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Interpretation analysis between rain, number of bunches and land slope on oil palm plantation productivity (*Elaeis guineensis* Jacq.) in Huta Padang Plantation PT Perkebunan Nusantara IV Regional I

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ABSTRACT

This study aims to determine and analyze the effect of rainfall, rainy days, number of bunches and land slope on the productivity of oil palm plants (*Elaeis guineensis* Jacq.) in the Huta Padang plantation of PT Perkebunan Nusantara IV Regional I from February to March 2025. The hypothesis of this study is that there is a real effect of rainfall, rainy days, number of bunches and land slope on the productivity of oil palm plants (*Elaeis guineensis* Jacq.) in the Huta Padang plantation of PT Perkebunan Nusantara IV Regional I. This study uses secondary data including FFB production and number of bunches from 2015 to 2024, rainfall and rainy days from 2014 to 2023 and DEM data from lidar drone processed with QGIS. Analysis uses multiple linear regression and correlation. Classical assumption test includes normality (Kolmogorov-Smirnov), heteroscedasticity (Glejser), multicollinearity (VIF <10), and autocorrelation (Run Test) using SPSS v.25. The data is tested and analyzed based on the slope of the land, namely flat, medium and high slopes. Results indicate that rainfall and rainy days have no significant partial effect on all slopes. Number of bunches has significant effect on all slopes. Simultaneously, all variables have significant effect. Correlation is very strong (R = 0.992 flat, 0.928 medium, 0.973 high).

Keywords: Land slope, number of bunches, oil palm productivity, rainfall



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1. Introduction

Oil palm is one of the plantation commodities that plays an important role in Indonesia's economic growth. It is also one of the leading plantation crops and a source of foreign exchange earnings from non-oil and gas exports for Indonesia. The growing prospects of palm oil in the global vegetable oil trade have encouraged the government to accelerate the development of oil palm plantation areas (Masykur, 2013). PT Perkebunan Nusantara IV Regional I is one of the state-owned plantation companies involved in oil palm cultivation. This company is a holding company under *PalmCO*, which comprises several other state-owned plantation companies engaged in oil palm cultivation. Based on the actual production data of PT Perkebunan Nusantara IV Regional I in 2023, the Huta Padang plantation unit recorded relatively low annual productivity compared with other plantation units, at approximately 17,404 kg ha⁻¹.

Oil palm productivity can be affected by rainfall and rainy days during 24 months preceding harvest. Rainfall is a major factor limiting the potential yield of oil palm and because it is difficult to control. High and low rainfall levels can be used to evaluate production performance in subsequent years (Junaedi et al., 2021). Rainfall plays an important role in ensuring adequate soil water availability throughout oil palm growth. Two important aspects of rainfall should be considered: annual rainfall (mm year⁻¹) and monthly rainfall

distribution. The ideal annual rainfall for oil palm ranges from 2,000–3,500 mm⁻¹, distributed evenly throughout the year, with a minimum of 100 mm month⁻¹. In addition, oil palm production is directly related to rainfall during the preceding 12 months, increased rainfall is associated with increased production over the following 12 months (Marpaung, 2021).

In addition to rainfall and rainy days, soil conditions and topography are important factors that may influence oil palm productivity. Soil properties determine the capacity of land to retain water and supply essential nutrients for plant growth, while slope gradients may affect surface runoff, erosion, and the distribution of nutrients within plantation areas. Lubis et al. (2024) demonstrated that soil quality can vary across different topographic conditions, although land management history also contributes to these differences. Furthermore, Pratama et al. (2025) reported strong relationships between soil macrofauna diversity and richness and several soil chemical properties, particularly organic carbon and total nitrogen, in smallholder oil palm plantations. These findings highlight the importance of considering soil conditions and topographic characteristics when evaluating factors associated with oil palm productivity.

Water availability is another important factor in maintaining optimal oil palm growth and development. Although rainfall provides the primary water supply in rainfed plantation systems, its distribution and availability within the root zone may vary over time and across locations. Kautsar et al. (2022) reported that water stress reduced the height and shoot dry weight of oil palm seedlings, demonstrating the importance of adequate water availability for plant growth. However, responses observed during the nursery stage should not be directly generalized to mature, productive palms. Therefore, evaluating rainfall, rainy days, bunch number, and land slope together may provide a more comprehensive understanding of the factors associated with fresh fruit bunch production and oil palm productivity at Huta Padang Estate, PT Perkebunan Nusantara IV Regional I. Such an evaluation may also help identify which variables show the strongest relationships with productivity and support more appropriate plantation management decisions.

According to Irsal et al. (2018), based on rainfall and rainy-day records collected at the Huta Padang plantation from 2013 to 2015, the mean annual rainfall was 3,647.6 mm year⁻¹, and average of 125.6 rainy days year⁻¹. Topographic conditions are one of the important factors that must be considered because in the topography of terraces or sloping the condition of nutrients is lost because the soil is wasted during the construction of terraces, in addition to that in the topography area of terraces when the implementation of work is more difficult to do than expanse areas, conditions that are not in accordance with the growth needs of oil palm plants will affect the growth conditions of oil palm plants. The large effect of erosion on the soil is what causes a decrease in soil permeability along with the increase in slope. The amount of organic matter in the soil will be influenced by the steepness of the slope which also affects the availability of nutrients if the soil condition is too sloppy, the potential for water loss and nutrients provided is greater (Megayanti et al., 2022).

The number of bunches also greatly affects the production of oil palm plants. Based on production data from the Huta Padang plantation unit of PT Perkebunan Nusantara IV Regional I in 2023, the average monthly bunch number was 1,004.6 bunches ha⁻¹. According to Bata et al. (2016), a high number of bunches will increase the number of bunches which affects the weight of the total production so that it will automatically increase productivity in oil palm plants. Based on the description above, the researcher is interested in finding out the relationship between rainfall, rainy days, number of bunches and land slope to the productivity of oil palm plants (*Elaeis guineensis* Jacq.) at the Huta Padang Plantation, PT Perkebunan Nusantara IV Regional I.

2. Method

This study employed quantitative and qualitative descriptive analysis methods. The data were collected, compiled, described, and analyzed using multiple linear regression and correlation analysis. The data included oil palm productivity and the number of bunches for the years 2015–2024, as well as rainfall and the number of rainy days for the years 2014–2023. All data were classified according to land slope categories, namely the slope of the flat land, medium and high.

The analysis method used in this study is regression analysis, multiple linear regression analysis and correlation. Multiple linear regression analysis is used to determine the functional influence of two or more independent variables on bound variables, and correlation analysis is useful to see the strength or weakness of the relationship between free and bound variables of bound variables. Bound variables are variables whose existence is influenced by independent variables and denoted by Y. The bound variable in this study is palm

oil productivity. While the free variable is the variable that affects or causes the change, the variable is not free and is notated with X. The free variables in this study are rainfall and monthly rainy days and the number of bunches from each level of land slope. Data processing is assisted by SPSS.v.25 software for windows.

The functional effect of rainfall, rainy days and number of bunches per level of land slope on oil palm productivity was analyzed by multiple linear analysis using the following equation model:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + \varepsilon$$

Explanation:

Y : FFB productivity
 a : Intercept and line on the Y
 b : Linear regression coefficients
 X₁ : Monthly rainfall
 X₂ : Monthly rainy day
 X₃ : Number of bunches
 E : Error

2.1. Determining Research Locations

This research was conducted at Huta Padang Plantation, PT Perkebunan Nusantara IV Regional I, located in Bandar Pasir Mandoge District, Asahan Regency, North Sumatra Province, Indonesia. The research commenced in February 2025 and continued until completion. The research data were obtained from PPKS varieties. The geographical coordinate of the study site are 2°53'07.4"N, 99°25'09.0"E.

2.2. Literature Study

The literature study was carried out by tracing and studying literature studies related to rainfall, rainy days, land slope, number of bunches and oil palm productivity and studying previous studies that are in line with this research.

2.3. Data collection

The collection of secondary data used for research needs was obtained from literature studies in the garden office. Primary data for analysis is adjusted to the completeness of the data in the plantation administration. Secondary data for general reports include the general state of the company, geographical location, soil and climate conditions, area of garden use, and crop productivity status. The secondary data processed was obtained from the monthly report of the plantation office Huta Padang Plantation, PT Perkebunan Nusantara IV Regional I, Bandar Pasir Mandoge District, Asahan Regency, North Sumatra Province. Secondary data for analysis purposes were taken monthly data for 10 years, namely from 2024 to 2015 including crop productivity data and bunch number data, and from 2023 to 2014 including monthly rainfall and rainy-day data. The land slope data is taken from the Digital Elevation Model (DEM) obtained from a lidar-sensing drone in the PTPN IV Regional I Plant Section.

2.4. Data Management and Data Analysis

Data processing is assisted by QGIS software to obtain land slope data with the intersection overlay method and SPSS.v.25 software for windows to conduct data analysis and test classical assumptions first. This test is useful to see if the secondary data obtained is worth testing or not. Data that are suitable for testing will be followed by multiple linear regression analysis and correlation analysis then compared with previously made hypotheses, then conclusions are drawn on the hypothesis that has been tested. The tests carried out on the secondary data are as follows:

2.5. Classic assumption test

The classical assumption test is useful for testing whether the regression model used in research is worth testing or not. The feasibility of the regression model can be seen from the resulting data being normally distributed, there is no multicollinearity, heteroscedasticity and autocorrelation in the model used. If all these conditions are met, it means that the analysis model is suitable for use.

2.5.1. Normality Test

Normality test to test whether in the regression model the dependent variable and independent variables have normally distributed data or not. Normally distributed data shows that there are no extreme values that could

later interfere with the research results. A good regression model is one that has a normal and close to normal data distribution. In this discussion, the one sample Kolmogorov – Sminov test will be used using a significance level of 0.05. Data is declared to be normally distributed if it is significant and the one sample Kolmogorov – Sminov test value is greater than 5% or 0.05.

2.5.2. Heteroscedasticity Test

The heteroscedasticity test is used to determine whether or not there are deviations from the classic assumption of heteroscedasticity, namely the inequality of variance and residuals from one observation to another in the regression model. The prerequisite that must be met in the regression model is the absence of symptoms of heteroscedasticity or what is usually called homoscedasticity. The test method used is the Glejser test. The Glejser test is carried out to regress the absolute residual value against other independent variables. If the β value is significant, it indicates that there is heteroscedasticity in the model.

2.5.3. Multicollinearity Test

Multicollinearity test is used to determine whether or not there is a linear relationship between independent variables in the regression model. The prerequisite that must be met in the regression model is the absence of multicollinearity. The multicollinearity test was carried out by looking at the variance inflation factor (VIF) value and the tolerance value in the regression model. A good regression model is one where multicollinearity occurs as evidenced by a VIF value of 0.1.

2.5.4. Autocorrelation Test

The autocorrelation test is used to determine whether or not there is a deviation that occurs between the residual in one observation and the presence of another observation in the regression model. To find out whether there is autocorrelation or not, it can be seen by an autocorrelation test using a run test, an Asymp.Sig (2-tailed) value is obtained based on the autocorrelation test if the value of Asymp.Sig (2-tailed) is greater than the significance level of 0.05, then it can be concluded that there is no autocorrelation.

2.6. Hypothesis test

Based on the hypothesis proposed, to test the hypothesis, t-test (partial), F-test (simultaneous) and R test are used. Hypothesis testing was carried out with a two-way test with a significant level (α) of 5% whether accepted or rejected. Value of the determination coefficient (R^2) is used to see the percentage of the influence of the free variable on the value of the bound variable. R^2 The closer it is to zero, the less influence all the independent variables have on the value of the bound variable. Hypothesis testing was partially used to determine the influence of each independent variable on the bound variable. This test is carried out by comparing the value of t calculated with the t table. Hypothesis tests were simultaneously used to determine the influence of the independent variable as a whole on the bound variable. This test is carried out by comparing the value of the F calculation with the F table, the hypothesis proposed in the analysis is:

$H_0: b_i = 0$

$H_i: b_i \neq 0$,

B_i = regression coefficient of the i variable

Conclusions are drawn to see if the H_0 hypothesis is accepted or rejected. The H_0 hypothesis is rejected to prove that the independent variables used have a real effect on palm oil productivity.

3. Result and Discussion

In Table 1, it can be seen that the total average productivity of oil palm on flat land in the Huta Padang plantation for 10 years (2015–2024) is 21,622 kg ha⁻¹, the total average rainfall for 10 years (2014–2023) is 2,960 mm year⁻¹, the total average rainy day for 10 years (2014–2023) is 152 days year⁻¹ and the total average number of bunches on flat land for 10 years (2015–2024) is 1,372 bunches ha⁻¹.

Table 1. Average productivity, rainfall, rainy days, and number of bunches in oil palm plants on flat land

Month	Productivity (kg ha ⁻¹)	Rainfall (mm month ⁻¹)	Number of Rainy Days (days month ⁻¹)	Number of Bunches (bunches ha ⁻¹)
January	1,333	169	11	90
February	1,309	120	7	88
March	1,447	99	8	94
April	1,503	146	9	97
May	1,666	247	14	105

Month	Productivity (kg ha ⁻¹)	Rainfall (mm month ⁻¹)	Number of Rainy Days (days month ⁻¹)	Number of Bunches (bunches ha ⁻¹)
June	1,830	215	10	116
July	2,099	203	12	129
August	2,159	336	14	129
September	2,289	336	16	138
October	2,188	346	18	137
November	1,979	448	19	129
December	1,822	296	15	120
Total	21,622	2,960	152	1,372

In Table 2, it can be seen that the total average productivity of oil palm on medium land slopes in Huta Padang plantations for 10 years (2015–2024) is 18,683 kg ha⁻¹, the total average rainfall for 10 years (2014–2023) is 2,960 mm year⁻¹, the total average rainy days for 10 years (2014–2023) is 152 days year⁻¹ and the total average number of bunches on medium slopes for 10 years (2015–2024) is 1,496 bunches ha⁻¹.

Table 2. Average productivity, rainfall, rainy days, and number of bunches in oil palm plants on medium land slopes

Month	Productivity (kg ha ⁻¹)	Rainfall (mm month ⁻¹)	Number of Rainy Days (days month ⁻¹)	Number of Bunches (bunches ha ⁻¹)
January	1,185	169	11	87
February	1,159	120	7	84
March	1,265	99	8	95
April	1,341	146	9	115
May	1,476	247	14	135
June	1,522	215	10	137
July	1,761	203	12	134
August	1,818	336	14	138
September	1,923	336	16	145
October	1,887	346	18	152
November	1,705	448	19	138
December	1,643	296	15	137
Total	18,683	2,960	152	1,496

In Table 3, it can be seen that the total average productivity of oil palm on high land slopes in Huta Padang plantations for 10 years (2015–2024) is 17,959 kg ha⁻¹, the total average rainfall for 10 years (2014–2023) is 2,960 mm year⁻¹, the total average rainy days for 10 years (2014–2023) is 152 days year⁻¹ and the total average number of bunches on high land slopes for 10 years (2015–2024) is 1,073 bunches ha⁻¹.

Table 3. Average productivity, rainfall, number of rainy days, and number of bunches in oil palm plants on high land slopes

Month	Productivity (kg ha ⁻¹)	Rainfall (mm month ⁻¹)	Number of Rainy Days (days month ⁻¹)	Number of Bunches (bunches ha ⁻¹)
January	1,186	169	11	76
February	1,116	120	7	71
March	1,181	99	8	72
April	1,236	146	9	77
May	1,345	247	14	80
June	1,480	215	10	86
July	1,662	203	12	93
August	1,749	336	14	98
September	1,873	336	16	105
October	1,874	346	18	111
November	1,642	448	19	100
December	1,616	296	15	102
Total	17,959	2,960	152	1,073

3.1. Multiple Linear Regression Analysis

As shown in Table 4, it is obtained that the rainfall, rainy days, and number of bunches in oil palm productivity on flat land have a coefficient value (R) of 99.2%, the determination coefficient (R^2) of 98.4% and the correction coefficient of determination (Adjusted R^2) by 97.8%. Coefficient of determination (R^2) indicates that 98.4% of oil palm productivity on flat land can be explained by variations in the variables of rainfall, rainy days, and number of bunches that occur and the remaining 1.6% is explained by other variables that are not included in this model.

Table 4. Value of coefficient of multiple linear regression equation on rainfall, day rainfall, and the number of bunches on the flat land for 10 years

Model	R	R Square	Adjusted R Square
1	0.992a	0.984	0.978

In Table 5, it is obtained that the rainfall, rainy days, and number of bunches in oil palm productivity on the medium slope of the land have a coefficient value (R) of 92.8%, the determination coefficient (R^2) of 86.1% and the correction coefficient of determination (Adjusted R^2) by 80.9%. Coefficient of determination (R^2) indicates that 86.1% of oil palm productivity on medium slopes can be explained by variations in the variables of rainfall, rainy days, and number of bunches that occur and the remaining 13.6% is explained by other variables that are not included in this model.

Table 5. Value of coefficient of multiple linear regression equation on rainfall, day rainfall, and the number of bunches on medium land slopes for 10 years

Model	R	R Square	Adjusted R Square
1	0.928a	0.861	0.809

In Table 6, it is obtained that rainfall, rainy days, and the number of bunches in oil palm productivity on the slope of the land have a high coefficient value (R) of 97.3%, the determination coefficient (R^2) of 94.7% and the determination coefficient was corrected (Adjusted R^2) by 92.8%. Coefficient of determination (R^2) indicates that 94.7% of oil palm productivity on high slopes can be explained by variations in the variables of rainfall, rainy days, and the number of bunches that occur and the remaining 5.3% is explained by other variables not included in this model.

Table 6. Value of coefficient of multiple linear regression equation on rainfall, day rainfall, and the number of bunches on high land slopes for 10 years

Model	R	R Square	Adjusted R Square
1	0,973a	0,947	0,928

The results of the t-partial test (Table 7), show that the significance value of the rainfall variable in oil palm plants on flat land for 10 years (2015–2024) is greater than 5% ($\text{Sig} > \alpha 0.05$), which is $0.876 > 0.05$. The t-value of the table is obtained 2,306, thus the t-value of the t-table is $< t\text{-table}$, which is $-0.162 < 2,306$. So it can be concluded that the different t calculations are not real at the 95% confidence level (H_0 acceptance). Thus, the rainfall variable partially has an unreal effect on increasing productivity Squirring on a flat ground. The significance value of the rainy-day variable in oil palm plants on flat land for 10 years (2015–2024) is greater than 5% ($\text{Sig} > \alpha 0.05$) which is $0,453 > 0.05$ and the t-value calculated $< t$ table is $-0,789 < 2,306$. So it can be concluded that the different t calculations are not real at the 95% confidence level (H_0 acceptance). Thus, the variable of rainy days partially has an intangible effect on increasing productivity Squirring on a flat ground. The significance value of the variable number of bunches in oil palm plants on flat land for 10 years (2015–2024) is less than 5% ($\text{Sig} < \alpha 0.05$) which is $0.000 < 0.05$ and the t-value calculated $> t$ table is $13,720 > 2.306$. So, it can be concluded that t calculates a real effect on the confidence level of 95% (H_0 minus). Thus, the variable number of bunches partially has a real effect on increasing the productivity of the crop Squirring on a flat ground.

The results of the t-partial test (Table 8), show that the significance value of the rainfall variable in oil palm plants on medium land slopes for 10 years (2015–2024) is greater than 5% ($\text{Sig} > \alpha 0.05$), which is $0.691 > 0.05$. The t-value of the table is obtained 2.306, thus the t-value of calculating the t-value of the $< t$ of the table is $0.412 < 2,306$. So it can be concluded that the different t calculations are not real at the 95% confidence level (H_0 acceptance). Thus, the rainfall variable partially has an unreal effect on increasing productivity on a

medium slope. The significance value of the rainy day variable in oil palm plants on medium land slopes for 10 years (2015–2024) is greater than 5% ($\text{Sig} > \alpha 0.05$) which is $0.904 > 0.05$ and the t-value calculated $< t$ table is $0.124 < 2,306$. So it can be concluded that the different t calculations are not real at the 95% confidence level (H_0 acceptance). Thus, the variable of rainy days partially has an intangible effect on increasing productivity on a medium slope. The results of the t-partial test, show that the significance value of the variable number of bunches in oil palm plants on medium land slopes for 10 years (2015–2024) is less than 5% ($\text{Sig} < \alpha 0.05$) which is $0.010 < 0.05$ and the t-value calculated $> t$ table is $3.376 > 2.306$. So it can be concluded that t calculates a real effect on the confidence level of 95% (H_0 minus). Thus, the variable number of bunches partially has a real effect on increasing the productivity on a medium slope.

Table 7. Partial T-test of rainfall, rainy days, and number of bunches on oil palm productivity on flat land for 10 years

Variables	10 Years of Productivity		
	t-count	Sig.	T-Table
Rainfall	-0.162	0.876tn	2,306
Rainy Day	-0.789	0.453tn	
Number of Bunches	13.720	0.000n	

Table 8. Partial T-test of rainfall, rainy days, and number of bunches on oil palm productivity in medium land slopes for 10 Years

Variables	10 years of productivity		
	t-count	Sig.	T-Table
Rainfall	0,412	0.691tn	2,306
Rainy Day	0,124	0.904tn	
Number of Bunches	3,376	0.010n	

The results of the t-partial test (Table 9), show that the significance value of the rainfall variable in oil palm plants on high land slopes for 10 years (2015–2024) is greater than 5% ($\text{Sig} > \alpha 0.05$), which is $0.647 > 0.05$. The t-value of the table is obtained 2,306, thus the t-value of the t-table $< 0.475 < 2,306$. So it can be concluded that the different t calculations are not real at the 95% confidence level (H_0 acceptance). Thus, the rainfall variable partially has an unreal effect on increasing productivity on a high slope. The significance value of the rainy-day variable in oil palm plants on high land slopes for 10 years (2015–2024) is greater than 5% ($\text{Sig} > \alpha 0.05$) which is $0.387 > 0.05$ and the t-value calculated $< t$ table is $-0.916 < 2,306$. So it can be concluded that the different t calculations are not real at the 95% confidence level (H_0 acceptance). Thus, the variable of rainy days partially has an intangible effect on increasing productivity on a high slope. The results of the t-partial test, show that the significance value of the variable number of bunches in oil palm plants on high land slopes for 10 years (2015–2024) is less than 5% ($\text{Sig} < \alpha 0.05$) which is $0.000 < 0.05$ and the t-value calculated $> t$ table is $6.311 > 2,306$. So, it can be concluded that t calculates a real effect on the confidence level of 95% (H_0 minus). Thus, the variable number of bunches partially has a real effect on increasing the productivity of the cropPalm trees on a high slope.

Table 9. Partial T-test of rainfall, rainy days, and number of bunches on palm oil productivity on high slopes for 10 Years

Variables	10 years of productivity		
	t-count	Sig.	T-Table
Rainfall	0,475	0.647tn	2,306
Rainy Day	-,916	0.387tn	
Number of Bunches	6,311	0.000n	

The partial regression analysis showed that rainfall did not have a statistically significant effect on oil palm productivity on flat land ($(p = 0.876)$), moderately sloping land ($(p = 0.691)$), or steep land ($(p = 0.647)$) during the 2015–2024 observation period. Similarly, the number of rainy days was not statistically significant on flat land ($(p = 0.453)$), moderately sloping land ($(p = 0.904)$), or steep land ($(p = 0.387)$). These findings indicate that rainfall and rainy days did not independently explain significant variation in productivity within the regression models used in this study. However, rainfall remains an important environmental factor in oil palm production, and its influence may depend on the timing, distribution, and intensity of precipitation rather than annual totals alone. Pradiko et al. (2023) demonstrated that climatic factors, including rainfall, solar

radiation, and vapor pressure deficit, contributed to variations in oil palm yield, although their relative contributions differed. Similarly, research by Fleiss et al. (2022) found that climatic conditions explained less than 1% of total yield variation across the commercial plantations examined, highlighting the importance of other factors, including differences among plantations. More recently, a study by Gunawan et al. (2025) reported that rainfall occurring 24–36 months before harvest was significantly associated with oil palm productivity and bunch number in Riau, Indonesia. This finding suggests that the delayed effects of rainfall on reproductive development may not be captured adequately when rainfall is analyzed only as a contemporaneous or annual variable. Therefore, the nonsignificant results in the present study may reflect the temporal complexity of climate–yield relationships rather than the absence of a biological relationship between rainfall and oil palm productivity.

In contrast to the climatic variables, the number of fruit bunches had a statistically significant effect on oil palm productivity across all three slope categories. On flat land, the effect was highly significant ($t = 13.720$), ($p < 0.001$); on moderately sloping land, it was also significant ($t = 3.376$), ($p = 0.010$); and on steep land, the effect was highly significant ($t = 6.311$), ($p < 0.001$). This consistent pattern indicates that bunch number was an important statistical predictor of productivity regardless of land slope. The result is consistent with the biological basis of oil palm yield, which is determined by the number of harvested fresh fruit bunches and their average weight. Pradiko et al. (2023) demonstrated that climatic conditions contribute to yield variation, while Gunawan et al. (2025) found that rainfall at specific time lags was associated with both productivity and bunch number. These studies emphasize the importance of reproductive yield components in explaining final production. Nevertheless, the significant association observed in the present study should be interpreted carefully because bunch number is directly related to total fresh fruit bunch production. If productivity was calculated from harvested bunch weight or total bunch production, a strong association between bunch number and productivity would be expected. Furthermore, the larger t-statistic observed on flat land does not necessarily demonstrate that bunch number has a greater biological effect on flat land than on sloping land. Such a comparison requires regression coefficients, confidence intervals, and, ideally, a formal statistical test of differences between slope categories.

The absence of statistically significant rainfall and rainy-day effects across the three slope categories suggests that annual climatic indicators alone may be insufficient to explain variations in oil palm productivity. Land slope may influence water infiltration, surface runoff, soil erosion, and root-zone moisture availability; however, these processes also depend on soil texture, soil depth, drainage, and rainfall intensity. Monzon et al. (2022), using long-term yield records from oil palm plantations in Indonesia, identified water stress and vapor pressure deficit as important factors contributing to spatial and temporal yield variation. Meanwhile, Anwar and Rahman (2024) reported relationships between rainfall, rainy days, and oil palm productivity in Berau, East Kalimantan, although their findings differed from those of the present study. These contrasting results demonstrate that climate–productivity relationships can vary according to plantation conditions, analytical methods, and the temporal resolution of climatic data. Consequently, the nonsignificant coefficients in the present study should not be interpreted as evidence that rainfall has no agronomic importance. Instead, they suggest that additional variables, such as soil moisture, nutrient availability, palm age, fertilizer management, and harvesting practices, may need to be considered to explain productivity differences among land-slope categories. Future research should also examine lagged rainfall effects and interactions between rainfall and slope to determine whether the influence of climatic conditions varies with topography.

Table 10. Analysis of the variance of multiple linear regression equations of rainfall, rainy days, and the number of bunches on oil palm productivity on flat land

Productivity	Sources of Diversity	F-count	Sig.	F-Table
10 years	Regression	163,085	0.000n	4,066

Based on Table 10, it shows that in the productivity of oil palm on flat land for 10 years (2015–2024), the F-calculated value of $> F$ -table was obtained which was $163.085 > 4,066$ and the significance value in this test was less than 5% ($\text{Sig } \alpha 0.05$) which was $0.000 < 0.05$. So it can be concluded that F calculation has a real effect on the confidence level of 95% (H_0 minus). This means that the variables of rainfall, rainy days and the number of bunches on flat land in the regression model simultaneously (together) have a real effect on the productivity of oil palm on flat land for 10 years (2015–2024).

Table 11. Analysis of the variance of multiple linear regression equations of rainfall, rainy days, and the number of bunches on oil palm productivity on medium land slopes

Productivity	Sources of Diversity	F-count	Sig.	F-Table
10 years	Regression	16,544	0.001n	4,066

Based on Table 11, it shows that in the productivity of oil palm on medium land slopes for 10 years (2015–2024), the F-calculation value $> F$ -table was obtained which was $16,544 > 4,066$ and the significance value in this test was less than 5% (Sig α 0.05) which was $0.001 < 0.05$. So it can be concluded that F calculation has a real effect on the confidence level of 95% (H_0 minus). This means that the variables of rainfall, rainy days and the number of bunches on medium slopes in the regression model simultaneously (together) have a real effect on oil palm productivity on medium slopes for 10 years (2015–2024).

Table 12. Analysis of the variance of multiple linear regression equations of rainfall, rainy days, and the number of bunches on oil palm productivity on high land slopes

Productivity	Sources of Diversity	F-count	Sig.	F-Table
10 years	Regression	47,977	0.000n	4,066

Based on Table 12, it shows that in the productivity of oil palm on high land slopes for 10 years (2015–2024), the F-calculated value of $> F$ -table was obtained which was $47,977 > 4,066$ and the significance value in this test was less than 5% (Sig α 0.05) which was $0.000 < 0.05$. So it can be concluded that F calculation has a real effect on the confidence level of 95% (H_0 minus). This means that the variables of rainfall, rainy days and the number of bunches on high slopes in the regression model simultaneously (together) have a real effect on oil palm productivity on high slopes for 10 years (2015–2024).

The simultaneous F-test showed that rainfall, the number of rainy days, and the number of fruit bunches jointly had a significant effect on oil palm productivity during 2015–2024 across flat land ($F = 163.085$; $p < 0.001$), moderately sloping land ($F = 16.544$; $p = 0.001$), and steep land ($F = 47.977$; $p < 0.001$). These results indicate that the regression models were statistically significant, although the individual effects of rainfall and rainy days were not significant in the partial tests. This finding suggests that bunch number may contribute substantially to the overall significance of the models. Monzon et al. (2022) and Fleiss et al. (2022) similarly highlighted the roles of climatic conditions and other factors in explaining oil palm yield variation. However, overall model significance does not mean that every explanatory variable independently affects productivity.

Table 13. Multiple linear regression testing model on flat land

Productivity	Variable	Regression coefficient	Sig.
10 Years	Constant	0,395	0,016
	Rainfall	0,008	0,876
	Rainy Day	-0,011	0,453
	Number of Bunches	0,021	0,000

Table 14. Multiple linear regression testing model on medium land slopes

Productivity	Variable	Regression coefficient	Sig.
10 Years	Constant	0,334	0,201
	Rainfall	-0,016	0,691
	Rainy Day	0,004	0,904
	Number of Bunches	0,008	0,010

Table 15. Multiple linear regression testing model on high land slopes

Productivity	Variable	Regression coefficient	Sig.
10 Years	Constant	0,271	0,223
	Rainfall	-0,033	0,647
	Rainy Day	-0,019	0,387
	Number of Bunches	0,022	0,000

From the results of the above analysis, regression equations can be formed produced by the variables of rainfall, rainy days, and the number of bunches on flat land in predicting the productivity of oil palm plants on flat land for 10 years (2015 – 2024) as follows:

$$\hat{Y} = 0.395 + 0.008 \text{ rainfall} - 0.011 \text{ rainy days} + 0.021 \text{ total bunches} + \varepsilon$$

The equation model for productivity data for 10 years (2015–2024) can be interpreted that every increase in rainfall by one unit will increase the productivity of oil palm on flat land by 0.008 units, every increase in rainy days by one unit will decrease the productivity of oil palm on flat land by 0.011 units and every increase in the number of bunches on flat land by one unit will increase the productivity of oil palm on flat land by 0.021 units.

From the results of the above analysis, a regression equation can be formed produced by the variables of rainfall, rainy days, and the number of bunches on medium land slopes in predicting the productivity of oil palm plants on medium land slopes for 10 years (2015–2024) as follows:

$$\hat{Y} = 0.334 - 0.016 \text{ rainfall} + 0.004 \text{ rainy days} + 0.008 \text{ total bunches} + \varepsilon$$

The equation model for productivity data for 10 years (2015–2024) can be interpreted that every increase in rainfall by one unit will decrease the productivity of oil palm on a medium slope by 0.016 units, every increase in rainy days on a medium slope will increase the productivity of oil palm on a medium slope by 0.004 units and every increase in the number of bunches on a medium slope by one unit will increase The productivity of oil palm in the medium slope of the land is 0.008 units.

From the results of the above analysis, regression equations can be formed produced by the variables of rainfall, rainy days, and the number of bunches on high land slopes in predicting the productivity of oil palm plants on high land slopes for 10 years (2015–2024) as follows:

$$\hat{Y} = 0.271 - 0.033 \text{ rainfall} - 0.019 \text{ rainy days} + 0.022 \text{ total bunches} + \varepsilon$$

The equation model for productivity data for 10 years (2015–2024) can be interpreted that every increase in rainfall by one unit will decrease the productivity of oil palm on high land slopes by 0.033 units, every increase in rainy days by one unit will decrease the productivity of oil palm on high land slopes by 0.019 units and every increase in the number of bunches on high land slopes by one unit will increase The productivity of oil palm on a high land slope is 0.022 units.

The regression equations revealed different relationships between rainfall, rainy days, bunch number, and oil palm productivity across the three land-slope categories during 2015–2024. On flat land, rainfall and bunch number had positive coefficients (0.008 and 0.021, respectively), whereas rainy days had a negative coefficient (−0.011). On moderately sloping land, rainfall had a negative coefficient (−0.016), while rainy days and bunch number had positive coefficients (0.004 and 0.008, respectively). On steep land, all three coefficients for rainfall (−0.033), rainy days (−0.019), and bunch number (0.022) indicated their respective negative or positive relationships with predicted productivity. These differences suggest that the relationships between climatic variables and oil palm productivity may vary with local growing conditions. According to Kamil et al. (2021), climate variability can affect oil palm production through changes in water availability and crop development. However, the positive and negative regression coefficients in the present study should be interpreted as conditional associations rather than direct evidence of causal effects, particularly because rainfall and rainy days may be correlated with each other.

The regression coefficients also suggest that bunch number had a positive association with predicted productivity across all slope categories, with coefficients of 0.021 on flat land, 0.008 on moderately sloping land, and 0.022 on steep land. This is consistent with the role of fruit bunch production as a key component of oil palm yield. Gunawan et al. (2025) found that rainfall occurring 24–36 months before harvest was significantly associated with oil palm productivity and bunch number, demonstrating that climatic effects may occur with considerable time lags. In addition, a 2023 study using an explainable gradient-boosting approach identified previous-year yield, palm age, and meteorological variables, including rainfall and rainy days, as relevant predictors of annual oil palm yield.

These findings support considering both crop production components and climatic conditions when modeling oil palm productivity. However, the coefficients in the present study should not be compared directly across

slope categories unless the variables use the same measurement units and model specifications; their statistical significance must also be verified using the individual regression tests.

3.2. Correlation Analysis

The results of the correlation analysis (Table 16), show that the productivity coefficient on flat land and rainfall has a sufficient density of 0.777. The productivity coefficient on flat land and rainy days has a sufficient density, which is 0.753. The productivity coefficient and number of bunches on flat land have a strong tightness of 0.989.

Table 16. Analysis test correlation of palm oil productivity, rainfall, rainy days, and the number of bunches on flat land for 10 years

Variable	Test Statistics	Variable			
		Productivity	Rainfall	Rainy Day	Number of Bunches
Productivity	Pearson Correlation	1	0.777**	0.753**	0.989**
	Sig. (2-tailed)		0.003	0.005	0.000
	N	12	12	12	12
Rainfall	Pearson Correlation	0.777**	1	0.953**	0.828**
	Sig. (2-tailed)	0.003		0.000	0.001
	N	12	12	12	12
Rainy Day	Pearson Correlation	0.753**	0.953**	1	0.810**
	Sig. (2-tailed)	0.005	0.000		0.001
	N	12	12	12	12
Number of Bunches	Pearson Correlation	0.989**	0.828**	0.810**	1
	Sig. (2-tailed)	0.000	0.001	0.001	
	N	12	12	12	12

The coefficient of rainfall and rainy days has a strong tightness of 0.953. The rainfall coefficient and the number of bunches on flat land have a strong tightness of 0.828. The coefficient of rainy days and the number of bunches on flat land has a strong tightness of 0.810. The positive coefficient number shows that if the rainfall, rainy days, and number of bunches increase, productivity will increase and if rainfall, rainy days, and the number of bunches decrease, productivity will also decrease. Therefore, it is concluded that the rainfall coefficient, rainy days, and number of bunches have a strong influence on the achievement of oil palm productivity on flat land. This can be seen from the significance value of less than α 5% (Sig > α 0.05). These results are consistent with Aji et al. (2022), who reported a strong, significant, and positive relationship between rainfall and rainy days on oil palm FFB production, and with Fahmi et al. (2026), who found a very strong positive correlation between rainfall and FFB productivity. Basri et al. (2025) also said that Rainfall is among the factors that influence the realization of oil palm production.

The results of the correlation analysis in Table 17, showed that the productivity coefficient in the medium slope and rainfall has a strong tightness of 0.808. The productivity coefficient on medium slopes and rainy days has a sufficient density, which is 0.801. The productivity coefficient and the number of bunches on the medium slope have a strong tightness of 0.917. The coefficient of rainfall and rainy days has a strong tightness of 0.953. The rainfall coefficient and the number of bunches on the medium slope of the land have a sufficient density, which is 0.784. The coefficient of rainy days and the number of bunches on the slope of the high land has a sufficient tightness, which is 0.783. The positive coefficient number shows that if the rainfall, rainy days, and number of bunches increase, productivity will increase and if rainfall, rainy days, and the number of bunches decrease, productivity will also decrease. Therefore, it is concluded that the rainfall coefficient, rainy days, and number of bunches have a strong influence on the achievement of oil palm productivity in medium land slopes. This can be seen from the significance value of less than α 5% (Sig > α 0.05). The positive correlation coefficients indicate that rainfall, rainy days, and the number of bunches tend to increase alongside oil palm productivity on medium-sloped land. The relationship between water availability and oil palm growth is supported by Kautsar et al. (2023), who reported that water stress reduced plant height and shoot dry weight in oil palm seedlings. This finding highlights the importance of adequate water availability for oil palm growth, although the response of seedlings may differ from the production response of mature palms. Therefore, the strong correlations observed in this study suggest that rainfall, rainy days, and bunch number are associated with oil palm productivity under the studied conditions. However, further interpretation should consider the

statistical significance of each correlation and the potential influence of other factors, including palm age, soil conditions, and plantation management.

Table 17. Analysis test correlation of palm oil productivity, rainfall, rainy days, and the number of bunches on medium land slopes for 10 years

Variable	Test Statistics	Variable			
		Productivity	Rainfall	Rainy Day	Number of Bunches
Productivity	Pearson Correlation	1	0.808**	0.801**	0.917**
	Sig. (2-tailed)		0.001	0.002	0.000
	N	12	12	12	12
Rainfall	Pearson Correlation	0.808**	1	0.953**	0.784**
	Sig. (2-tailed)	0.001		0.000	0.003
	N	12	12	12	12
Rainy Day	Pearson Correlation	0.801**	0.953**	1	0.783**
	Sig. (2-tailed)	0.002	0.000		0.003
	N	12	12	12	12
Number of Bunches	Pearson Correlation	0.917**	0.784**	0.783**	1
	Sig. (2-tailed)	0.000	0.003	0.003	
	N	12	12	12	12

The results of the correlation analysis in Table 18 showed that the productivity coefficient in the high slope of the land and rainfall has a strong tightness of 0.821. The productivity coefficient on high slopes and rainy days has a strong tightness of 0.814. The productivity coefficient and the number of bunches on the medium slope have a strong tightness, which is 0.970. The coefficient of rainfall and rainy days has a strong tightness of 0.953. The rainfall coefficient and the number of bunches on the high slope have a strong tightness of 0.865.

Table 18. Analysis test correlation of palm oil productivity, rainfall, rainy days, and the number of bunches on high land slopes for 10 years

Variable	Test Statistics	Variable			
		Productivity	Rainfall	Rainy Day	Number of Bunches
Productivity	Pearson Correlation	1	0.821**	0.814**	0.970**
	Sig. (2-tailed)		0.001	0.001	0.000
	N	12	12	12	12
Rainfall	Pearson Correlation	0.821**	1	0.953**	0.865**
	Sig. (2-tailed)	0.001		0.000	0.000
	N	12	12	12	12
Rainy Day	Pearson Correlation	0.814**	0.953**	1	0.873**
	Sig. (2-tailed)	0.001	0.000		0.000
	N	12	12	12	12
Number of Bunches	Pearson Correlation	0.970**	0.865**	0.876**	1
	Sig. (2-tailed)	0.000	0.00	0.00	
	N	12	12	12	12

The coefficient of rainy days and the number of bunches on the slope of the high land has a strong tightness of 0.873. The positive coefficient number shows that if the rainfall, rainy days, and number of bunches increase, productivity will increase and if rainfall, rainy days, and the number of bunches decrease, productivity will also decrease. Therefore, it is concluded that the rainfall coefficient, rainy days, and number of bunches have a strong influence on the achievement of oil palm productivity in moderate land slopes. This can be seen from the significance value of less than α 5% (Sig > α 0.05). The strong correlations among productivity, rainfall, rainy days, and the number of bunches in Table 18 agree with previous studies. Aji et al. (2022) reported a strong, significant, and unidirectional relationship between rainfall and rainy days ($r = 0.892, 0.887$, and 0.855). Manurung et al. (2024) likewise found that rainfall, rainy days, and dry spell had a positive effect on oil palm productivity. In addition, Desrihastuti et al. (2024) showed that the number of bunches per tree and bunch weight were better on an 8-18% slope, which they linked to soil conservation measures around the

plant plates. These findings suggest that adequate rainfall and suitable slope conditions support higher productivity.

4. Conclusion

Rainfall and rainy days have no significant partial effect on all slopes. Number of bunches has significant effect on all slopes. Simultaneously, all variables have significant effect. Correlation is very strong. Oil palm productivity will be better if planted on a flat slope, namely on a slope of 0-5% with areas that have optimal rainfall and rainy days. It is necessary to carry out further research with the addition of more detailed land slope observation variables with more degrees and varieties in different gardens.

5. Acknowledgements

Not applicable.

6. Declaration of Generative AI Use

The authors declare that no generative AI or AI-assisted technologies were used in the preparation of this manuscript.

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