Curah Hujan Menentukan Panen: Studi Kuantitatif Produksi Kelapa Sawit di Riau 2017–2021

Rainfall Determines the Harvest: Quantitative Study in Riau Palm Oil Production 2017–2021

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Abstrak

Curah hujan merupakan salah satu faktor iklim utama yang memengaruhi produksi kelapa sawit. Penelitian ini bertujuan untuk menganalisis pengaruh curah hujan bulanan terhadap produksi kelapa sawit, dengan pendekatan lag time pada periode 2017–2021. Penelitian ini menggunakan metode kuantitatif dengan pendekatan regresi linear dan korelasi pada data curah hujan bulanan periode 2016–2021 dan data produksi kelapa sawit periode 2017–2021. Penelitian ini dilaksanakan di Kecamatan Siberida, Kabupaten Indragiri Hulu, Provinsi Riau. Pemilihan lahan perkebunan didasarkan pada lokasi yang diberikan pupuk anorganik. Data produksi yang dikaji dalam penelitian meliputi produktivitas kelapa sawit (Kg/ha/Tahun), jumlah tandan buah kelapa sawit (TBS), dan berat jandan rata-rata(BJR) (Kg), dengan mempertimbangkan lag time hingga 48 bulan. Validitas model ditentukan melalui nilai R-Square dan nilai korelasi tertinggi variable penelitian. Hasil penelitian menunjukkan curah hujan bulanan memiliki pengaruh signifikan terhadap produktivitas kelapa sawit dengan korelasi pada lag-24 bulan ($r = 0,54084$; $R^2 = 67\%$). Produksi TBS menunjukkan korelasi tertinggi pada lag-8 bulan ($r = 0,68828$; $R^2 = 50\%$), sedangkan BJR pada lag-38 bulan ($r = 0,71137$; $R^2 = 40\%$). Efek lag yang berbeda menunjukkan respons setiap komponen produksi terhadap curah hujan bersifat spesifik dan tidak seragam. Curah hujan terbukti berpengaruh signifikan terhadap berbagai indikator produksi kelapa sawit dengan jeda waktu yang bervariasi. Pemantauan dan pemanfaatan data curah hujan jangka panjang perlu diintegrasikan dalam strategi pengelolaan kebun untuk meningkatkan produktivitas dan kualitas hasil panen secara berkelanjutan.
Kata kunci: Curah Hujan, Kelapa Sawit, Lag Time, Produktivitas, Jumlah TBS, Berat Janjang Rata-rata

Abstract

Rainfall is one of the main climate factors that affect palm oil production. This study aims to analyze the effect of monthly rainfall on palm oil production, with a lag time approach period 2017–2021. This study uses a quantitative method with a linear regression and correlation approach on monthly rainfall data for 2016–2021 and palm oil production data for 2017–2021. This study was conducted at Siberida District, Indragiri Hulu Regency, Riau

Province. The selection of plantation land was based on the location of the anorganic fertilizers. The production data included productivity (Kg/ha), Number of Bunch, and Average Bunch Weight(ABW) (Kg/Ha), considering a lag time of up to 48 months. The model's validity was determined through the R-Square value and the highest correlation value of the research variables. Monthly rainfall significantly affected oil palm productivity with a correlation at lag-24 months (r = 0.54084; R^2 = 67%). Number of Bunch production the highest correlation at lag-8 months (r = 0.68828; R^2 = 50%), while ABW at lag-38 months (r = 0.71137; R^2 = 40%). Different lag effects indicate that the response of each production component to rainfall is specific and not uniform. Rainfall has been shown to significantly affect various indicators of oil palm production with varying time lags. Monitoring and utilization of long-term rainfall data need to be integrated into plantation management strategies to increase productivity and quality of harvests sustainably.
Keyword: *Rainfall, Oil Palm, Lag Time, Productivity, Bunches, Average Bunch Weight*

- **Introduction**

Indonesia, especially Riau, is one of the main granaries of oil palm Fresh Fruit Bunches (FFB) with an average annual rainfall of 2,000–3,000 mm. Rainfall is the main water source for oil palm plants, playing a vital role in the physiological growth process, flowering, and fruit formation (Lu et al., 2023). Fluctuations in rainfall intensity and distribution greatly affect crop yields, potential water deficits, and ultimately plant productivity (Xu et al., 2021). Rainfall and the number of rainy days strongly correlate with fresh fruit bunch (FFB) production (Aji et al., 2022; Elwirehardja et al., 2023). Oil palm growth rates can vary significantly across the landscape due to differences in rainfall patterns (Beese et al., 2022). Therefore, understanding the quantitative relationship between rainfall and FFB production in tropical regions is crucial to improving agronomic efficiency and oil palm land management.

According to Khan et al. (2022), a positive correlation exists between rainfall and oil palm production. The negative impacts of climate change, especially the adverse effects of rising temperatures and rising sea levels, affect oil palm production in Malaysia (Sarkar et al., 2020). Meanwhile, Beringer et al (2023) emphasized that rainfall can affect production. Research by Abubakar, Ishak, and Makmom (2021) highlighted that climate change, including extreme weather events such as droughts and floods, significantly impacts oil palm production. National studies show that the optimal rainfall requirement for mature oil palm is around 2,000±2,500mm/year, with an even distribution and rainy days>100 per year. Tani et al (2020) showed that long-term cumulative rainfall affects oil palm growth.

Based on previous studies, a special strategy is needed because rainfall fluctuations can cause water deficits that threaten crop yields, thus requiring quantitative modeling to design harvest risk mitigation strategies. Therefore, this study aims to analyze the effect of monthly rainfall on palm oil production, with a lag time approach from 2017 to 2021. In practice, the hypothesis is that there is a significant positive correlation between the amount of monthly rainfall and FFB production volume, with a possible lag effect of several months. This study contributes to understanding quantitative drought modeling in the context of tropical oil palm agronomy, especially in Riau, which complements previous literature at a local scale and across plant ages. Thus, the results of this study are expected to be a reference for agronomic decision-making and climate adaptation policies by farmers and industry players.

This study offers a solution based on a statistical approach (correlation & multiple linear regression) and temporal lag analysis to predict FFB volume based on historical rainfall data. This model can be used to develop an early warning system for water deficits and declining harvests, so that oil palm land managers can plan interventions such as additional water management, adjusting fertilization patterns, or planting drought-resistant varieties. The implementation of this system can also be strengthened by integrating real-time weather data and recommendations based on machine learning models, encouraging more adaptive harvest resilience to climate change.

- **Methode**

Location

This research was conducted in Division IV of PT. Kencana Amal Tani 2, Siberida District, Indragiri Hulu Regency, Riau Province, Indonesia. Plantation production data is taken based on gardens fertilized with anorganic fertilizers.

Research Methode

In its implementation, this study uses a survey divided into two stages: the first and the second. The first survey aims to determine the general condition of the plantation to be studied. The second survey aims to obtain secondary data on fresh fruit Bunch (FFB) production, oil palm, and rainfall.

Observation parameters

This study's parameters include time series data for five years (2017–2021), consisting of rainfall and oil palm production. Monthly rainfall parameters (mm) and the number of rainy days per month are the leading indicators of humidity conditions and precipitation intensity for 2016-2021. Meanwhile, production parameters include yield data (kg/ha), average bunch weight (ABW kg/bunch), and number of FFB (kg) for the period 2017-2021 as a representation of productivity and efficiency of oil palm harvest results. This data is analyzed to understand the relationship between rainfall and production results in the field.

Data Analysis

The analysis method used is correlation and regression analysis. Correlation analysis was chosen because it can be used to determine the relationship between rainfall intensity and the production of FFB oil palm over the past 5 years. Regression model and regression coefficient

Yi = a + bXi + cXi2i = 1,2,.....,n

Yi is the prediction or interpretation of the Yi function; a, b, and c are the regression coefficients, which are estimates of β0, β1, and β2. The data obtained will be analyzed using the Time Lag model:

Rainfall (X) 2014 with Palm oil production (Y) 2014 = lag 0

Rainfall (X) 2014 with Palm oil production (Y) 2015 = lag 1

Rainfall (X) 2014 with Palm oil production (Y) 2016 = lag 2

- **Results**

Rainfall Period 2016-2021

The average annual rainfall at the research location from 2016 to 2021 is important information for understanding the climate dynamics that can affect oil palm production. The average monthly rainfall for 2016-2021 can be seen in Table 1.

Table 1. Average rainfall period 2016-2021

Month	Years (mm)					
Bulan	2016	2017	2018	2019	2020	2021
Januari	124	81	237	310	166	166
February	259	162	296	246	158	51
Maret	176	243	231	265	267	197
April	90	125	234	279	201	265
Mei	96	101	109	120	240	223
Juni	133	83	52	17	168	106
July	169	153	63	21	139	99
Agustus	123	140	84	68	116	
September	224	138	84	96	186	
Oktober	171	171	283	127	144	
November	363	494	288	108	271	
December	181	345	200	262	249	
Total	2,109	2,236	2,161	1,919	2,305	1,107

Based on Table 1, the highest rainfall each month from 2016 to 2021 shows significant variation. The highest monthly rainfall peak was in 2017 in November at 494 mm. The highest rainfall in 2016 was 363 mm in November, in 2018 the highest rainfall was in February at 296 mm, in 2019 it was 310 mm in January, in 2020 it was 271 mm in November, and in 2021 it was 265 mm in April. In terms of annual rainfall, the highest rainfall occurred in 2020 with a total of 2,305 mm, followed by 2017 (2,236 mm) and 2018 (2,161 mm). 2021 showed a drastic decrease of 1,107 mm because rainfall data was only recorded until July 2021.

Palm Oil Production Period 2017-2021

Palm oil productivity data for 2017–2021 reflect annual monthly harvest results. This data provides an overview of production trends influenced by seasonal factors and plant physiological conditions. Palm oil productivity results are presented in Table 1.

Table 2. Palm Oil Productivity Period 2017-2021

Month	**Years (Yield Kg /Ha)**

Month	Years (Yield Kg /Ha)				
	2017	**2018**	**2019**	**2020**	**Juli 2021**
January	1,706	1,530	1,806	1,785	2,480
February	1,654	1,534	1,655	1,650	1,550
March	1,502	1,452	1,520	1,500	1,430
April	1,500	1,645	1,500	2,130	1,890
May	1,495	1,500	1,498	1,450	1,448
June	1,529	1,527	1,530	1,510	1,518
July	1,526	1,530	1,528	1,520	1,523
August	1,553	1,922	1,833	1,704	-
September	1,567	1,505	1,677	1,650	-
October	2,230	1,422	2,389	1,950	-
November	1,903	1,512	1,870	1,859	-
December	1,550	1,560	1,677	1,675	-
Total	19,715	18,639	20,483	20,383	11,839
Average	**1,642.92**	**1,553.25**	**1,706.92**	**1,698.58**	**1,691.29**

Based on Table 2, oil palm productivity shows fluctuations influenced by monthly and annual variations. The highest monthly productivity was recorded in October 2019 at 2,389 kg/ha, while the lowest productivity occurred in March 2018 at 1,452 kg/ha. Annually, the highest yield occurred in 2019 with a total production of 20,483 kg/ha and an average of 1,706.92 kg/ha, followed by 2020 (20,383 kg/ha) and 2017 (19,715 kg/ha). Although the 2020 rainfall was the highest, the production yield was slightly lower than in 2019, indicating that other factors, such as rainfall distribution and plantation management, also played a role.

Fresh Fruit Bunch Period 2017-2021

Fresh Fruit Bunch (FFB) data represents the dynamics of monthly and annual harvest yields that reflect the plant's response to agroclimatic conditions and cultivation management. The results of the 2017-2021 oil palm FFB data are presented in Table 2.

Table 3. Data on the number of FFB period 2017 – 2021

Month	Years (FFB Kg)				
	2017	**2018**	**2019**	**2020**	**2021**
January	433.877	340.824	323.125	238.354	319.748
February	377.281	290.596	238.790	217.747	275.514
March	340.111	262.386	225.171	177.843	288.451
April	329.778	266.058	201.597	203.607	289.191
May	360.150	314.914	207.277	154.439	290.484
June	266.674	277.971	210.332	199.316	279.051
July	367.500	366.250	247.686	224.146	315.648
August	328.081	327.549	270.109	261.832	-
September	343.927	271.863	267.943	356.609	-
October	369.135	284.592	318.748	342.507	-
November	358.871	278.368	278.711	315.146	-

December	365.201	270.286	246.517	310.571	-
Total	4,240.586	3,551.657	3,036.006	3,002.117	2,058.087
Average	**353,382**	**295,971**	**253,001**	**250,176**	**294,012**

Based on Table 3, the number of fresh fruit bunches (FFB) shows a downward trend from 2017 to 2021, with monthly fluctuations in yield. The highest number of FFB per month occurred in January 2017 at 433,877 kg, while the lowest was recorded in May 2020 at 154,439 kg. The highest total annual FFB production occurred in 2017 with 4,240,586 kg and a monthly average of 353,382 kg, much higher than the following years. A sharp decline was seen in 2021, with a total of only 2,058,087 kg, most likely due to a significant decrease in rainfall that year.

Average Bunch Weight Period 2017-2021

Average Bunch Weight (ABW) data describes the quality of production influenced by plant physiological factors, fertilization, and climate conditions. This information is important for evaluating the success of cultivation practices and determining productivity improvement strategies. The results of ABW data for oil palm for 2017-2021 are presented in Table 3.

Table 4. Data ABW Period 2017 - 2021

Month	**Years (Kg / Ha)**				
	2017	**2018**	**2019**	**2020**	**2021**
January	1,510	1,610	1,450	1,485	2,560
February	1,250	1,325	1,445	1,265	2,545
March	1,134	1,226	1,442	1,325	2,342
April	1,242	1,265	1,453	1,354	2,476
May	1,365	1,325	1,456	1,360	1,876
June	1,258	1,454	1,227	1,465	1,873
July	1,450	1,458	1,236	1,242	1,865
August	1,445	1,465	1,265	1,365	
September	1,442	1,469	1,325	1,348	
October	1,453	1,473	1,354	1,465	
November	1,456	1,456	1,360	1,458	
December	1,252	1,430	1,465	1,445	
Total	16,257	16,956	16,478	16,577	15,537
Average	**1,355**	**1,413**	**1,372**	**1,381**	**2,220**

Based on Table 4, the Average Bunch Weight (ABW) data, or average weight of bunches per hectare, shows slight fluctuations throughout 2017–2021, with a significant increasing trend in 2021. The highest ABW value per month was recorded in January 2021 at 2,560 kg/ha, followed by February 2021 at 2,545 kg/ha, which far exceeded other months in previous years. Although the highest total ABW annually occurred in 2018 at 16,956 kg/ha, the highest monthly average was achieved in 2021, at 2,220 kg/ha. This shows that although the number of FFB in 2021 decreased, the average bunch weight increased, possibly as a physiological response of the plant to environmental stress such as decreased rainfall.

Rainfall on Monthly Productivity 2016-2021

Correlation analysis was conducted to determine the effect of rainfall on oil palm productivity by considering the time lag. Rainfall has a varying relationship with monthly oil palm productivity. The results of the correlation analysis of the relationship between monthly rainfall and oil palm productivity for 2016-2021 are presented in Table 4.

Table 5. Correlation of Monthly Rainfall 2016-2021 and Monthly Productivity 2017 – 2021

Lag Time	Rainfall vs. % Productivity
lag-0	0.04998
lag-1	0.29264
lag-2	-0.21160
lag-3	-0.35409
lag-4	0.16949
lag-5	-0.10481
lag-6	-0.07716
lag-7	0.13494
lag-8	0.32064
lag-9	0.22289
lag-10	0.34971
lag-11	0.12459
lag-12	0.09654
lag-13	0.11317
lag-14	-0.44668
lag-15	-0.36939
lag-16	-0.48036
lag-17	-0.37860
lag-18	-0.17061
lag-19	-0.21300
lag-20	0.11524
lag-21	0.45205
lag-22	0.37071
lag-23	0.33646
lag-24	**0.54084**
lag-25	0.02701
lag-26	0.00221
lag-27	-0.22954

lag-28	-0.55507
lag-29	-0.22070
lag-30	-0.39363
lag-31	-0.36580
lag-32	-0.07207
lag-33	0.30945
lag-34	0.31317
lag-35	0.49832
lag-36	0.28139
lag-37	0.38581
lag-38	0.45044
lag-39	-0.34574
lag-40	-0.31516
lag-41	0.04239
lag-42	-0.36440
lag-43	-0.27459
lag-44	-0.28796

Based on Table 5, the results of the correlation analysis between monthly rainfall and monthly oil palm productivity show a pattern of relationships that vary depending on the lag time. The highest correlation value occurs at lag-24 with a coefficient of 0.54084, indicating that rainfall in the previous two years strongly influences current productivity. Other fairly strong positive correlations appear at lag-21 (0.45205), lag-35 (0.49832), and lag-38 (0.45044), indicating a delayed effect of rainfall in influencing oil palm production. Conversely, the largest negative correlation is at lag-28 with a value of -0.55507, indicating that rainfall in the previous 28 months negatively correlates with current productivity. The highest correlation between rainfall and productivity occurs at lag-24 with a value of 0.54084.

Regression analysis is used to determine how much rainfall affects oil palm productivity. The results of the regression analysis of the relationship between monthly rainfall and oil palm productivity for 2016-2021 are presented in Table 5.

Table 6. Regression of Monthly Rainfall and Monthly Productivity 2017 – 2021.

Regression Statistic	
Multiple R	0.819894046
R Square	0.672226247
Adjusted R Square	0.66442211
Standard Error	0.139892568
Observations	44

Based on the regression results in Table 6, the relationship between monthly rainfall and monthly productivity shows a strong correlation with a Multiple R value of 0.82. The R Square value of 0.67 indicates that around 67% of productivity variations can be explained by changes in rainfall. The almost identical Adjusted R Square of 0.66 confirms the consistency of this regression model in explaining data by considering the number of variables and samples. The standard error of 0.14 indicates a fairly good level of prediction accuracy. Monthly rainfall significantly affects productivity, with a prediction ability of 67%.

Rainfall on Fresh Fruit Bunches Monthly 2016-2021

Correlation analysis was conducted to determine the effect of rainfall on the amount of oil palm FFB by considering the time lag. Rainfall has a varying relationship with the amount of monthly oil palm FFB. The results of the correlation analysis of the relationship between monthly rainfall and the amount of oil palm FFB for the period 2016-2021 are presented in Table 6.

Table 7. Correlation of Monthly Rainfall and Monthly FFB Period 2017 – 2021

Lag Time	Rainfall vs % FFB
lag-0	-0.14932
lag-1	-0.21511
lag-2	-0.26532
lag-3	-0.17806
lag-4	0.11644
lag-5	0.08439
lag-6	0.47883
lag-7	0.55310
lag-8	**0.68828**
lag-9	0.65813
lag-10	0.48183
lag-11	0.15999
lag-12	-0.07130
lag-13	-0.36621
lag-14	-0.63654
lag-15	-0.73623
lag-16	-0.67914
lag-17	-0.42417
lag-18	-0.17719
lag-19	0.05191
lag-20	0.31166
lag-21	0.41040
lag-22	0.42597
lag-23	0.35397
lag-24	0.11655

lag-25	-0.21895
lag-26	-0.35980
lag-27	-0.55081
lag-28	-0.62298
lag-29	-0.43614
lag-30	-0.34253
lag-31	-0.08992
lag-32	0.13839
lag-33	0.40148
lag-34	0.51867
lag-35	0.46007
lag-36	0.29533
lag-37	0.28949
lag-38	0.15908
lag-39	-0.02917
lag-40	-0.10051
lag-41	-0.05617
lag-42	-0.12519
lag-43	-0.04651
lag-44	-0.04604

Based on Table 7, the correlation between monthly rainfall and the number of fresh fruit bunches (FFB) shows a strong pattern with a certain time lag. The highest correlation was recorded at lag-8 at 0.68828, indicating that rainfall in the previous eight months had the most significant positive effect on the number of FFB. Other strong correlations occurred at lag-9 (0.65813) and lag-7 (0.55310), reinforcing the hypothesis that rainfall in the previous 7–9 months greatly determines FFB production. Conversely, the strongest negative correlation occurred at lag-15 with a value of -0.73623, indicating that rainfall in the previous fifteen months negatively correlated with the current number of FFB. The highest correlation between rainfall and FFB occurred at lag-8 with a value of 0.68828.

Regression analysis determines how much rainfall affects the amount of oil palm FFB. The results of the regression analysis of the relationship between monthly rainfall and FFB for 2017-2021 are presented in Table 7.

Table 8. Monthly Rainfall Regression and Monthly FFB Period 2017 – 2021.

Regression Statistic	
Multiple R	0.71050027
R Square	0.50481063
Adjusted R Square	0.49302041

Standard Error	0.192191585
Observations	44

Based on the regression results in Table 8, the relationship between monthly rainfall and monthly FFB production shows a fairly strong correlation with a Multiple R value of 0.71. The R Square value of 0.50 indicates that around 50% of the variation in FFB production can be explained by changes in rainfall. The Adjusted R Square of 0.49 indicates that this regression model is quite reliable in explaining the data, even though it takes into account the number of variables and observations. The standard error of 0.19 reflects a relatively moderate level of prediction error. Monthly rainfall significantly influences FFB production, with an explanatory contribution of around 50%.

Rainfall on Average Monthly ABW 2017-2021

Correlation analysis was conducted to determine the effect of rainfall on the ABW of oil palm by considering the time lag. Rainfall has a varying relationship with the amount of monthly ABW oil palm. The results of the correlation analysis of the relationship between monthly rainfall and ABW oil palm for 2017-2021 are presented in Table 8.

Table 9. Correlation of Monthly Rainfall and Monthly ABW 2017–2021

Lag Time	Rainfall vs. % ABW
lag-0	-0.19314
lag-1	-0.07568
lag-2	0.04975
lag-3	0.14531
lag-4	0.14253
lag-5	0.06686
lag-6	0.02453
lag-7	0.12257
lag-8	0.29125
lag-9	0.30457
lag-10	0.40383
lag-11	0.31356
lag-12	0.17185
lag-13	0.28161
lag-14	0.06909
lag-15	-0.12190
lag-16	-0.21024
lag-17	-0.37645
lag-18	-0.46443
lag-19	-0.51838
lag-20	-0.51501

lag-21	-0.28199
lag-22	-0.06570
lag-23	0.08434
lag-24	0.29285
lag-25	0.23166
lag-26	0.19012
lag-27	0.21114
lag-28	0.00266
lag-29	-0.13873
lag-30	-0.27910
lag-31	-0.47782
lag-32	-0.48846
lag-33	-0.31686
lag-34	-0.19967
lag-35	0.03840
lag-36	0.18143
lag-37	0.38994
lag-38	**0.71137**
lag-39	0.57733
lag-40	0.39549
lag-41	0.26925
lag-42	0.04818
lag-43	-0.04990
lag-44	-0.18202

Based on Table 9, the correlation between monthly rainfall and average bunch weight (ABW) shows significant variation depending on the lag time. The highest positive correlation was found at lag-38 with a value of 0.71137, indicating that the influence of rainfall around 38 months earlier was very strong on the current increase in ABW. Other positive correlations that were quite high were found at lag-39 (0.57733) and lag-10 (0.40383), indicating that the effect of rainfall on bunch weight can also be felt in a shorter period. Conversely, the strongest negative correlation appeared at lag-32 of -0.48846, indicating a certain period where rainfall had a negative effect on ABW. The highest correlation between rainfall and ABW occurred at lag-38 with a value of 0.71137.

Regression analysis determines how much rainfall affects the ABW of oil palm. The results of the regression analysis of the relationship between monthly rainfall and ABW for 2017-2021 are presented in Table 9.

Table 10. Regression of Monthly Rainfall and Monthly ABW 2017–2021.

Regression Statistic	
Multiple R	0.635068235
R Square	0.403311664
Adjusted R Square	0.389104799
Standard Error	0.175403057
Observations	44

The regression results in Table 10 show a moderate relationship between monthly rainfall and monthly average fruit weight (ABW) with a Multiple R value of 0.64. The R Square value of 0.40 indicates that about 40% of the variation in ABW can be explained by changes in rainfall. The slightly lower Adjusted R Square of 0.39 indicates that this regression model remains representative after considering the number of variables and observations. The standard error of 0.18 indicates a moderate level of prediction accuracy. Monthly rainfall significantly affects ABW variation with an explanatory contribution of 40%.

- **Discussion**

Effect of Rainfall on Oil Palm Productivity

The effect of rainfall on productivity shows that the highest correlation between monthly rainfall and oil palm productivity occurs at a lag time of 24 months with a correlation value of 0.54084. This indicates a significant delay in the effect of rainfall on increasing productivity. In addition, the regression analysis results show that monthly rainfall significantly affects productivity with a predictive ability of 67%, indicating a strong relationship and a fairly good model in explaining productivity variability based on rainfall patterns. This finding aligns with the study of Watson-Hernández et al (2022), which states that rainfall is an important climate factor that affects the physiology and yield of oil palm production over a certain period, including the lag effect. Rainfall significantly affects oil palm productivity (Monita & Zebua, 2023). Rainfall is indeed a significant climate factor that affects the physiology and yield of oil palm production over time (Paterson, 2021). The impact of climate change can affect palm oil production (Ahmed Abubakar et al., 2021). However, other studies, such as Sibhatu (2023), remind us that other factors, such as plantation management and varieties, can also significantly affect productivity. Hence, the effect of rainfall is not always dominant. Therefore, although correlation and regression show a strong influence of rainfall on productivity, it is also necessary to consider other factors in oil palm plantation management.

Effect of Rainfall on the Number of FFB

The effect of rainfall on the amount of FFB shows the highest correlation between monthly rainfall and Fresh Fruit Bunch (FFB) production at a time lag of 8 months, with a correlation value of 0.68828. This indicates a delay of about eight months between changes in rainfall patterns and the response of FFB production in oil palm plantations. The regression results also confirm that monthly rainfall significantly influences FFB production, with an explanatory contribution of about 50%, which means that rainfall is an important but not the only factor in determining FFB production. This study is supported by research by Cranko-Page et al (2023), which showed the effects of delayed rainfall on ecosystem functions, including potential impacts on agricultural output. Fluctuations in rainfall affect oil palm production temporally, with typical delayed effects (Lan et al., 2023; Sanjeevaiah et al., 2021). Delayed rainfall can impact agricultural practices, including palm oil production (Creedy et al., 2022; Song et al., 2021). However, other researchers, such as Dassou et al (2022), stated that although rainfall is important, agronomic factors and crop management, such as fertilization, play a significant role in determining oil palm FFB yields. So, the correlation of rainfall does not always describe the entire variability of production as a whole. Therefore, combining climate and management factors to understand oil palm production dynamics comprehensively is important.

Effect of Rainfall on ABW

The effect of rainfall on ABW shows the highest correlation between monthly rainfall and ABW, which occurs at a time lag of 38 months with a correlation value of 0.71137. This indicates that rainfall about three years earlier has a strong positive relationship to the average weight of fresh fruit bunches. The regression results also show that monthly rainfall significantly affects ABW variations with an explanatory contribution of 40%, which means that this climate factor is quite important in determining the quality and size of oil palm fruit. This study aligns with the findings of Marwanto et al. (2021), who state that long-term environmental factors such as rainfall patterns play an important role in determining the physical characteristics of oil palm harvests, including fruit bunch weight. Rainfall affects production in Peninsular Malaysia with physical characteristics of oil palm plants, such as fruit bunch weight (A. Abubakar et al., 2022). Rainfall patterns significantly affect the physical characteristics of oil palm plants, especially the amount of FFB (Gunawan et al., 2020; Savitrie & Liyantono, 2022). However, research by Luke et al (2020) suggests that, In addition to climate factors, agronomic variables and land management play a significant role in determining ABW. So the correlation of rainfall needs to be seen as one of several factors that affect the quality of the harvest. Therefore, a multifactorial approach must be applied to evaluate oil palm productivity.

- **Conclusion**

The results showed that monthly rainfall significantly affected oil palm productivity, with the highest correlation at a lag time of 24 months (correlation value of 0.54084) and a predictive ability of 67%. In addition, Fresh Fruit Bunch (FFB) production was also significantly influenced by rainfall, with the highest correlation at a lag of 8 months (correlation value of 0.68828) and an explanatory contribution of around 50%. Meanwhile, the average fruit bunch weight (ABW) had the highest correlation with rainfall at a lag of 38 months (correlation value of 0.71137), where rainfall explained around 40% of the variation in ABW. Thus, rainfall has a lagged effect on different aspects of oil palm production, indicating the importance of long-term climate monitoring in plantation management. This study concludes that rainfall has a significant and different time-period effect on oil palm productivity, FFB quantity, and ABW. Therefore, the main recommendation is to integrate long-term rainfall data into plantation management planning and strategies to optimally improve oil palm production yields and quality optimally.

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Conflict Of Interest
The authors declare no conflict of interest, financial or otherwise.

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