

Not Just Rain: Quantitative Evidence of the Impact of Historical Rainfall Period 2016-2021 on Palm Oil Production in Riau Indonesia

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ABSTRACT

Environmental factors greatly influence oil palm productivity, especially rainfall, which impacts the plant's physiological state. This study aims to analyze the relationship between rainfall and oil palm production. This study used a two-stage survey method. Time series data from 2016-2021 were used to evaluate the relationship between monthly rainfall and three production parameters (productivity, number of fresh fruit bunches (FFB), and average bunch weight (ABW)). Correlation and regression analyses were conducted to identify significant contributions of rainfall to yield variables by considering the time lag. The results showed that rainfall that occurred 24-36 months previously had a significant effect on productivity and the number of FFB with R² values of 53.93% and 54.83%, and rainfall 37-38 months previously contributed to BJR with an R² value of 40.33%. Rainfall has historically played an important role in determining oil palm yields. Plantation management based on long-term climatological data can be a new approach to optimizing sustainable oil palm production.

Keywords: palm oil, rainfall, agroclimatology, productivity, fresh fruit bunches, average weight bunches.

INTRODUCTION

Oil palm productivity is greatly influenced by many factors, one of which is agroclimate, especially rainfall. Rainfall plays a role in supporting the physiological processes of plants, from flower formation to fruit enlargement. Indonesia is a tropical region with a medium-criteria rainfall pattern with an average annual rainfall of 1500 - 3000 mm/year [1]. Rainfall not only directly impacts plant growth but also has long-term effects that are not yet fully understood. Oil palm is naturally suited to areas with

consistently high rainfall, supporting its growth and oil yield [2]. Increased rainfall generally encourages the accumulation of biomass and nutrients in plants, resulting in increased root, stem, and leaf growth and productivity [3], [4]. Therefore, it is important to evaluate the historical contribution of rainfall to oil palm production to support more data-driven agronomic decision-making.

Rainfall is a major climatological factor that

significantly affects the growth and productivity of oil palm. Irregular rainfall can cause physiological stress in plants, negatively impacting production and quality [5], [6]. Therefore, it is important to understand the impact of climate change on rainfall patterns as a basis for sustainable agricultural management practices [7]. Rainfall is one of the keys to successful oil palm cultivation. Understanding rainfall patterns amidst climate change is essential to support sustainable oil palm cultivation strategies.

Managing oil palm plantations that consider long-term rainfall patterns as a predictive variable for production is not yet optimal. The relationship between rainfall and oil palm production has long been recognized. According to Wu et al. [8], the timing and amount of rainfall are important for healthy plant growth. Significant changes in rainfall impact agricultural productivity [9]. High rainfall increases soil moisture, directly affecting plant transpiration and photosynthesis, which are important for oil palm growth [10]. Furthermore, Cui et al. [11], better rainfall patterns can optimize the rate of evapotranspiration, balancing water loss and absorption, which are very important for

maintaining the health of oil palm trees. Rainfall can provide adequate moisture to help oil palms resist abiotic stresses, ensuring consistent growth performance [12]. However, few studies still examine the relationship between historical rainfall and production yields quantitatively.

Considering the importance of long-term climate influence on palm oil production, conducting a study that integrates historical rainfall data with statistical production data is necessary. Various previous studies have highlighted the short-term effects of rainfall on crop yields, but few have explored the significant impact of rainfall in the last five years. Therefore, this study fills this gap with a quantitative approach based on time series and linear regression to understand the relationship better. Therefore, this study aims to analyze the relationship between rainfall and oil palm production for 2016-2021. This study provides a scientific basis for long-term management through a precise and adaptive climate calendar. This solution is relevant for farmers, companies, and policymakers in developing production strategies and mitigating climate risks in palm oil plantations.

METHODE

Location

This research was conducted in Division IV of PT. Kencana Amal Tani 2, Siberida District, Indragiri Hulu Regency, Riau Province, Indonesia.

Research Methode

In its implementation, this study uses a survey divided into two stages, namely the first and second surveys. 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 produced over the past 5 years. Regression model and regression coefficient

$$Y_i = a + bX_i + cX_i^2 \quad i = 1, 2, \dots, n$$

Y_i is the prediction or interpretation of the Y_i function, a , b , and c are the regression coefficients, which are estimates of β_0 , β_1 , and β_2 . The data obtained will be analyzed using the Time Lag model:

Rainfall (X) 2014 with Palm oil production (Y)

RESULTS

Palm Oil Production

Palm oil productivity data for 2017–2021 reflects annual monthly harvest results. This data

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

provides an overview of production trends influenced by seasonal factors and plant physiological conditions. Palm oil productivity results are presented in Table 1.

Table 1. Palm Oil Productivity Period 2017-2021

Month	Years (Yield Kg /Ha)				
	2017	2018	2019	2020	Juli 2021
January	1,806	1,630	1,756	1,785	2,480
February	1,754	1,634	1,655	1,650	1,550
March	1,602	1,552	1,520	1,650	1,630
April	1,500	1,645	1,500	2,130	1,890
May	1,595	1,500	1,498	1,450	1,548
June	1,530	1,527	1,530	1,534	1,518
July	1,528	1,530	1,528	1,520	1,523
August	1,550	1,922	1,833	1,704	-
September	1,567	1,505	1,677	1,650	-
October	2,230	1,542	2,389	1,950	-
November	1,903	1,522	1,870	1,859	-
December	1,550	1,560	1,677	1,675	-
Total	20,115	19,069	20,433	20,557	12,139
Average	1,676.25	1,589.08	1,702.75	1,713.08	1,734.14

Based on Table 1, oil palm productivity in the 2017–2021 period showed relatively stable annual fluctuations with an increasing trend from year to year. 2020 recorded the highest yearly productivity of 20,557 kg/ha, slightly higher than 2019 (20,433 kg/ha) and 2017 (20,115 kg/ha). The highest monthly average occurred in July 2021 at 2,480 kg/ha, while the months with the lowest productivity were generally in the May to June period in several years. Overall, productivity tended to increase at the beginning and end of the

year and decrease in the middle of the year, which can be attributed to the physiological cycle of the plant and seasonal climate conditions.

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 2. Data on number of FFB period 2017 – 2021

Month	Years (FFB Kg)				
	2017	2018	2019	2020	2021
January	380.750	350.824	390.125	338.354	319.748
February	280.281	390.596	350.790	317.747	275.514
March	340.111	362.386	360.171	377.843	288.451
April	329.778	266.058	361.597	303.607	289.191
May	360.150	314.914	207.277	254.439	290.484
June	280.674	277.971	320.332	299.316	279.051
July	267.500	366.250	247.686	250.146	315.648
August	228.081	327.549	270.109	361.832	-
September	243.927	271.863	367.943	356.609	-
October	259.135	284.592	318.748	342.507	-
November	358.871	278.368	278.711	320.146	-
December	365.201	270.286	346.517	325.571	-
Total	3,694.459	3,761.657	3,820.006	3,848.117	2,058.087
Average	307.872	313.471	318.334	320.676	294.012

Based on Table 2, the amount of oil palm FFB production from 2017–2021 consistently increased from year to year. The highest production was recorded in 2020, with a total of 3,848,117 kg and a monthly average of 320,676 kg, slightly higher than 2019. The monthly pattern shows that production tends to be high at the beginning and end of the year and decreases in the middle of the year, which is likely influenced by weather conditions and the physiological phase of the plant. Although 2021 data is only available

until July, the monthly production trend remains relatively stable and competitive.

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 3. 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	1,361	1,382	1,398	2,220

Based on Table 3, the average ABW of oil palm from 2017 to July 2021 shows a relatively stable trend with a slight increase from year to year. The highest average ABW occurred in 2021 at 2,220 kg/bunch, much higher than previous years, ranging from 1,355 to 1,398 kg/bunch. The significant increase in 2021, especially from January to April, may indicate improvements in agronomic conditions, such as fertilization, plant care, or more favorable climate conditions. Meanwhile, 2019 recorded the third-highest ABW after 2021 and 2020.

Rainfall on Monthly Productivity 2017-2021

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

Lag Time	Rainfall vs. % Productivity
lag-0	-0.15661
lag-1	0.10747
lag-2	-0.02065
lag-3	-0.05972
lag-4	0.22401
lag-5	-0.02924
lag-6	-0.05312
lag-7	0.10145
lag-8	0.32346
lag-9	0.29224
lag-10	0.44356
lag-11	0.29030
lag-12	0.17813
lag-13	0.28707
lag-14	-0.12899
lag-15	-0.22006
lag-16	-0.34888
lag-17	-0.41288
lag-18	-0.41516
lag-19	-0.53134

Lag Time	Rainfall vs. % Productivity
lag-20	-0.36083
lag-21	-0.01267
lag-22	0.12035
lag-23	0.20953
lag-24	0.48715
lag-25	0.19164
lag-26	0.16188
lag-27	0.10055
lag-28	-0.21618
lag-29	-0.17068
lag-30	-0.40972
lag-31	-0.53250
lag-32	-0.41985
lag-33	-0.10727
lag-34	-0.02257
lag-35	0.24301
lag-36	0.24519
lag-37	0.46271
lag-38	0.75929
lag-39	0.28510
lag-40	0.12937
lag-41	0.23568
lag-42	-0.14675
lag-43	-0.17970
lag-44	-0.29441

Based on Table 4, the relationship between monthly rainfall and oil palm productivity appears quite complex because it involves a significant lag effect. The highest positive correlation value was found at lag-38 ($r = 0.75929$), indicating that rainfall around 38 months earlier contributed strongly to the increase in current productivity, followed by lag-24 ($r = 0.48715$) and lag-10 ($r = 0.44356$). Conversely, a relatively strong negative correlation was identified at lag-31 ($r = -0.53250$) and lag-19 ($r = -0.53134$), indicating that high rainfall during that period impacted reducing productivity. These findings show that the response of oil palm plants to rainfall is indirect and occurs in the long term, depending on the physiological phase of the plant.

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 5. Regression of Monthly Rainfall and Monthly Productivity 2017 – 2021.

Regression Statistic	
Multiple R	0.7344
R Square	0.5393
Adjusted R Square	0.5283
Standard Error	0.1614
Observations	44

The regression analysis results between monthly rainfall and monthly oil palm productivity during the 2016–2021 period show a fairly strong and statistically significant relationship. The multiple R-value of 0.7344 indicates a high linear relationship strength between the variables. In contrast, the R Square of 0.5393 suggests that around 53.93% of the variation in oil palm productivity can be explained by variations in rainfall. The Adjusted R Square value of 0.5283 strengthens the model's validity after being adjusted for the number of variables and observation data used (as many as 44 data). The relatively low Standard Error value (0.1614) indicates good model prediction accuracy. Thus, this regression model can explain more than half of the variation in productivity based on rainfall factors.

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 6. Correlation of Monthly Rainfall and Monthly FFB Period 2017 – 2021

Lag Time	Rainfall vs % FFB
lag-0	0.13695
lag-1	-0.12082
lag-2	-0.44281
lag-3	0.02579
lag-4	-0.20108
lag-5	-0.16006
lag-6	-0.09243
lag-7	-0.21747
lag-8	0.12200
lag-9	0.08190
lag-10	0.26746
lag-11	0.28942
lag-12	0.18727
lag-13	-0.17508
lag-14	-0.28520
lag-15	-0.44254
lag-16	-0.19229
lag-17	0.04411
lag-18	-0.21539
lag-19	0.09760
lag-20	0.21116
lag-21	0.32571
lag-22	0.51252
lag-23	0.48019
lag-24	0.20977
lag-25	-0.02479
lag-26	-0.13938
lag-27	-0.32766
lag-28	-0.10935
lag-29	-0.38777
lag-30	-0.27027
lag-31	-0.10131
lag-32	0.03830
lag-33	0.49976
lag-34	0.43017
lag-35	0.29047
lag-36	0.13109
lag-37	0.05766
lag-38	-0.25539
lag-39	-0.36836
lag-40	-0.15261
lag-41	-0.20894
lag-42	-0.19536
lag-43	-0.29681
lag-44	-0.23367

Based on Table 3, the relationship between monthly rainfall and the number of FFB oil palm shows a pattern that varies depending on the lag time. The highest positive correlation occurs at lag-22 ($r = 0.51252$), lag-23 ($r = 0.48019$), and lag-33 ($r = 0.49976$), which means that rainfall around 22 to 33 months previously had a significant effect on increasing the number of current bunches. Conversely, a relatively strong negative correlation was found at lag-2 ($r = -0.44281$) and lag-15 ($r = -0.44254$), indicating that high rainfall at that time reduced FFB production. This finding suggests that the response of oil palm plants to rainfall is indirect and occurs in the long term.

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 7. Monthly Rainfall Regression and Monthly FFB Period 2017 – 2021.

Regression Statistic	
Multiple R	0.7404
R Square	0.5483
Adjusted R Square	0.5375
Standard Error	0.1944
Observations	44

Based on Table 4, the regression analysis results between monthly rainfall and the number of FFB oil palm during 2017–2021 show a fairly strong and statistically significant relationship. The Multiple R-value of 0.7404 indicates a high linear correlation between the two variables. With an R Square value of 0.5483, it can be explained that around 54.83% of the variation in the number of FFB can be influenced by variations in rainfall. In addition, the Adjusted R Square value of 0.5375 indicates that this model is reliable after being adjusted for the amount of observation data. The Standard Error value of 0.1944 indicates good prediction accuracy.

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 8. 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	-0.1219
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	-0.0657
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	-0.2791
lag-31	-0.47782

lag-32	-0.48846
lag-33	-0.31686
lag-34	-0.19967
lag-35	0.0384
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	-0.0499
lag-44	-0.18202

Based on Table 5, the correlation analysis between monthly rainfall and ABW oil palm showed a varying relationship depending on the lag time. The highest positive correlation occurred at lag-38 ($r = 0.71137$), followed by lag-39 ($r = 0.57733$) and lag-37 ($r = 0.38994$), indicating that rainfall around 37 to 38 months previously had a significant effect on increasing ABW. Conversely, a relatively strong negative correlation was detected at lag-19 ($r = -0.51838$) and lag-20 ($r = -0.51501$), indicating that high rainfall decreased ABW. This finding suggests that the response of oil palm plants to rainfall in the long term has a significant effect on yield quality ABW.

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 9. Regression of Monthly Rainfall and Monthly ABW 2017–2021.

Regression Statistic	
Multiple R	0.6350
R Square	0.4033
Adjusted R Square	0.3891
Standard Error	0.1754
Observations	44

Based on Table 6, the regression analysis results between monthly rainfall and ABW oil palm during 2017–2021 show a reasonably strong relationship, although not completely perfect. The Multiple R-value of 0.6350 illustrates a moderate linear relationship between the two variables. With an R Square value of 0.4033, it can be explained that around 40.33% of the variation in ABW can be influenced by variations in rainfall. The Adjusted R Square value of 0.3891 indicates that this model still has good predictive power even though several other factors affect ABW. The relatively low Standard Error value (0.1754) indicates adequate prediction accuracy.

DISCUSSION

Effect of Rainfall on Oil Palm Productivity

Rainfall in the previous 24–36 months significantly contributed to monthly oil palm productivity. The regression analysis results had a value of 54.83% ($R^2 = 0.5483$), indicating that more than half of the variation in productivity could be explained by rainfall conditions in that period. Previous rainfall conditions affected physiological stages such as flower induction and fruit initiation in oil palms. According to Vogado et al. [13], rainfall directly affects soil moisture, which is very important for maintaining the rate of

photosynthesis, which results in plant generative growth. Rainfall can affect ecological processes related to plant growth and productivity [14]. Based on Li et al. [15], rainfall in the previous year is the primary determinant of the generative phase of plants. Rainfall in the last 24–36 months is a key factor in current oil palm productivity, significantly impacting plant physiological and ecological processes.

However, according to Zhai et al. [16], the generative phase of plants is mainly influenced by current climate conditions, not long-term rainfall

patterns. Other studies, such as Zainuddin et al. [17], stated that productivity is more influenced by agronomic management. Regular upkeep of oil palm plants can have an impact on their productivity in the long term [18]. Even so, this study makes a new contribution by showing the importance of the influence of rainfall, which is often overlooked in production planning. The novelty of this study lies in the quantitative approach to the effect of rainfall lag time on oil palm productivity output.

Effect of Rainfall on the Number of FFB

Lag time correlation analysis shows that monthly rainfall in the previous 22–33 months contributed significantly to the FFB, with an R^2 regression value of 54.83%. This period coincides with the flower initiation and differentiation phase, where oil palm plants are susceptible to water stress. This finding is supported by Lee et al. [12], water availability significantly impacts plant growth and development. This balance affects photosynthetic efficiency and growth, which are important for flower development [19]. Plants depend on water from the previous season, affecting long-term physiological processes such as flowering [20]. The rainfall factor is important to maintain the energy balance for reproductive processes such as flower formation [21]. Rainfall in the previous 22–33 months is key in determining the number of fresh fruit bunches of oil palm because it plays a significant role in flower formation, which is highly dependent on water availability and the physiological energy balance of plants.

In contrast, in the study of Ariesca et al. [22], Soil Type and Land Management affect oil palm growth. While the availability of nutrients and maintaining soil health are essential for sustainable crop production [17]. Management practices upkeep organic-rich topsoil are recommended for crop productivity [23]. Even so, the results of this study reinforce the importance of integrating historical rainfall data into crop planning systems and production predictions. This category's novelty is identifying a more specific and relevant period for medium-term planning related to predicting the

number of FFB oil palms.

Effect of Rainfall on ABW

This study shows that the results of the rainfall lag time that occurred 37–38 months previously have a significant effect on increasing ABW) with a regression value (R^2) of 40.33%. This indicates that the quality and size of the current oil palm bunches are the result of the water conditions that were available more than three years ago, which affected the development of oil palm fruit. This finding is supported by Singh [24], who states that optimal water and land resource allocation can increase agricultural productivity. The relationship between resource limitations and absorption in oil palm trees shows that managing the number of bunches and adjusting carbon allocation can stabilize the components of yield and fruit size [25]. We found that air stress was the main factor causing variation in influencing FFB yields [26]. Plants with appropriate soil water content can maintain high yields [27]. Rainfall in the previous 37–38 months significantly increased current oil palm ABW, confirming the importance of long-term water availability in determining FFB quality and size.

Based on Arifin et al. [28], the provision of nutrients for oil palms can affect the potential yield, which varies according to genotype, soil, age of oil palm, and environmental factors. ABW is influenced by groundwater dynamics that support optimal fruit filling. ABW of oil palm is influenced by the number of normal fruits per bunch of plants [29]. Numata et al. [30] showed that ABW is determined mainly by agronomic practices such as fertilization and frond sanitation. However, the regression approach in this study provides strong statistical evidence of the long-term relationship between rainfall and ABW. These results provide a new basis for historical data-based management in increasing ABW of oil palm harvests. The novelty lies in emphasizing the importance of historical rainfall history with a lag time of 37–38 months, which is rarely studied in previous literature. These findings provide a relevant scientific basis for long-term management based on historical rainfall data to improve harvest quality. This study's main

novelty lies in identifying the lag time of 37–38 months as a critical period that has not been widely discussed in the oil palm literature, thus enriching

CONCLUSION

Rainfall plays an important role in the performance of oil palm production. Rainfall that occurred 2–3 years previously significantly affected productivity. Rainfall 22–33 months previously was positively correlated with the amount of FFB, and rainfall 37–38 months previously was proven to increase the ABW of oil palm. The contribution of the R² regression analysis results is 53.93% for productivity, 54.83% for the amount of FFB, and 40.33% for ABW. This finding confirms that the influence of rainfall is

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the scientific approach to sustainable production strategies.

time-lag and accumulated, which is needed in technical planning and long-term agronomic strategies in oil palm plantations. This study explicitly reveals the lag period of rainfall (44 lag time), which has not been widely revealed in the literature as an important factor in increasing oil palm yields. Agronomic management and fertilization strategies in oil palm plantations should consider historical rainfall data of at least three years previously to optimize long-term and sustainable productivity.

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