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The Impact of Rainfall on Oil Palm Production: A Case Study in Berau Regency, East Borneo, Indonesia

Rusli Anwar [a*] and Arief Rahman [a]

[a] *Departement of Plantation Management, Politeknik Pertanian Negeri Samarinda, Kampus Gunung Panjang Samratulangi Street, Samarinda, East Borneo-75131, Indonesia.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

This study examines the impact of rainfall on oil palm growth and productivity in the Berau region of East Borneo, Indonesia. The research utilized qualitative and quantitative field studies, employing correlation and regression analysis. The study focused on the oil palm plantation area as its subject. Data was collected from a plantation in the Berau region of East Borneo. The plantation has homogeneous plant age (same planting year, 2009) and homogeneous progeny (Scofindo variety) and is included in the company's core plantation. The observation parameters included rainfall, rainy days, fresh fruit bunches, and plant productivity. It was found that rainfall and rainy days have an impact on oil palm productivity. The regression results indicate a positive correlation between rainfall and oil palm productivity, with a correlation coefficient of 0.025109171. However, rainy days have a negative effect on oil palm productivity, with a correlation coefficient of -0.036778304, despite being positively correlated with rainfall. The correlation coefficient of 0.768386269 indicates a direct impact on reducing oil palm productivity. Rainfall indirectly affects oil palm productivity by influencing temperature, humidity, intensity, and length of daily irradiation. These factors directly affect the productivity of oil palm plants.

**Corresponding author: Email: ruslianwar70@gmail.com;*

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1. INTRODUCTION

Palm oil is currently the largest vegetable oil-producing crop, surpassing other crops in terms of production. According to Shahbandeh [1], palm oil consumption is expected to reach 77.99 million metric tons in 2023, making it the most widely consumed vegetable oil in the world, followed by soybean vegetable oil, rapeseed oil, sunflower seed oil, and other vegetable oils. Indonesia and Malaysia dominate the world's palm oil production, accounting for 58% or 42.5 million tons, while Malaysia alone produces 26% or 19 million tons [2]. The expansion of oil palm plantations in Indonesia has supported this production, with the area increasing by 51.27 times from 1980 to 2021 [3]. The rapid increase in oil palm plant growth is due to their tolerance of unfavorable environmental conditions. However, to achieve optimal growth rates, a certain range of environmental conditions is required. Growth and productivity are affected by three factors: (i) environmental factors such as climate, soil, and land capability, (ii) plant material factors including botany and propagation of plant material, and (iii) tissue culture factors [4]. Climatic conditions significantly impact the success of oil palm development. It is important to consider these factors when developing oil palm plantations. The influence of climate on vegetation growth is often stronger than that of soil. According to Paterson et al. [5], climate variability can affect oil palm growth through drought stress, excess water stress (such as rainfall, rainy days, wet months, dry months, humid months, and water deficit), and heat stress (as measured by the air temperature index). Water deficiency in oil palm plants can have several negative effects, including slow fruit ripening, reduced fruit bunch weight, decreased CPO extraction yield, decreased fruit bunch number up to nine months later, and increased male flowers and decreased female flowers. Insufficient rainfall distribution can negatively impact flower development in oil palm plants, leading to increased rates of miscarriages, failed or rotten bunches, low productivity, and long inflorescences lasting about 8-9 months. Additionally, excessive rainfall can damage fresh fruit bunches (FFB) [6,7].

Oil palm plants require high annual rainfall, ranging from 2000-2500 mm, evenly distributed throughout the year. Sufficient rainfall will cause the opening of unblossomed leaves in succession, resulting in a flush of leaves that will then spur a flush of flowers, leading to optimal production. High and low rainfall can be used to evaluate production achievements in the coming years. To understand how plants can thrive in specific climates, it is necessary to have detailed climate information spanning several decades, including monthly averages and distribution patterns throughout the year. Daily weather information is also required to estimate crop diversity and crop production in the work calendar and field workability [8]. Rainfall is the primary factor limiting the yield potential of oil palm. Therefore, it is more practical to modify agronomic practices to adapt to existing climatic conditions to support the achievement of good yield potential in oil palm [9]. Currently, Indonesia is facing increasingly precarious issues, particularly due to global climate change events such as El Nino and La Nina, which have impacted the country's climate. This study focuses on rainfall as a major factor in oil palm growth and development, exploring its effects on oil palm productivity, specifically in the Berau region of East Borneo, Indonesia.

2. MATERIALS AND METHODS

The study focused on an oil palm plantation area in the Berau region of East Borneo. Both secondary and primary data were collected from a plantation estate that had homogeneous plant age (same planting year, 2009) and homogeneous progeny (Scofindo variety) and was included in the company's core plantation. This study was conducted through field research in the Afdeling. The research followed a nested design, with 'afdeling' as the determining factor. Each 'afdeling' was then divided into three blocks. The necessary secondary and primary data were collected from each sample 'afdeling'. The details of the blocks used in this study are as follows: a. blok A was located in one of the afdeling 1; b. blok B was located in one of the afdeling 1; c. blok C was located in one of the afdeling 1; d. blok D was located in one of the afdeling 2; e. blok E was located in one of the afdeling 2; f. blok F was located in one of the afdeling 2; g. blok G was located in one of the afdeling 3; h. blok H was located in one of the afdeling 3; and i. blok I was located in one of the afdeling 3.

2.1 Data Collection

2.1.1 Rainfall and rainy days

Rainfall data is obtained from the climatology station observationreports of each afdeling from 2018-2022.

2.1.2 Weight per Fresh Fruit Bunch (FFB)

Weight per FFB is obtained by measuring the weight of samples taken from each block in the afdeling under study.

2.1.3 Plant productivity

The collected productivity data is presented as the weight of fresh fruit bunches in units of tons per hectare per year. The production data describes the productivity of oil palm plants in each afdeling that was researched during the period of 2018-2022.

2.2 Statistical Analysis

The analysis carried out is correlation and regression analysis. Correlation and partial correlation analyses were conducted to determine the relationship between climate and production variables. Partial correlation analysis was also carried out when two variables were significantly correlated. Regression analysis was performed by regressing production variables onto climatic variables with significant correlation.

3. RESULTS AND DISCUSSION

3.1 Rainfall

In terms of climate classification according to Schmidt-Ferguson, East Borneo Province, particularly Berau Regency, has a wet and very wet climate (A and B) with high rainfall, which is suitable for oil palm growth. The rainfall data obtained from 2018-2022 falls under the very wet climate classification. Based on the results of data processing of rainfall observations at the afdeling station from 2018-2022, it is evident that the amount of rainfall varies every year. There are fluctuations in rainfall, with long dry periods and extraordinary increases in rainfall each month, as shown in Fig. 1. The average annual rainfall fluctuation is 3,450 mm. During the 5-year period, most months were very wet, except for 2 dry months in 2019. Over the past five years, there has been a surplus of water available for plant growth. Despite a drought in August and September 2019, the water reserves from the previous month were sufficient to meet the needs of August 2019. Cock et al. [10] noted a seasonal dry period from August to October with a trend of rainfall. This variation in seasonal length is caused by climate change resulting from the impact of El Nino and La Nina events. As a result, many impacts on plant growth and development must be anticipated. According to Mengel et al. [11], climate change causes higher rainfall fluctuations and unpredictable rainfall due to long dry periods and extraordinary increases in rainfall. Both drought and flooding can negatively impact the growth and development of oil palm plants. For example, drought can result in increased flower fall, bunch rot, low plant productivity, and a longer flowering period of 8-9 months. Additionally, drought can cause an increase in broken fronds, which reduces the production of fresh fruit bunches (FFB) of oil palm [12].

3.2 Relationship between Rainfall, Rainy Days and Oil Palm Productivity

Rainfall and rainy days are significant climatic factors that can impact the growth and development of oil palm plants. The data obtained shows that rainfall over the past five years (2018-2022) has had an impact on fluctuations in oil palm productivity. The lowest oil palm productivity occurred in 2021, which had an average rainfall of 295 mm (Fig. 2). The average rainy days factor in that year also contributed to the low productivity (Fig. 3). That year had a high number of rainy days on average, which affected the distribution pattern of rainfall. The high number of rainy days caused a decrease in air temperature, light intensity, and the length of daily irradiation, which prevented plants from maximizing the photosynthesis process. The regression results indicate that rainfall can affect the productivity of oil palm plants and is positively correlated (Fig. 4). The correlation between rainfall and productivity has no direct effect, as indicated by a correlation coefficient of 0.025109171. It is suspected that rainfall indirectly affects other factors, such as temperature and humidity, which in turn impact plant productivity (Table 1). However, rainy days have a negative effect on oil palm plant productivity, as shown by a correlation coefficient of -0.036778304 in the regression analysis. The more frequent the occurrence of rain each month, especially with high rainfall intensity, the greater the impact on reducing plant productivity. It is worth noting that rainy days are positively correlated with rainfall, with a correlation coefficient of 0.768386269, which also has a negative impact on oil palm productivity.

Heavy rainfall can cause a decrease in air temperature by reducing the intensity and duration of daily irradiation. This reduction in daily irradiation can inhibit transpiration rates, which in turn can lead to decreased humidity around the plant canopy. Conversely, during periods of low daily rainfall, the intensity and duration of daily irradiation are high, which can trigger transpiration rates. The transpiration rate of plants can increase the concentration of water vapor in the atmosphere near the plant canopy, leading to higher humidity around the canopy. Additionally, the low intensity and duration of irradiation that reaches the canopy of oil palm plantations due to high rainfall can directly affect the low air temperature around the canopy. Conversely, high intensity and duration of irradiation that reaches the canopy of oil palm plantations due to low rainfall directly affects the high air temperature around the canopy of oil palm plantations. Abubakar et al. [13], Abubakar et al. [14] reported that heavy rainfall can delay FFB harvest activity, causing water blockage, damaging FFB, and lowering the quality of CPO. Additionally, if the average temperature is ≥ 27.83 °C for 8 months before harvest, it can cause a decrease in FFB yield.

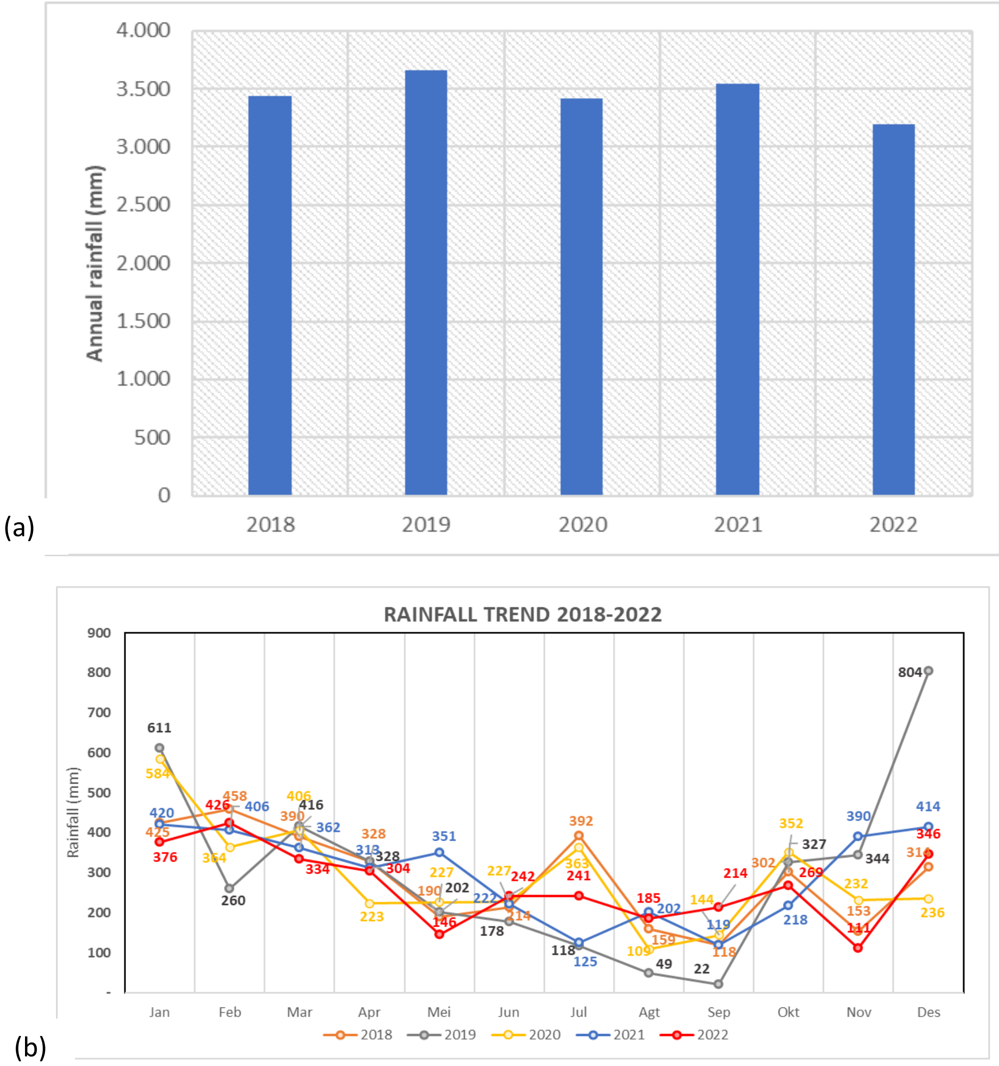

Fig. 1. Annual (a) and Rainfall patterns monthly (b) between 2018 and 2022

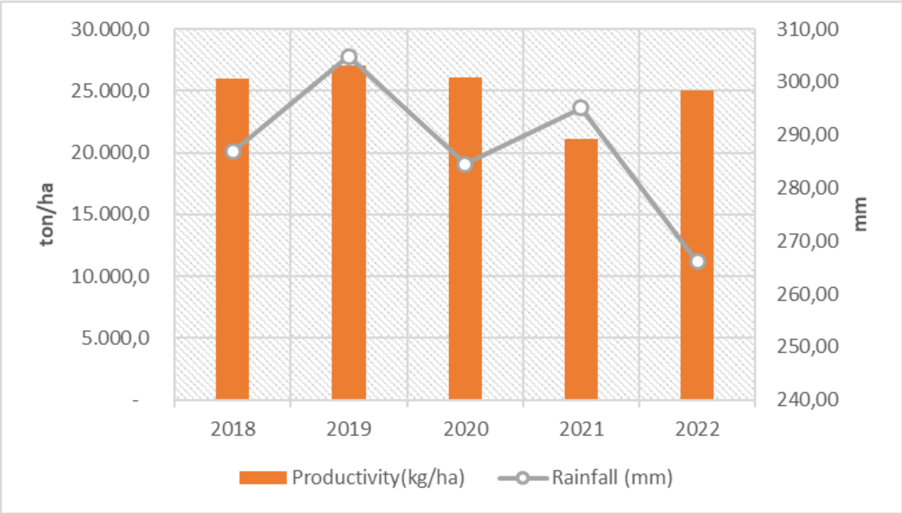

Fig. 2. Relationship pattern between rainfall and palm oil productivity 2018-2022

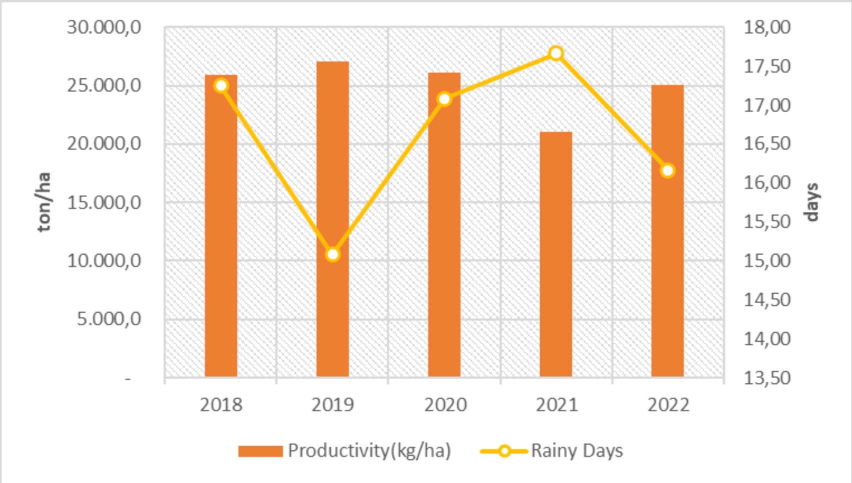

Fig. 3. Relationship pattern between rainy days and palm oil productivity 2018-2022

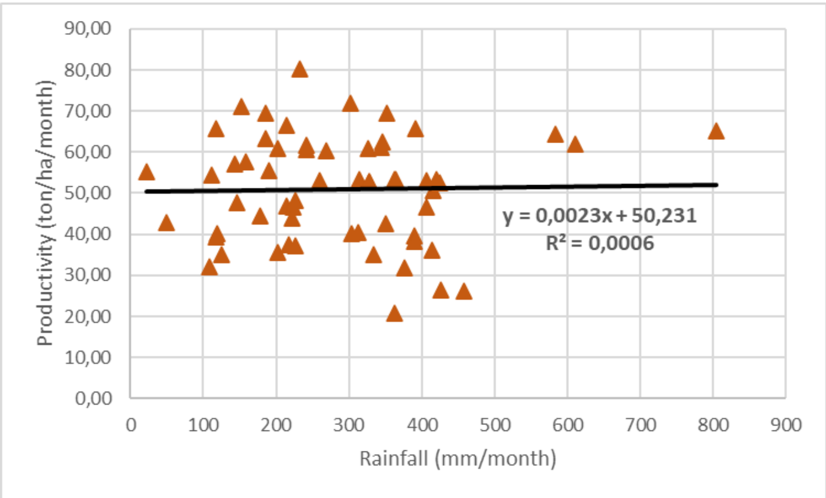

Fig. 4. Regression of reletaionship between rainfall and palm oil productivity

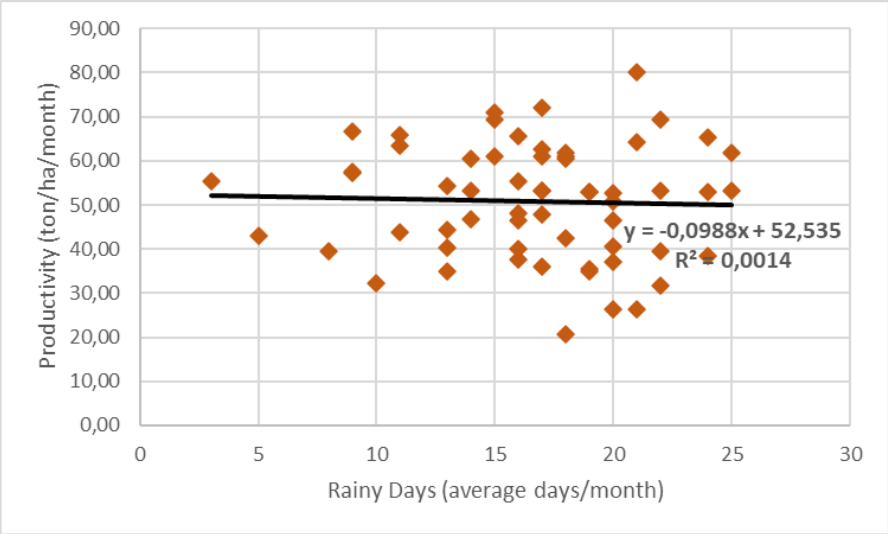

Fig. 5. Regression of reletaionship between rainy days and palm oil productivity

Table 1. Correlation of rainy days, rainfall and palm oil productivity

Parameters	Rainy Days	Rainfall	Productivity
Rainy Days	1	0,768386269*	-0,036778304
Rainfall		1	0,025109171
Productivity			1

Excess water in the plantation resulting from rainy days and high rainfall can lead to low fresh fruit bunch production and poor drainage [10]. High rainfall can also cause surface flow to carry fertilizers, resulting in low crop production [15,16]. Inundation stress activates the plant's defense mechanism, which initially affects the root organs to support plant growth and ultimately impacts oil palm production. Rainfall exceeding 4000 mm/year can cause flooding and landslides. Poor drainage systems on agricultural land can disrupt flowering and fruiting processes, ultimately leading to decreased production or crop failure during floods [17]. Rainfall and rainy days can also affect temperature and humidity.

The temperature around the oil palm canopy is higher, which reduces humidity in the area. This makes oil palm cultivation more suitable for land areas with altitudes between 0-400 meters above sea level. In such environments, solar radiation is intense, resulting in high air temperatures and increased evapotranspiration rates in the oil palm plantation area, leading to low air humidity. Low air humidity, high air temperature, and high solar radiation intensity in land areas with an altitude of 0-400 masl stimulate oil palm flowering. The flower clusters that form can develop perfectly, resulting in a high pollination success rate. This, in turn, increases fruit set, resulting in larger and denser fresh fruit bunches (FFBs). FFBs with larger size and high fruit set have a significantly heavier weight, leading to increased land productivity. Air temperature plays a crucial role in the flowering and fruiting process. Low temperatures can lead to increased flower abortion, increased male flower, slower vegetative growth rates, and inhibited bunch maturity, ultimately disrupting fruit ripening and resulting in decreased palm oil yield [18].

Air humidity is a climatic factor that measures the level of evaporation and water availability for plants. Optimal air humidity suppresses evaporation rates, allowing plants to utilize soil water content for key metabolic activities in their tissue. Low air humidity can increase the rate of evaporation, which can negatively impact the growth and development of oil palm plants in areas with limited soil water content and low rainfall. This can lead to decreased plant productivity and oil yield. Additionally, low air humidity can exacerbate drought conditions for plants with limited soil moisture, as the availability of water in the root zone may not be sufficient to compensate for water loss through transpiration. Humidity affects the rate of photosynthesis, which is regulated by VPD

(Vapor Pressure Deficit). An increase in VPD leads to a decrease in the rate of photosynthesis due to a decrease in stomatal conductance, which disrupts the carbon dioxide diffusion process and inhibits the photosynthetic rate. High humidity conditions typically result in low VPD, indicating that the air is close to saturation with water vapor. Under such conditions, stomatal conductance may increase to facilitate CO_2 uptake, as there is less pressure for water loss through transpiration. Conversely, low humidity conditions lead to higher VPD, prompting stomatal closure to conserve water and reduce transpirational losses. However, stomatal closure also restricts CO_2 diffusion into the leaf, limiting the rate of photosynthesis [19,20]. The potential negative impact of temperature rise on oil palm production is significant. According to Sarkar et al. [21], if temperatures rise by 1°C, 2°C, 3°C, or 4°C, oil palm production could decrease by 10-41%. To mitigate and adapt to the effects of climate change on the agriculture sector, strategies must be implemented. Mitigation strategies include conserving existing carbon stocks, forest biomass, and soil carbon; reducing carbon losses from biota and soils through management changes; preventing deforestation; and enhancing carbon sequestration in soils and biota through increased forestation [22,23,24]. Adaptation strategies should take into account current and future technological perspectives that can influence adaptation choices. The development of adaptation should prioritize the use of climate-resilient varieties with high-tolerance planting materials and new crop varieties, which are critical for changing climate conditions. Soil and water conservation are essential for increasing oil palm production. This can be achieved by improving water infiltration through the application of organic matter, which enhances water-holding capacity and reduces water run-off. Proper management techniques such as drainage, mulching, weed and cover crop management can help reduce water evaporation and prevent soil erosion. These techniques also help maintain soil moisture and improve water infiltration, which is crucial during extreme weather or climate change conditions. Additionally, they aid in the reabsorption of CO_2 emissions from the land [21,25,26].

4. CONCLUSION

Rainfall in Berau Regency's oil palm plantations is part of a very wet climate that indirectly affects the productivity of oil palm plants. Rainfall has a direct impact on temperature, humidity, intensity, and duration of daily irradiation, which in turn affects the productivity of oil palm plants. The mitigation and adaptation of oil palm cultivation to climate change can be achieved through effective crop management, including the use of tolerant varieties, organic fertilizers to increase water infiltration and retention capacity, and mulching, weed and cover crop management to reduce evaporation. Further research is needed to determine the effects of temperature, humidity, and length of irradiation on the physiology of oil palm plants to support yields during climate change.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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