi.org/10.1051/e3sconf/202021105005.

Tabe-Ojong MPJ, Molua EL, Nanfouet MA, Mkong CJ, Kiven V, Ntegang VA. 2023. Oil palm production, income gains, and off-farm employment among independent producers in Cameroon. Ecol Econ. 208:107817. https://doi.org/10.1016/j.ecolecon.2023.107817.

Tani N, Abdul Hamid ZA, Joseph N, Sulaiman O, Hashim R, Arai T, Satake A, Kondo T, Kosugi A. 2020. Small temperature variations are a key regulator of reproductive growth and assimilate storage in oil palm (*Elaeis guineensis*). Sci Rep. 10(1):650. https://doi.org/10.1038/s41598-019-57170-8.

Tarwaca E, Putra S. 2015. The productivities responses of oil palms (*Elaeis guineensis* Jacq.) to variation of climate element. Vegetalika. 4(4):21–34. https://doi.org/10.22146/veg.23941.

Uning R, Latif MT, Othman M, Juneng L, Mohd Hanif N, Nadzir MSM, Abdul Maulud KN, Jaafar WSWM, Said NFS, Ahamad F, et al. 2020. A review of Southeast Asian oil palm and its CO2 fluxes. Sustainability. 12(12):5077. https://doi.org/10.3390/su12125077.

Xu Y, Ciais P, Yu L, Li W, Chen X, Zhang H, Yue C, Kanniah K, Cracknell AP, Gong P. 2021. Oil palm modelling in the global land surface model ORCHIDEE-MICT. Geosci Model Dev. 14(7):4573–4592. https://doi.org/10.5194/gmd-14-4573-2021.