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Indonesian Climatic Factors and Its Effect on Cocoa Productivity

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ABSTRACT

One of the important aspects in cocoa cultivation is productivity, as it is related to the ability of national cocoa producers to meet market demand. Cocoa productivity is affected by many factors, including climate factors. On this basis, this study aims to determine the trend of national cocoa productivity and climatic factors (maximum temperature, minimum temperature, mean temperature, and rainfall) and to determine the influence of climatic factors on cocoa productivity. By applying a descriptive method, this research utilized secondary data with a time span between 1961-2021, which were analyzed using quadratic regression model. From the analysis, it was clear that there had been increasing tendency for national cocoa productivity, maximum temperature, minimum temperature, mean temperature and rainfall from year to year. Meanwhile, the climatic factors that affect cocoa productivity are the maximum temperature, minimum temperature, and mean temperature with an optimum point of 30.53°C; 21.31°C and 25.87°C respectively. Temperature generally has a negative effect on cocoa productivity, although it does not have a big impact. However, continuous exposure to temperature will lead to a more harmful threat to cocoa productivity. This research contributes to the use of non-linear regression analysis, especially quadratic regression model in determining climatic factors that influence cocoa productivity in Indonesia, considering that not many studies have used similar model.

Keywords: *Climate Change, Cocoa, Temperature, Rainfall*

1. INTRODUCTION

As one of Indonesia's leading plantation commodities, cocoa bean has been exported on the international market and serves as an important source of foreign exchange for the country. Over the past 20 years, there had been an increasing demand for Indonesian cocoa in the international market. The 2023 FAO data reported that the export value of Indonesian cocoa beans amounted to US$ 10.49 billion in 2021, indicating an increase of 373% compared to that in 2000 with a value of US$ 2.2 billion. Cocoa is an essential commodity in the international market [1]. However, during the last 20 years, there has been a dwindling rate of cocoa beans export by an average of 7% per year, as opposed to the imports of Indonesian cocoa beans that have increased every year with an average import growth rate of 32% per year. Constant fall in cocoa export may pose a threat to Indonesia's cocoa trading performance. On the other hand, there has been a constantly increasing demand for cocoa in the international market, which serves as a considerable opportunity for Indonesian cocoa exports as a way to increase the country's foreign exchange.

This vast market potential certainly demands for adequate quality and quantity of cocoa production. Indonesia has witnessed a fluctuating trend in cocoa bean production with a projected rising trend at a rate of 3% per year. However, in terms of productivity, there has been a significant decline, according to FAO, in 2021 cocoa productivity was recorded at 0.49 tons/ha, while in 1998 it was 1.13 tons/ha. The declining cocoa productivity can be attributed to several factors, one of which is the impact of climate change.

Climate change has led to significant impact on agricultural commodities in the world, such as rice in Indonesia where temperatures and climate anomaly such as El Nino and La Nina affect rice production [2]. On the other hand, climatic factors (temperature and rainfall) also affect maize yield in Ethiopia [3]. Furthermore, climatic factors such as temperature and rainfall affected cocoa production in the short run, as well as the long run [4]. Therefore, it is not surprising if it also affects cocoa production in Indonesia. The phenomenon of climate change has brought about extensive impact, particularly depending on its location [5]. Studies on the influence of climate, especially rainfall and temperature on cocoa production have been widely studied in many countries such as Brazil, West Africa, Malaysia and Nigeria [6]; [7]; [8]; [9], but similar studies rarely found on Indonesia. Cocoa production throughout the year is affected by temperature and rainfall intensity during the main rainy season and minor dry season [10]. Excessive rainfall can reduce cocoa yields, while temperature rise and relative humidity enhance several physiological processes for pod production in cocoa [11]. Rainfall and temperature are important elements to explain variations in cocoa production.

The effect of climate variability on cocoa production have also been widely studied in various regions in Indonesia. In Pacitan, higher rainfall and relative humidity resulted in lower cocoa productivity [12]. In Jember, high monthly rainfall and temperatures two, three, and four months before harvest were detrimental. Meanwhile, high monthly cocoa production coincided with lower temperatures and rainfall for four to five months during the development of cocoa pod [13]. Rainfall plays an important role in determining the quality of cocoa pods [14]. In Sulawesi, it was revealed that average rainfall had a positive effect on cocoa growth [15], while reduced rainfall and increased temperature lead to prolonged periods of drought, thus resulting to a reduction in soil moisture during the dry season and a decrease in soil fertility [16]. Prolonged drought has a negative impact on decreasing cocoa yields [17]; [9]. The original habitat for cocoa plants is a wet tropical forest that grows under the shade of tall trees, high rainfall, relatively constant temperatures throughout the year and high humidity [15]. Cocoa plants are very vulnerable to changes in temperature as affected by climate change, particularly due to rainfall, which leads to noteworthy impact on cocoa productivity [18].

There have not been many studies on the influence of climate change in the macro region of Indonesia, since several studies generally focused on certain areas. Therefore, this research seeks to present a comprehensive empirical study on the influence of climate on cocoa productivity in Indonesia with climate variables of minimum temperature, mean temperature, maximum temperature and rainfall. This research is expected to explain the impact of climate change in Indonesia at the macro level to see whether it affects agricultural productivity, especially cocoa commodities. The results of the study can serve as considerations for policy makers and farmers to make climate adaptation measures for sustainable cocoa production in Indonesia.

2. LITERATURE REVIEW

2.1 *Agricultural Production Economics*

Production can be defined as an action where inputs are turned into outputs, inputs are also called factors of production, it includes anything that a firm must use as a part of the production process. Inputs can be divided into broad categories of labour, materials, and capital [19]. The relationship between input combinations in a production process that produces output can be shown by a production function, where this function describes the quantity of output that can be produced from each particular input combination [20].

Meanwhile agricultural production economics is concerned primarily with economic theory as it relates to the producer of agricultural commodities. Goals and objectives of the farm manager, choice of outputs to be produced, allocation of resources among outputs, and assumption of risk and uncertainty are some major concerns in agricultural production economics. Production economic models in general cannot be simply applied to the agricultural sector, because agricultural objects face many risks and uncertainties, the assumption of knowledge with respect to the production function is almost never met. Weather is one of the key variables, but nature often presents other challenges [21].

2.2 Climate Change

Climate change is a process where temperature, rainfall, wind and other elements vary over decades or more, it is caused by increasing greenhouse gas emissions from human activities that trapped the sun's heat resulting in rising temperatures [22]. It is reported that human activities have caused global warming from unsustainable energy use, land use and land-use change where global surface temperature reaching 1.1°C above 1850-1900 in 2011-2020 [23].

Crop failure and a fall in agricultural productivity were brought on by the effects of climate change. Rainfall patterns, extreme weather events (droughts and floods), and rising air temperatures are the key components of climate change that have an impact on the agriculture sector [24]. Besides, change in climate will affect several things such as groundwater recharge, water cycle, and soil moisture. It also increases the incidence of pest and diseases that causes loss in crop production [25].

3. METHODS

This study used time series data of national cocoa bean productivity data for 61 years, from 1961 to 2021. This secondary data was obtained from FAOSTAT. In addition, it used four climate variables: maximum temperature, minimum temperature, mean temperature, and Indonesian rainfall/precipitation in the same time period taken from the Climate Knowledge Portal, World Bank.

Stationarity is an essential concept in research applying time series data, and thus it is important to achieve it in this research. Non-stationary data will have varying means, or different variances, or both [26], [27], [28]. The stationarity test was carried out using the Augmented Dickey Fuller Test, which indicated that all the variables used in this study were stationary at levels. The results of the analysis are presented in the following table:

Table 1. Augmented Dickey Fuller Test

Variable	Stage	ADF Statistic	Prob.	Information
Yield	1st difference	10.148	0.000	Stationary
Max Temp	1st difference	7.577	0.000	Stationary
Min Temp	1st difference	8.623	0.000	Stationary
Mean Temp	1st difference	7.622	0.000	Stationary
Precipitation	1st difference	6.998	0.000	Stationary

Source: Secondary Data Analysis, 2023

After stationary data were collected, an analysis was carried out on climate factors that affect cocoa productivity in Indonesia. This study used non-linear regression model, using a quadratic function or what is referred to as second-degree-polynomial on variable X, based on the following equation [26]:

$$Y = \beta_0 + \beta_1 X_i + \beta_2 X_i^2 + u_i \quad (1)$$

Where Y is the dependent variable, X is the independent variable, while β_0 indicates a constant value and β_1 and β_2 as variable coefficients with u_i describing the error term.
Non-linear regression was chosen because this analysis can be used to determine the optimum point for each climatic factor that influences cocoa productivity. By knowing this value, various efforts to prevent, anticipate and mitigate the declines due to certain climatic conditions can be planned and implemented.

The quadratic model has only one independent variable, but can appear in several different powers, which is included in multiple linear regression. This model was analyzed using the usual OLS method and did not violate the assumption of collinearity [26]. Therefore, this study used OLS regression analytical model with 4 equation models so that we are able to see the optimum point of each climatic factors, the models are as follows:

$$Y_t = \alpha_0 + \alpha_1 max_t + \alpha_2 max_t^2 + \varepsilon \quad (2)$$
$$Y_t = \alpha_0 + \alpha_1 min_t + \alpha_2 min_t^2 + \varepsilon \quad (3)$$
$$Y_t = \alpha_0 + \alpha_1 mean_t + \alpha_2 mean_t^2 + \varepsilon \quad (4)$$
$$Y_t = \alpha_0 + \alpha_1 pre_t + \alpha_2 pre_t^2 + \varepsilon \quad (5)$$

Description:

Yt	= Indonesian cocoa productivity in year t (kg/ha)
α_0	= constant
α_1-α_2	= variable coefficient
Max_t	= Maximum temperature in year t
Min_t	= minimum temperature in year t
$Mean_t$	= mean temperature in year t
Pre_t	= rainfall in year t
ε	= error term

The regression analysis obtained the inflection point that serves as a representation of the optimal point based on the following formula:

$$\text{Optimum point} = \frac{\alpha_1}{2\alpha_2} \quad (6)$$

The inflection point represents the point where the growth of the curve begins to decrease (from concave up to concave down), or increase (from concave down to concave up) (Solomentsev, 2001 cit [29]).

4. RESULTS AND DISCUSSION

4.1 The Trend of Cocoa Productivity and Climatic Factors in Indonesia, 1961-2021

This study addressed the effect of maximum temperature, mean temperature, minimum temperature and rainfall on cocoa productivity. Table 2 represents a statistical summary of each variable. The trend of cocoa productivity, maximum temperature, mean temperature, minimum temperature and rainfall is explained in more detail in Figure 1, Figure 2, and Figure 3.

Table 2. Summary Statistics

Variable	Obs	Mean	Std. dev.	Min	Max
Yield (kg/ha)	61	534.47	266.75	121.60	1132.30
Max Temp	61	30.38	0.22	29.93	30.80
Mean Temp	61	25.75	0.26	25.26	26.23
Min Temp	61	21.16	0.32	20.47	21.79
Precipitation	61	2763.92	223.45	2248.20	3289.37

Source: Secondary Data Analysis (2023)

The trend of Indonesian cocoa productivity for 61 years tends to fluctuate with a standard deviation reaching 266.75 kg/ha (figure 1). In 2021, cocoa productivity amounted to 486.2 kg/ha, thus indicating an increase of 215% compared to 60 years ago (1961), which was only 154.1 kg/ha. In 1998, cocoa productivity reached its highest point after 61 years with a productivity of 1132.30 kg/ha. In 2021, cocoa productivity was not as high as in the previous year due to the old age of the cocoa plants. Research by [30], demonstrated that cocoa of less than fifteen years of productive age has better productivity as compared to cocoa that has entered an unproductive age of more than fifteen years. The average productive age of cocoa is 744.20 kg/ha, while the average productivity of unproductive cocoa is 588.41 kg/ha. Production can also be achieved by increasing harvest effectiveness by adjusting the position of the fruit, for example by maintaining tree height to match the age and height limitations of harvesters [31]. Cocoa productivity potential can reach 2,000 kg/ha, but cocoa farming has yet to reach this level of productivity due to pest attacks, low plant maintenance, low farmer access to capital [32], and due to tree aging, and emergence of pests and diseases [33]. Counseling and training for farmers as well as support for women farming groups and credit programs are also important for cocoa farmers [34] to make farming more efficient as a way to produce optimal output. In addition, farmers also need to implement Good Agricultural Practice (GAP) and Best Agricultural Practice (BAP).

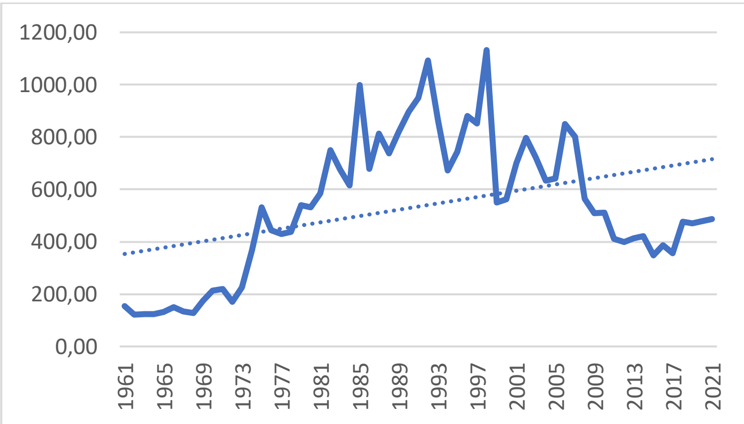

Figure 1. The Trend of Indonesian Cacao Productivity, 1961-2021

Source: Secondary Data Analysis (2023)

In addition to the aforementioned impacts, Climatic Factors also affect cocoa productivity. In this sense, [35], held that cocoa is vulnerable to climatic conditions as indicated by a decrease in cocoa's adjustment for climate change. Areas with high rainfall and areas with dry conditions can affect cocoa productivity through the emergence of pests and diseases. Regular pruning of cocoa and shade trees is necessary to increase aeration and prevent attack from insects and black pod disease in areas with high rainfall. Improvement of shade tree components in dry areas is necessary for insect pest control in cocoa systems.

Climate change occurs as a result of global warming, particularly due to an increase in the mean temperature above the earth's surface. As reported, the average air temperature of the earth's surface has increased by around 0.74°C in the last 100 years[36]. In Indonesia, the mean temperature rise has also occurred over the past 61 years (figure 2). The same notion is also applicable with the minimum temperature and maximum temperature, which continues to increase (figure 3).

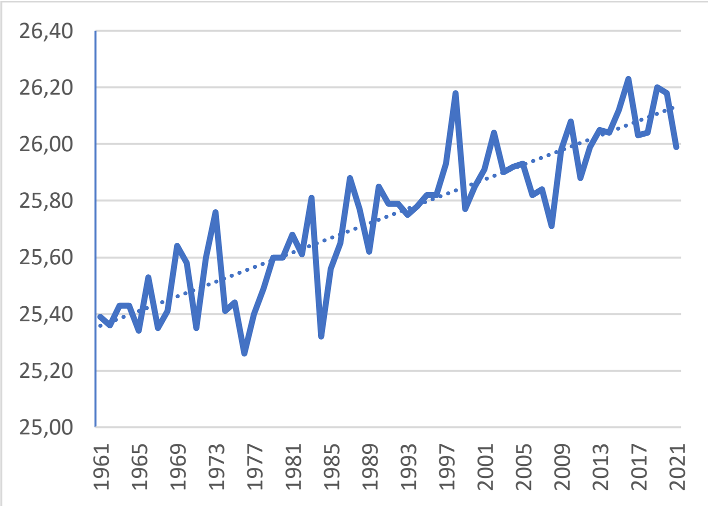

Figure 2. The Trend of Mean Temperature in Indonesia, 1961-2021

Source: Secondary Data Analysis (2023)

During the span of 61 years, Indonesia's mean temperature has seen a fluctuation with an overall increasing trend. In 2021, Indonesia's mean temperature accounted for 25.99°C, thereby revealing a growth of 2.48% compared to 1961 with temperatures ranging from 25.39°C. The highest mean temperature was seen in 2016 (26.23°C) and the lowest mean temperature occurred in 1976 (25.26°C) with a temperature difference of 0.97°C. Climate change has also caused Indonesia's minimum temperature for 1961-2021 to fluctuate with a projected increasing trend from year to year. In 2021, Indonesia's minimum temperature accounted for 21.44°C, resulting in an increase of 3.38% compared to 1961 with temperatures ranging from 20.74°C. This demonstrates that the temperature in Indonesia is getting hotter. The highest mean temperature was seen in 2016 (21.79°C) and the lowest was witnessed in 1976 (20.47°C) with a temperature difference of 1.32°C, thereby indicating a considerable temperature difference.

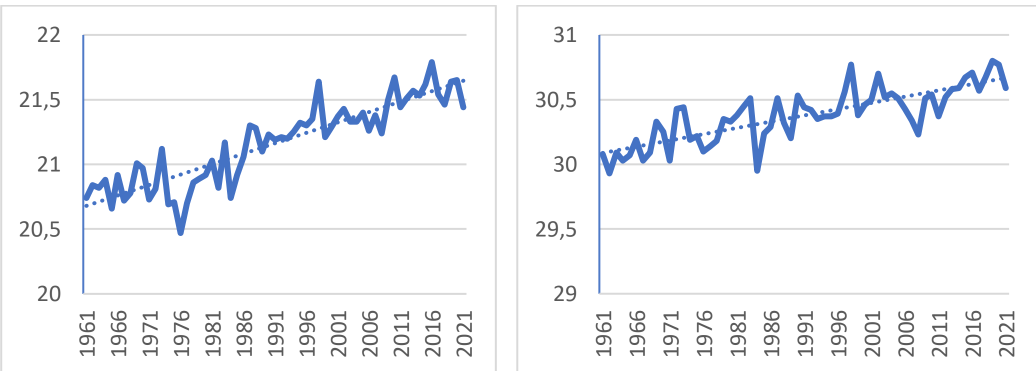

Figure 3. The Trend of Minimum (left) and Maximum (right) Temperature in Indonesia, 1961-2021

Source: Secondary Data Analysis (2023)

Changes in Indonesia's minimum temperature is also entailed by changes in maximum temperature. For 61 years, Indonesia's maximum temperature has also fluctuated with an increasing temperature trend. In 2021, Indonesia's minimum temperature amounted to 30.59°C, thereby indicating an increase of 1.69% compared to 1961, with temperatures ranging from 30.08°C. However, the maximum temperature increase is not as significant as the minimum temperature increase. This fact highlights that the climate in Indonesia is getting warmer with the highest maximum temperature seen in 2019 (30.80°C) and the lowest mean temperature in 1984 (29.95°C) with a temperature difference of 0.85°C.

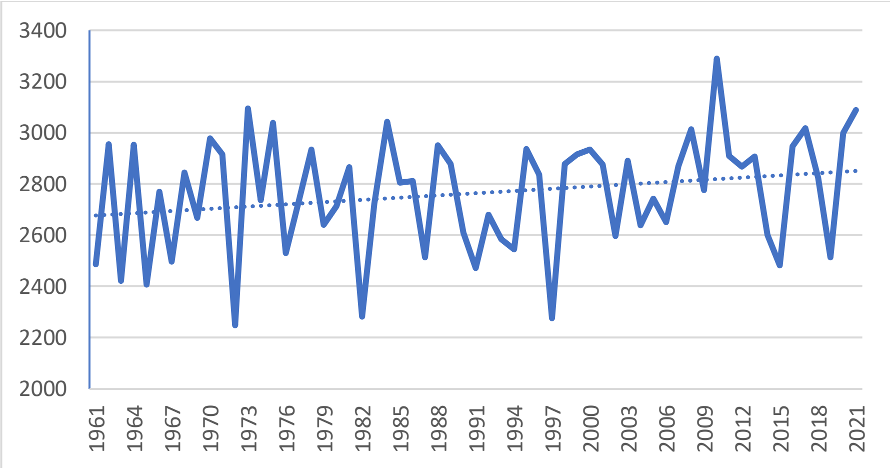

Figure 4. The Trend of Rainfall in Indonesia, 1961-2021
Source: Secondary Data Analysis (2023)

Temperature changes in Indonesia are resulted from climate change due to escalating greenhouse gases, which are dominantly caused by industries. The extensive impact of greenhouse effect will accelerate the process of global warming [37]. An increase in global temperatures will certainly lead to other changes, such as rising sea levels, an increased intensity of extreme weather, and the changing amount and pattern of rainfall [38]. There has been a fluctuating rainfall intensity in Indonesia with an increasing tendency and an average rainfall of 2763.92 mm per year with the highest rainfall seen in 2019 of 3289.37 mm and the lowest rainfall in 1972 of 2248.2 mm (figure 4).

According to [39], climate change results in several impacts, namely: (a) an increase in air temperature that occurs in all regions of Indonesia, at a lower rate than subtropical regions; (b) a decreasing rainfall in the southern part of Indonesia, but an increasing rainfall in the northern part, which leads to changes in rain patterns. The southern part of Indonesia will experience a shorter rainy season thereby reducing the cropping index (IP) and leading to a high rate of flood in the rainy season, and decreased rainfall during the dry season that increases the risk of drought. In contrast, in northern Indonesia, increased rainfall during the rainy season will increase the chances of planting index, but the land conditions are not as good as in Java. The trend of climate change will certainly have an impact on the agricultural sector which is very dependent on the season, one of which is the cocoa farming business.

4.2 Effect of Climatic Factors on Cocoa Productivity

Cocoa productivity is affected by many factors, and this research examined the impact of Climatic Factors on cocoa productivity. These factors cover the maximum temperature, minimum temperature, mean temperature and rainfall. The results of the stationarity found that all variables were stationary at the 1st difference level. Quadratic regression results for the maximum temperature variable are presented in table 3.

Table 3 illustrates the results of quadratic regression highlighting the effect of maximum temperature on cocoa productivity. Based on the F test, the maximum temperature and maximum temperature squared simultaneously affect cocoa productivity. Partially, the maximum temperature and squared maximum temperature have a significant effect on alpha 10%. The maximum temperature coefficient is 29,367.17, which indicates that an increase in maximum temperature of 1°C will reduce cocoa productivity by 29,367 kilograms per hectare. This is in accordance with research conducted by [40] articulating that decreasing temperature has an impact on increasing productivity. On the other hand, Najihah et al. (2018) conducted a study where cocoa growth experienced a negative impact when it was in conditions of a high maximum temperature followed by a low minimum temperature. The regression analysis concludes that the increase of maximum temperature will reduce cocoa productivity up to a certain point, in this case 30.5°C.

Table 3. Quadratic Regression Results of Maximum Temperature Variables

Variable	Coefficient	Std. Error	t-Statistic	Prob
Inflection Point	30.5326***	0.0816	374.3200	0.0000
C	2.8038	16.3204	0.1718	0.8642
D(MAXT)	-29367.1700*	16627.8000	-1.7661	0.0827
D(MAXTSQ)	489.3438*	274.0316	1.7857	0.0795
Adjusted R^2		0.171562		
F-statistic		7.109183***		
Prob. (F-statistic)		0.001752		

Source: Secondary Data Analysis (2023)

Description: *significant at 10% alpha ***significant at 1% alpha

The optimum point in the minimum temperature quadratic regression model demonstrates significant results at 1% alpha, thereby highlighting that the relationship between minimum temperature and productivity has a quadratic form. Based on the results of the regression analysis, an increase of 1°C in the minimum temperature will reduce cocoa productivity by 12,505 kilograms per hectare until it reaches an optimum temperature of 21.3°C. Research conducted by [41] pronounced that an extreme increase in temperature followed by a decrease in rainfall will greatly affect cocoa productivity.

Table 4. Quadratic Regression Results of Minimum Temperature Variables

Variable	Coefficient	Std, Error	t-Statistic	Prob
Inflection Point	21.3081***	0.0745	286.1900	0.0000
C	3.4956	17.1397	0.2039	0.8391
D(MINT)	-12505.8000*	6518.4270	-1.9185	0.0601
D(MINTSQ)	300.6308*	154.3642	1.9475	0.0564
Adjusted R^2		0.087792		
F-statistic		3.839113**		
Prob. (F-statistic)		0.027279		

Source: Secondary Data Analysis (2023)

Description: *significant at 10% alpha ***significant at 1% alpha

Table 5 presents the quadratic regression for the mean temperature, where it also serves as a quadratic model with an optimum point of 25.9°C. Based on the F test, the mean temperature and its squared value simultaneously affect cocoa productivity. Partially, the two variables also affect cocoa productivity, with negative and positive coefficient values, respectively. The results of the regression analysis insinuates that an increase in the mean temperature will lead to a decrease in cocoa productivity, where an increase in the mean temperature of 1°C will reduce cocoa productivity by 20,798 kilograms per hectare.

As is revealed, climate change, including the escalating mean temperature due to human-caused greenhouse gas emissions, also contributes to drought. In addition, higher air temperatures not only encourage drought, but also intensify the circumstance, as indicated by severe drought in an area where there should only be mild or moderate drought, due to enhanced evaporation [42]. In relation to cocoa productivity, extreme drought caused an even greater reduction in cocoa productivity up to 89%. A study conducted by Mensah et al. [43] stated that heat caused damages that resulting in lower rate of maximal photosynthesis, lower the concentrations of chlorophyll and changed pigment composition, reduced specific leaf areas, and plant biomass. Furthermore, the use of shade might be one of the mitigating measures to minimize the negative impact of the elevating temperatures, whether it's maximum temperature, mean temperature or minimum temperature. Shade does benefit cocoa seedlings, but the positive effect is not enough to counteract the negative effects of increased temperatures [43]. Nevertheless, the use of shade still helps minimize the negative impact of rising temperatures.

Table 5. Quadratic Regression of Mean temperature

Variable	Coefficient	Std, Error	t-Statistic	Prob
Inflection Point	25.8685***	0.0534	484.0400	0.0000
C	2.813075	16.64293	0.169025	0.8664
D(MEANT)	-20798.63*	11416.25	-1.821844	0.0737
D(MEANTSQ)	410.0978*	221.9479	1.847721	0.0698
Adjusted R^2		0.139611		
F-statistic		5.786836***		
Prob. (F-statistic)		0.005152		

Source: Secondary Data Analysis (2023)

Description: *significant at 10% alpha ***significant at 1% alpha ^ns^non significant

The regression results for the rainfall variable highlights a quadratic model as indicated by the significant inflection point of variable at 1% alpha. Based on the F test, the two variables together have no significant effect on cocoa productivity in Indonesia. Partially, the rainfall variable and the squared value of rainfall have no significant effect on cocoa productivity. Meanwhile, this model leads to an impact on an increasing value at decreasing rate, where an increase in rainfall will increase cocoa productivity until it reaches the optimum point of 2,684 mm. The decrease in the amount of rainfall due to climate change can result in a reduction in the amount of available water that can be utilized by plants [44]

Table 6. Quadratic Regression of Rainfall Variable

Variable	Coefficient	Std, Error	t-Statistic	Prob
Inflection Point	2684.9640***	112.1087	23.9500	0.0000
C	5.9379	18.0846	0.3283	0.7439
D(PRE)	1.0253ns	1.1032	0.9294	0.3566
D(PRESQ)	-0.0002ns	0.0002	-0.9397	0.3513
Adjusted R^2		-0.018659		
F-statistic		0.459638ns		
Prob. (F-statistic)		0.633832		

Source: Secondary Data Analysis (2023)

Description: *significant at 10% alpha ***significant at 1% alpha ns non significant

Drought inhibits plant growth and plant performance. Cocoa is sensitive to water deficit pressures that limit productivity [45][46]. It is reported that the water requirement for cocoa for a monoculture planting system is around 1.2 mm/day, with Gliricidia plant protection around 2.2 mm/day, and for multispecies (agroforestry systems) around 1.1 mm/day. If there is excess water, it can cause plant productivity to be less than optimal because plants are more easily attacked by diseases which can disrupt plant growth and even cause plants to die.

CONCLUSION

There has been an increase in annual trend of cocoa productivity from year to year, and so does maximum temperature, minimum temperature, mean temperature and rainfall. Climatic factors that have a significant effect on cocoa productivity are maximum temperature, minimum temperature, and mean temperature, while rainfall has no significant effect. All models tested resulted in a quadratic shape with an optimum point of 30.53°C; 21.31°C and 25.87°C respectively for maximum temperature, minimum temperature and mean temperature while rainfall has an optimum point of 2.684, 96 mm. The effect of temperature on cocoa productivity is significant, but it doesn't affect much because annual temperature increase does not reach 1°C, and thus there's only a small decline in national cocoa productivity. However, since such a prolonged condition will threaten national cocoa productivity in the future, it is thus necessary to make preventive efforts in dealing with climate change, especially temperature at all levels ranging from maximum, minimum and mean temperature.

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