EFFECTS OF CLIMATIC FACTORS ON THE PRODUCTIVITY OF SMALLHOLDER RUBBER PLANTATIONS IN SOUTH SUMATRA, INDONESIA

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Abstract

South Sumatra Province is known as Indonesia's largest natural rubber-producing center. In the last few decades, South Sumatra has faced climate change issues marked by increased variability of maximum temperature, mean temperature, minimum temperature, and rainfall. On the other hand, smallholder rubber plantations are considered to be particularly vulnerable to climate change. Therefore, the goal of this study was to identify the climatic factors that affect the productivity of smallholder rubber plantations in South Sumatra. The data was gathered from the Indonesian Central Bureau of Statistics and the Indonesian Agency for Meteorology, Climatology, and Geophysics from January 2006 to December 2019. A quadratic regression model was used to analyze the data. The results showed that maximum temperature, mean temperature, minimum temperature, and rainfall affect the productivity of smallholder rubber plantations. Maximum temperature and rainfall indicate a pattern that is increasing to the optimum point of 32.29 °C and 281.40 mm respectively and after that, it will slow down. The mean temperature and minimum temperature show a pattern that is decreasing to the optimum point of 26.84 °C and 22.14 °C respectively and after that, it will slow down.

Keywords: productivity, smallholder rubber plantations, temperature, rainfall
JEL classification: Q15, Q54, Q57

1. Introduction

Indonesia's agriculture sector plays a vital role in the country's economy. The agricultural sector is considered to have great potential in absorbing labor (Fafurida, Setiawan, and Oktavilia 2019). The agricultural sector absorb 34.60% of Indonesia's overall population and has big effects on economic growth (Dewi, Prihanto, and Edy 2016; Abd. Majid et al. 2018; Rahmi and Aliasuddin 2020). Labour absorption must be accompanied by an increase in agricultural labor productivity and a decrease inequality in every region in Indonesia (Feriyanto and Sriyana 2016; Purnastuti, Suprayitno, and Sugiharsono 2016). Higher labor productivity can trigger economic expansion and increase added value to agricultural products (Hurri et al. 2019). Agricultural products are critical to a country's population's resiliency (Stratigea 2014). Agricultural products vary widely and are divided into several sub-sectors, with the plantation sub-sector being one of them.

Rubber is one of Indonesia's most essential plantation commodities (Kadir et al. 2018). Several provinces have become rubber-producing centers in Indonesia, but South Sumatra Province is the primary producer of natural rubber production. According to Indonesia's Central Statistics Agency, South Sumatra accounts for 27.87 percent of the country's total natural rubber production in 2019 (BPS 2019). Smallholder plantations dominate natural rubber production in South Sumatra. Smallholder plantation rubber accounts for 95.28 percent of total rubber production in South Sumatra. This shows that the rubber commodity is a community's economic center and that it can encourage the downstream industry from processed natural rubber products to grow (Syahril et al. 2019). However, smallholder plantations are highly vulnerable to various socioeconomic and environmental changes (Jamshidi et al. 2019). In the socio-economics aspect, rubber smallholders are sensitive to price fluctuations, land fragmentation, uncertainty and instability in social and political issues (Gyulgyulyan and Bobojonov 2019; Mukhlis et al. 2020; Dovgal et al. 2017). In terms of the environment, rubber smallholders are vulnerable to geographic conditions that lead to differences in climatic factors in each region of Indonesia (Panjawa, Samudro, and Soesilo 2018). This level of vulnerability is getting bigger along with the occurrence of climate change in Indonesia.

Currently, almost all regions in Indonesia are facing a quite alarming climate change phenomenon. Climate change is marked by the emergence of several phenomena, such as increased temperature, unpredictable rainfall, and extreme weather events (Harvey et al. 2018; Onzima, Katungi, and Bonabana-Wabbi 2019). This impacts the increasing frequency of droughts, floods, unpredictable precipitation patterns, and heatwaves (Arora 2019; Diendéré 2019). Indonesia is expected to experience an increase in temperature of around 0.80 °C in 2030. In addition, the rainfall pattern is also expected to change, with the rainy season ending sooner and the length of the rainy season shortening (Oktaviani et al. 2011). Climate change is associated with an increase in biotic and abiotic environmental stress to directly affect the decrease in agricultural production quantity and quality (Mall, Gupta, and Sonkar 2017; Stevanovic et al. 2016).

Climate change causes the increase in variability of climatic factors, such as temperature, humidity, and rainfall (Thornton et al. 2014). Climate change, in the form of increased air temperatures and unpredicted rainfall, has decreased the quality of soil and water (Gornall et al. 2010; Lemi and Hailu 2019). This condition causes a decrease in the optimum production of agricultural commodities that can be achieved (Chandio et al. 2020). In addition, extreme weather days negatively correlate with the gross output value of agriculture due to a decrease in the level of efficiency of agricultural production (Shi et al. 2020). A study in Ekiti State, Nigeria showed that the amount and frequency of rainfall and minimum temperature were positively correlated with rice cultivation during the planting period, while the maximum temperature was negatively correlated over the same phase (Olanrewaju, Tilakasiri, and Oso 2017).

According to Wildayana (2017), climate change also affects the production and productivity of rubber plants. The tapping results depend on the climate and conditions of rubber trees and plantations. On the other hand, Budiasih et al. (2020) stated that the impact of prominent climate change would affect and decrease the production of rubber plants. Not to mention the fact that this plant is susceptible to climatic variability (Hutapea, Siregar, and Astuti 2015). An increase in the minimum temperature of 1 °C has the potential to reduce rubber production by 3 g per tapping per tree (Ali, Aziz, and Williams 2020). In addition, rainfall has a positive and significant effect on latex production, with a 1 mm rise in rainfall increasing rubber latex output by 924.335 milliliters (Sinaga, Irsal, and Mawarni 2017; Umar et al. 2017).

Previous studies on the impact of climate on rubber production used a linear model, but this method has a weakness of could not predicting the optimum value of each climatic factor. Therefore, this study uses a quadratic regression model to overcome this weakness. This method has the advantage of being able to predict the inflection point, which shows the optimal point of each climate factor for smallholder rubber plantation productivity (Correia et al. 2017). We believe this study will provide researchers with perspectives on how better to assess the effects of climate change on agriculture. Meanwhile, this study will provide practical contributions, especially strategic steps to mitigate climate change's effects. This study aimed to determine the climatic factors that affect the smallholder rubber plantation productivity in South Sumatra and determine its optimal point.

2. Literature Review

Indonesia is known as one of the largest natural rubber exporters in the world. Indonesia's natural rubber production is recorded to share 28.06 percent in the international market, with an average production of 2,810,379 tons per year (Trademap 2021). Indonesian rubber has a competitive advantage to compete in the international natural rubber commodity market. However, the current climate change phenomenon is a challenge that Indonesia must face.

The annual mean temperature in Indonesia has increased by 0.30 °C per decade, accompanied by a decrease in overall annual precipitation by 2-3 percent (Case et al., 2007). The increase in temperature is expected to continue to increase up to 0.80 °C in 2030 (Oktaviani et al. 2011). In addition, Indonesia has also experienced a trend of increasing sea surface temperature and sea wave height in recent years (Zikra et al., 2015). This phenomenon is expected to worsen along with the increase in pollution and greenhouse gas emissions in Indonesia (Amheka 2018; Nastiti and Giyarsih 2019; Miyata, Wahyuni, and Shibusawa 2013)

Climate change is not only happening at the national level but also the provincial level. South Sumatra Province is also experiencing the phenomenon of climate change. This is indicated by the increasing temperature and rainfall which tend to fluctuate (BMKG 2021). The average maximum temperature in South Sumatra was recorded to increase by 0.004 °C per month in 2006-2019. Meanwhile, the average minimum and mean temperatures also increased by 0.007 °C and 0.003 °C per month in 2006-2019. Meanwhile, the rainfall in South Sumatra tended to decrease in the same period by 0.215 mm per month.

High rainfall is predicted to reduce rubber production due to wasting latex by rainwater (Mesike and Esekhade 2014). On the other hand, low rainfall can also trigger a groundwater balance deficit and inhibit the latex flow of rubber plants (Sahuri 2018). Changes in temperature that occur, either at maximum, mean or minimum temperatures can trigger changes in the physiological processes of rubber plants. Temperature can affect the turgor pressure, evapotranspiration rate, and respiration of rubber plants, affecting the production of natural rubber produced by rubber plants (Ali et al., 2020; Ulfah et al., 2015).

By looking at the various literature reviews, the hypotheses of this study are:

Hypothesis 1: Rainfall has a significant effect on the productivity of smallholder rubber plantations in South Sumatra Province

Hypothesis 2: The maximum temperature has a significant effect on the productivity of smallholder rubber plantations in South Sumatra Province

Hypothesis 3: The mean temperature has a significant effect on the productivity of smallholder rubber plantations in South Sumatra Province

Hypothesis 4: The minimum temperature has a significant effect on the productivity of smallholder rubber plantations in South Sumatra Province

3. Methods

The data of this study is sourced from the Indonesian Central Bureau of Statistics (BPS) and the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG). The data were collected monthly from January 2006 to December 2019. In addition, the selection of the research location, namely South Sumatra, was carried out using the purposive sampling method. South Sumatra was chosen because it is Indonesia's largest natural rubber-producing center (Table 1).

Table 1. Top 5 Natural Rubber Production Centers in Indonesia

Province	Production (ton)	Share of Production (%)	Ranks
South Sumatra	927,023	27.87	1
North Sumatra	400,372	12.04	2
Riau	318,043	9.56	3
Jambi	306,998	9.23	4
West Kalimantan	259,545	7.80	5
Indonesia	**3,325,894**	**66.51**	

Research variables include dry natural rubber productivity data from smallholder rubber plantations, maximum temperature, mean temperature, minimum temperature, and rainfall in South Sumatra. The dry natural rubber productivity variable is obtained by dividing total dry natural rubber production by the area of productive rubber plantations. The variables of maximum temperature, mean temperature, minimum temperature, and rainfall are indicators for climatic factors. The following is the formula for calculating rubber productivity:

$$Productivity = \frac{Rubber\ Production\ (ton)}{Land\ Area\ (ha)} \quad (1)$$

The use of time-series data requires consideration of the data's nature, which is the emergence of specific patterns in the data, causing the data to be non-stationary over time. Non-stationary data can lead to spurious regression with biased results (Asafo 2017; Chamalwa and Bakari 2016; Okon and Sunday 2014). The stationarity test can be used to determine the data's stationarity. The Augmented Dickey-Fuller test was used to determine stationarity in this study. The results of the stationarity test show that all research variables are stationary at the level stage (Table 2).

Table 2. Stationarity Test

Variable	Stage	ADF Statistic	Prob.	Information
PDVT	Level	-5.42	0.00	Stationary
MAX	Level	-5.99	0.00	Stationary
AVG	Level	-6.26	0.00	Stationary
MIN	Level	-5.39	0.00	Stationary
RAIN	Level	-8.16	0.00	Stationary

After obtaining stationary data, the next step is to determine the climatic factors that affect the productivity of smallholder rubber plantations in South Sumatra. It can be done using a quadratic regression model. The quadratic regression is used in this study due to the advantages of the model. The quadratic regression model can predict the optimum point of a variable that affects other variables. The output of this analysis is the influence of each climate factor on the productivity and the inflection point (Correia et al. 2017; Susetyo and Hadi 2012). The inflection point will show the optimum point of each climate factor that affects the productivity of smallholder rubber plantations in South Sumatra. The quadratic regression model can be written mathematically as follows (Gujarati 2004):

$$Y = \alpha_0 + \alpha_1 X + \alpha_2 X^2 \quad (2)$$

where Y is the dependent variable, X is the independent variable in the model and α_0, α_1, and α_2 are constant parameters. Four possibilities can occur in the quadratic regression model as follows.

1. Increases at an increasing rate, when 1st order derivative > 0 and 2nd order derivative > 0;
2. Increases at a decreasing rate, when 1st order derivative > 0 and 2nd order derivative ≤ 0;
3. Decreases at an increasing rate, when 1st order derivative ≤ 0 and 2nd order derivative < 0;
4. Decreases at a decreasing rate, when 1st order derivative ≤ 0 and 2nd order derivative ≤ 0.

Based on this theory, this research can be structured into a quadratic regression model by placing the natural rubber productivity variable as the dependent variable and climate factors as the independent variable. The quadratic regression model of this study is as follows.

$$PVID_t = \alpha_0 + \alpha_1 MAX_t + \alpha_2 MAXSQ_t + e \quad (3)$$
$$PVID_t = \alpha_0 + \alpha_1 AVG_t + \alpha_2 AVGSQ_t + e \quad (4)$$
$$PVID_t = \alpha_0 + \alpha_1 MIN_t + \alpha_2 MINSQ_t + e \quad (5)$$
$$PVID_t = \alpha_0 + \alpha_1 RAIN_t + \alpha_2 RAINSQ_t + e \quad (6)$$

where:

$PVID_t$ = Productivity of smallholder rubber plantations in year t (ton/ha)
MAX_t = Average maximum temperature in year t (°C)
$MAXSQ_t$ = Average maximum temperature square in year t (°C)
AVG_t = Average mean temperature in year t (°C)
$AVGSQ_t$ = Average mean temperature square in year t (°C)
MIN_t = Average minimum temperature in year t (°C)
$MINSQ_t$ = Average minimum temperature square in year t (°C)
$RAIN_t$ = Average rainfall in year t (mm)
$RAINSQ_t$ = Average rainfall square in year t (mm)
e = Error term

The validation of the quadratic regression model can be seen from the significance value of the inflection point and the significance value of the F-statistics. When the inflection point in a model has a significant effect, it means that a regression model has an optimum point. Furthermore, when a model has an optimum point, the regression model can form a U-shape curve, a special characteristic of the quadratic model (Hintz et al., 2019). The significant value of the F-statistic confirms that the quadratic regression model used is valid. In addition, the accuracy in using the quadratic model can be seen from the adjusted R2 value in each model used. The higher the adjusted R2 value, the higher the accuracy of the quadratic regression model (Gholami et al., 2012; Shahbazi, 2015).

4. Findings and Discussion

According to summary statistics, the average productivity of smallholder plantations in South Sumatra from January 2006 to December 2019 was 0.09 tonnes per month with the characteristics of monthly climatic factors, such as the average maximum temperature of 32.41 °C, average mean temperature of 27.12 °C, the average minimum temperature is 23.66 °C, and the average rainfall is 209.66 mm (Table 3). Smallholder rubber plantation productivity in South Sumatra fluctuates with a standard deviation value of 0.02 tonnes per hectare. The minimum productivity was 0.04 tonnes per hectare in October 2006. In the same period, the maximum temperature and mean temperature reached their highest point of 34.90 °C and 28.37 °C, respectively, in January 2006 and December 2019. In addition, the minimum temperature was also recorded to have increased from the previous month's average (21.57 °C) to 23.23 °C in October 2006. Furthermore, the rainfall in October 2006 was one of the lowest rainfall in South Sumatra, which is 27.30 mm, well below the average rainfall from January 2006 to December 2019. This phenomenon shows that the low productivity of smallholder rubber plantations in South Sumatra is linked to high maximum temperature, mean temperature and minimum temperature, as well as low rainfall.

Table 3. Summary Statistics

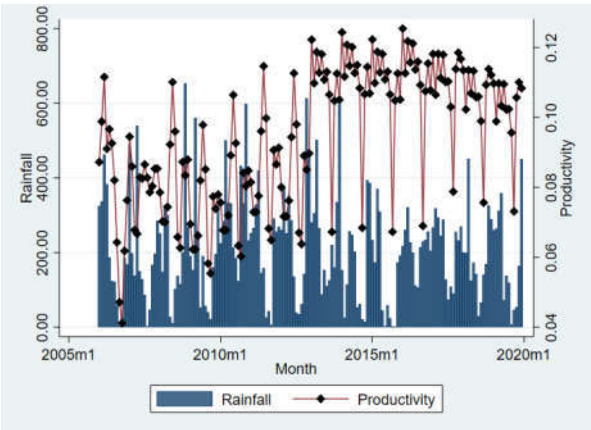
Variable	Obs.	Mean	Std. Dev.	Min.	Max.
PVID	168.00	0.09	0.02	0.04	0.13
MAX	168.00	32.41	0.91	29.83	34.90
AVG	168.00	27.12	0.65	24.66	28.37
MIN	168.00	23.66	0.67	20.87	25.11
RAIN	168.00	209.66	141.06	1.00	653.10

The productivity of smallholder rubber plantations in South Sumatra reached its highest point in January 2016, reaching 0.13 tonnes per hectare. This productivity is supported by different climatic characteristics when productivity reaches its lowest point. In January 2016, the maximum temperature was recorded at 32.56 °C, slightly higher than the average maximum temperature. In addition, the mean and minimum temperatures at this point are 27.32 °C and 24.34 °C, respectively. This value is higher than the average mean or minimum temperatures from January 2006 to December 2019. Other climatic factors, namely rainfall, reached 217.50 mm during the same timeframe, higher than the average rainfall from January 2006 to December 2019.

Figure 1 shows the pattern of smallholder rubber plantation productivity in South Sumatra against various climatic factors, namely maximum temperature, mean temperature, minimum temperature, and rainfall. From January 2006 to December 2019, the productivity of smallholder rubber plantations tended to increase, although it seemed to fluctuate. Rainfall data also shows a high degree of fluctuation (see Figure 1a). The highest rainfall in South Sumatra was 653.10 mm in November 2008. The high rainfall was caused by the impact of the La Nina phenomenon (the Oceanic Niño Index or ONI value was less than -0.50) that occurred during that period. On the other hand, the ONI value was greater than +0.50 occurred in September 2015. The ONI value in that period was +2.16, putting it in the range of a compelling El Nino phenomenon (Azlan et al. 2016). This causes the monthly rainfall in South Sumatra Province to reach its lowest point of 1.00 mm.

The El Nino and La Nina phenomenon not only affects rainfall, but also the variability of other climatic factors, such as maximum (Figure 1b), mean (Figure 1c), and minimum (Figure 1d) temperatures. The highest maximum, mean, and minimum temperatures in South Sumatra are closely related to the El Nino phenomenon. In contrast, decreases in maximum, mean, and minimum temperatures were strongly related to La Niña events (Azmoodehfar & Azarmsa, 2013; Salau, et al., 2016).

Image 1: (a) Indonesia's Dry Natural Rubber Productivity Versus Rainfall, (b) Indonesia's Dry Natural Rubber Productivity Versus Maximum Temperature, (c) Indonesia's Dry Natural Rubber Productivity Versus Mean Temperature, (d) Indonesia's Dry Natural Rubber Productivity Versus Minimum Temperature



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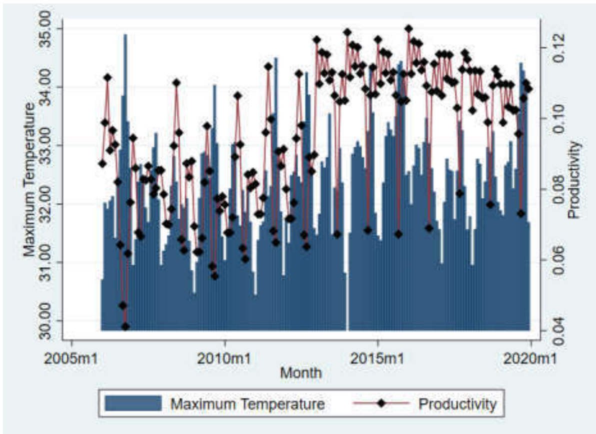

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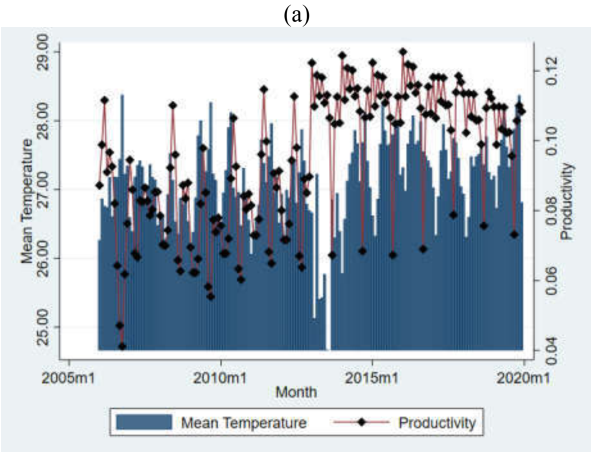

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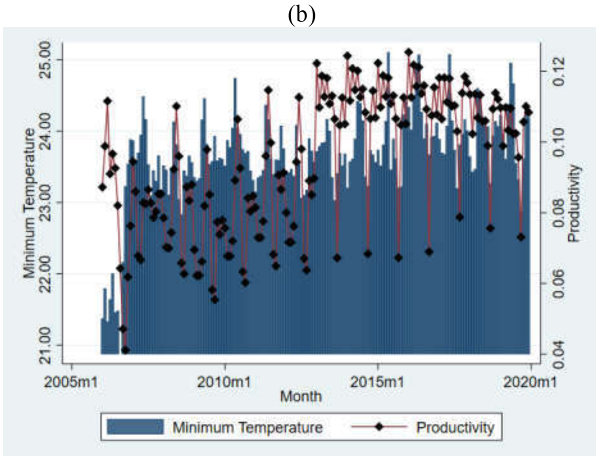

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Figure 1a shows that the pattern of increasing productivity is positively associated with a pattern of increasing rainfall. As an example, the year 2006 can be used. The month with the most rain was March 2006, with 462.70 mm. At the same time, smallholder rubber plantations were able to produce 0.11 tonnes per hectare. In 2006, this was the highest value of productivity. On the other hand, low rainfall is associated with low productivity levels. For example, September 2015 saw the lowest rainfall total for the whole year. There was only 1 mm of rain in that month, and productivity was only 0.07 tonnes per hectare. The productivity value for September 2015 is the lowest productivity value for the whole year of 2015.

Table 4. Quadratic Model of Rainfall

Variable	Coefficient	Std, Error	t-Statistic	Prob
Inflection Point	281.39740***	35.69235	7.88000	0.00000
RAIN	0.00008***	0.00003	2.77000	0.00600
RAINSQ	-1.50e10-07***	-5.48e10-08	-2.75000	0.00700
Cons.	0.08602***	0.00367	23.44000	0.00000
Adjusted R^2				0.03390
F-statistic				3.93000
Prob. (F-statistic)				0.02160

Where: ***Significant at 1 percent alpha

The trend seen in Figure 1a can be confirmed using the quadratic regression model in Table 4. The regression model shows that the variable rainfall (RAIN) and RAINSQ affect the productivity of smallholder rubber plantations in South Sumatra at a 1% alpha level. According to the model. the inflection point is significant at a 1% alpha level, and the probability F-statistic is significant at the 5% alpha level. The coefficients of RAIN and RAINSQ are both positive and negative, so it can be interpreted that the higher rainfall, the higher of smallholder rubber plantations productivity until the optimum point of rainfall, and a further increase in rainfall (after reaching the optimum point) can further increase rubber productivity at a decreasing rate (see Figure 2a). The optimum point of rainfall is the inflection point with a value of 281.40 mm. The regression coefficient for the RAIN variable is 0.00008, while the regression coefficient for the RAINSQ variable is -1.50e10-07. This value can be interpreted as follows: a 1 mm increase in rainfall increases productivity by 0.00008 tonnes per hectare until it reaches an optimum point of rainfall of 281.40 mm. An increase in rainfall can slows the rate of increase in natural rubber productivity.

Rainfall has a positive correlation with rubber plant growth. Increased rainfall can increase the girth of rubber trees, which has a beneficial effect on increasing rubber plant productivity (Sangchanda et al., 2014). The availability of groundwater strongly correlated to rainfall will affect latex production (Budiasih et al. 2020). The lack of rain will reduce groundwater level, resulting in a water balance deficit in rubber plants. When the Soil water level drops below 100 mm, the maximum latex yield that rubber plants can produce is only 18 g / t / t, much less than normal conditions, which can reach 28 g / t / t (Sahuri 2018). However, excessive rainfall will reduce latex production. According to Mesike & Esekhade (2014), rubber production can be hampered by high rainfall because of reduced tapping frequency and latex waste by rainwater. Furthermore, high rainfall causes runoff erosion and depletes soil nutrients, resulting in reduced smallholder rubber plantation productivity (Vrignon-brenas et al. 2019).

The productivity of smallholder rubber plantations in South Sumatra has a positive relationship with the pattern of maximum temperature (Figure 1b). Increases in maximum temperature have been shown to increase productivity. This can be seen from the movement of productivity and maximum temperature in May 2008. During this period, the maximum temperature reached its highest point (32.82 °C), while natural rubber productivity reached 0.09 tonnes per hectare. In the same year, when the maximum temperature reached its lowest point of 31.20 °C in January, the productivity of natural rubber was only 0.08 tonnes per hectare.

Table 5. Quadratic Model of Maximum Temperature

Variable	Coefficient	Std. Error	t-Statistic	Prob
Inflection Point	32.29030***	0.25579	126.24000	0.00000
MAX	0.21389***	0.08172	2.62000	0.01000
MAXSQ	-0.00331***	0.00126	-2.63000	0.00900
Cons.	-3.35639**	1.32669	-2.53000	0.01200
Adjusted R^2				0.03180
F-statistic				3.74000
Prob. (F-statistic)				0.02570

Where: ***Significant at 1 percent alpha **Significant at 5 percent alpha

The analysis results show that the maximum temperature (MAX) and MAXSQ affect the productivity of smallholder rubber plantations in South Sumatra (Table 5). In addition, the inflection point is also significant at the 1% alpha level, resulting in a quadratic pattern relationship between maximum temperature and productivity (Figure 2b), and the F-statistics probability is significant at the 5% alpha level. Table 4 shows that increasing the maximum temperature by 1 °C increases productivity by 0.21 tonnes per hectare until it reaches the optimum temperature at 32.29 °C. The effect comes at a declining rate as the maximum temperature rises and passes the optimum limit, implying that the maximum temperature that exceeds the threshold (optimum maximum temperature) will minimize the increase in natural rubber productivity. Rubber plants require a maximum temperature within the threshold to maintain a low viscosity level, so the water absorption and photosynthesis are not inhibited (Marpaung and Hartawan 2014). In their study, Yu et al. (2014) found that maximum temperatures above 28.50 °C will increase rubber plant productivity. However, an excessively high maximum temperature can interfere with plant physiological processes, thereby reducing plant productivity (Yohannes 2016).

The mean temperature fluctuated in its movement pattern (Figure 1c). The movement of the mean temperature exhibits a tendency that is inversely proportional to the movement of natural rubber productivity. Increasing mean temperature tends to decrease productivity. This phenomenon can be seen in September 2006 where the mean temperature reached the highest temperature of 28.37 °C, but productivity reached the lowest point of 0.04 tonnes per ha. In January of the same year, the mean temperature fell to 26.26 °C, and productivity fell to 0.09 tonnes per hectare.

Table 6. Quadratic Model of Mean Temperature

Variable	Coefficient	Std, Error	t-Statistic	Prob
Inflection Point	26.83630***	0.29717	90.30000	0.00000
AVG	-0.20905*	0.11067	-1.89000	0.06100
AVGSQ	0.00389*	0.00206	1.89000	0.06100
Cons.	2.89731*	1.48470	1.95000	0.05300
Adjusted R^2				0.00930
F-statistic				1.78000
Prob. (F-statistic)				0.17110

Where: ***Significant at 1 percent alpha *Significant at 10 percent alpha

Table 6 indicates the significant mean temperature inflection point at the 1% alpha level. These results confirm a quadratic pattern between mean temperature and productivity of smallholder rubber plantations in South Sumatra (Figure 2c). The regression coefficients AVG and AVGSQ also have a significant effect on productivity. According to the findings, a 1°C rise in mean temperature reduces smallholder rubber plantation productivity by 0.21 tonnes per hectare until it reaches the optimum point mean temperature of 26.84 °C. The effect of increasing the mean temperature above the threshold has a minor declining effect. According to Yu et al. (2014), increasing the mean temperature will decrease rubber productivity, while an average temperature below 25.70 °C will increase rubber productivity. Excessively raising the mean temperature will minimize latex flow (Zhang et al. 2014).

Figure 1d shows the movement pattern of dry natural rubber productivity for smallholder rubber plantations in South Sumatra against the minimum temperature. The minimum temperature and productivity have an inverse relationship in terms of movement; an increase in the minimum temperature is correlated with a reduction in the productivity of dry natural rubber. This can be seen in the productivity against the minimum temperature data in 2012. The highest minimum temperature in 2012 was 24.08 °C with a productivity of only 0.09 tonnes per ha. This value is lower than the productivity of dry natural rubber, which was 0.10 tonnes per hectare when the lowest minimum temperature occurred in 2012 (23.06 °C) This statement is supported by the quadratic regression model in Table 7.

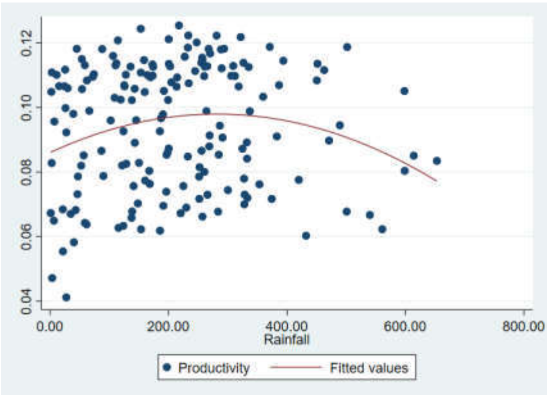
Table 7. Quadratic Model of Minimum Temperature

Variable	Coefficient	Std, Error	t-Statistic	Prob
Inflection Point	22.14086***	0.36927	59.96000	0.00000
MIN	-0.22807***	0.07069	-3.23000	0.00200
MINSQ	0.00515***	0.00152	3.38000	0.00100
Cons.	2.60488***	0.81979	3.18000	0.00200
Adjusted R^2				0.18280
F-statistic				19.67000
Prob. (F-statistic)				0.00000

Where: ***Significant at 1 percent alpha

The significant inflection point at the 1 percent alpha level indicates a quadratic relationship between minimum temperature and productivity of smallholder rubber plantations (Figure 2d). In addition, the MIN and MINSQ variables are also significant at the 1% alpha level with the negative and positive regression coefficients, respectively. The quadratic regression model between the minimum temperature and dry natural rubber productivity shows that a 1 °C rise in minimum temperature will reduce dry natural rubber productivity in South Sumatra by 0.23 tons per hectare until it reaches the optimum point minimum temperature of rubber plants of 22.14 °C. The minimum temperature has a negative relationship with productivity. This is closely related to the turgor pressure conditions of rubber plants. Rubber that is tapped under conditions of high turgor pressure produces more latex (Ulfah, Thamrin, and Natanael 2015). The highest turgor pressure in rubber plants occurs when the minimum temperature is reached. Turgor pressure is associated with latex flow. The evapotranspiration rate in rubber plants increases as the minimum temperature rises, lowering the turgor pressure and reducing latex flow (Ali, Aziz, and Williams 2020).

Image 2: (a) Quadratic model of Indonesia's Dry Natural Rubber Productivity Versus Rainfall, (b) Quadratic model of Indonesia's Dry Natural Rubber Productivity Versus Maximum Temperature, (c) Quadratic model of Indonesia's Dry Natural Rubber Productivity Versus Mean Temperature, (d) Quadratic model of Indonesia's Dry Natural Rubber Productivity Versus Minimum Temperature



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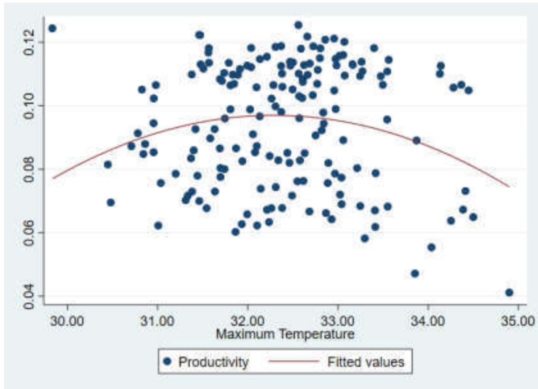

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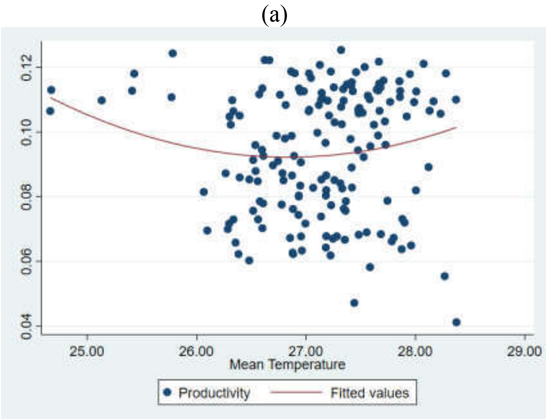
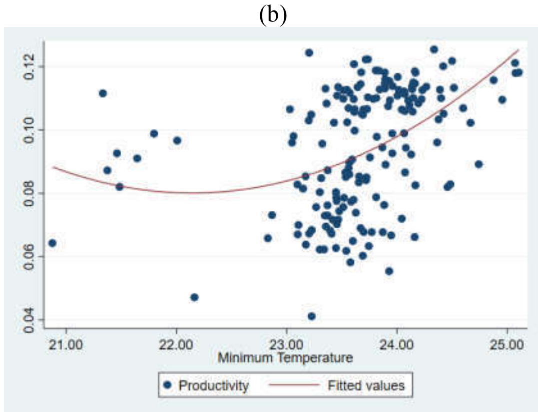


(c)



(d)

In South Sumatra, appropriate mitigation measures on smallholder rubber plantations are needed due to the fluctuating climatic factors such as rainfall, maximum temperature, mean temperature, and minimum temperature. To overcome this, making bio pores can be the best alternative. Bio pores can absorb rainwater during high rainfall and store it properly, so that rubber plants can use it when there isn't a lot of rain. In addition, bio pores have a role in maintaining optimum temperature and humidity. Implementing a rubber-based agroforestry scheme will also help to mitigate smallholder rubber plantations. Some plants can synergize well with rubber plants such as peanut, sweet potato, maize, T. cacao, C. arabica, F. macrophylla, or D. cochinchinensis (Chen et al., 2017; Singh, 2018). A rubber-based agroforestry system is considered capable of overcoming erosion from runoff due to the participation of intercrops in rubber plantations which can act as a mulch for the beating action of raindrops (Chen et al. 2017).

5. Conclusion

The productivity of smallholder rubber plantations in South Sumatra is influenced by climatic factors, such as rainfall, maximum temperature, mean temperature, and minimum temperature. The optimum rainfall that affects smallholder rubber plantations' productivity is 281.40 mm, while the optimum temperatures for maximum, mean, and minimum temperatures are 32.29 °C, 26.84 °C, and 22.14 °C, respectively. The high fluctuations of climatic factors affect the productivity of smallholder rubber plantations. This indicates the need to implement appropriate mitigation strategies. This strategy can make bio pores on smallholder rubber plantations and implement a rubber-based agroforestry system, allowing smallholder rubber plantations in South Sumatra to be more resilient to climate change. Finally, this study increases experts', the public's, and the government's understanding of the need to mitigate the effects of climate change. Based on engagement theory, this awareness can be developed by education and involvement of all stakeholders in the rubber plantation

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