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Relationship between climate change adaption strategy and cocoa farming productivity in Trenggalek

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Abstract. Climate change, characterized by extreme La Niña and El Niño events, led to a drastic 52% decline in cocoa production in Suruh Village, Trenggalek, in 2022. This study aims to identify farmer adaptation strategies, measure farm productivity, and analyze the relationship between them. Employing descriptive, productivity, and Pearson correlation analyses on a sample of 111 farmers, the study found that although seven adaptation strategies exist, such as constructing *rorak* and using botanical pesticides, their adoption rate is low, averaging only 46.85%. Meanwhile, the average cocoa farm productivity is moderate, at 0.54 tons/hectare/year. Crucially, the analysis reveals a strong, positive, and significant correlation (r=0.740) between the implementation of adaptation strategies and productivity levels. This key finding underscores that increasing the adoption of adaptation techniques is an effective strategic pathway to boost cocoa productivity and strengthen farmer resilience against the impacts of climate change. Consequently, this research provides a clear directive for policymakers and agricultural extension services to design targeted interventions that bridge this adoption gap, thereby securing local livelihoods and the stability of the regional cocoa supply chain.

Keywords. Cocoa; Climate Change; Productivity; Adaptation Strategies; Farmer Resilience.

1 Introduction

Cocoa (*Theobroma cacao* L.) is one of the agricultural sectors that has a significant contribution in strengthening the Indonesian economy. Indonesia's cocoa production in 2022

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ranked third in the world after Côte d'Ivoire and Ghana. The area of Indonesian smallholder cocoa plantations reached 1,421,009 hectares in 2022 with total production reaching 665,372 tons and productivity of 0.717 tons per hectare (1). However, Indonesia's cocoa productivity is still far below the expected average of 2 tons per hectare. East Java Province is one of the centers of smallholder cocoa production in Indonesia with production reaching 21,696 tons. In 2023, the East Java Department of Communication and Information reported a plan to develop 5,025 hectares of cocoa plantation land, including in Trenggalek Regency. Based on data from the East Java Central Bureau of Statistics, Trenggalek Regency is among the ten regencies with the highest cocoa production in East Java, reaching 2,821 tons in 2022.

The potential for cocoa development in Trenggalek is supported by a mostly mountainous topography, but there are complex challenges in cocoa development. One of them is the decline in production due to climate change in several sub-districts (2). Climate change has a negative impact on agricultural commodities, including cocoa crops, such as in Suruh Subdistrict, cocoa production decreased by 52% in 2022 due to changes in rainfall. This is supported by BMKG data which states that rainfall in Suruh Sub-district has continued to increase since September 2022 with rainfall reaching 300 mm. Rainfall data from BPS Suruh District shows fluctuations in rainfall from 2018 to 2022 which shows the phenomenon of La Nina with high rainfall and El Nino with prolonged drought. Erratic weather changes due to the La Nina factor cause a high level of pest attack, many cocoa flowers fall off, and cocoa pods rot on the tree (3). Interestingly, this sharp production decline in Suruh Village occurred even as the cocoa cultivation area remained stable, averaging 80.37 hectares. This indicates that the core issue is not the land area but a severe drop in farm productivity directly linked to climate impacts. The trend detailing this decrease in both cocoa production and productivity is presented in Fig. 1.

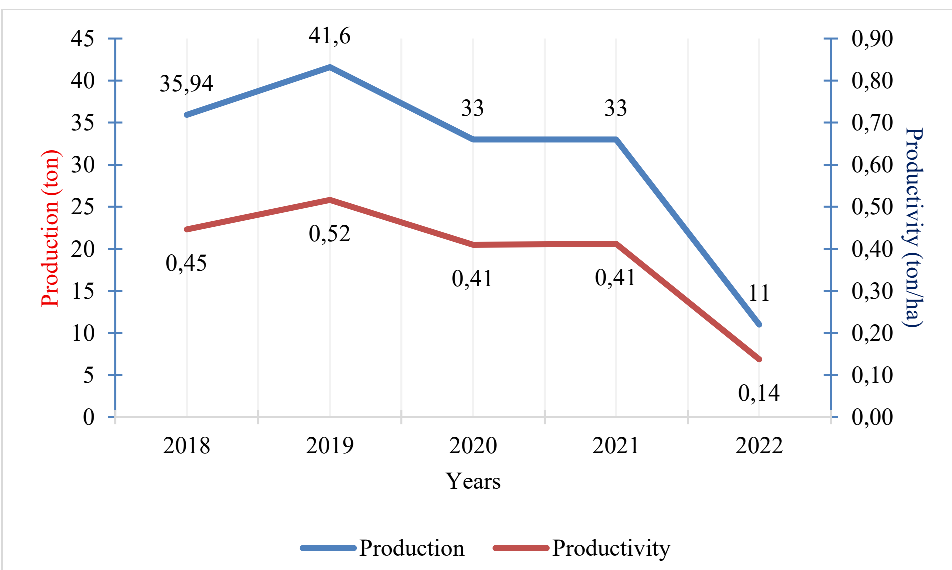

Fig. 1. Cocoa Production in Suruh Village in 2018-2022

Based on Fig. 1, cocoa production in Suruh Village is not determined by land area but is strongly influenced by crop productivity, which saw a drastic decline in 2022 due to climate change. The La Nina phenomenon increases humidity resulting in cocoa pod borer (PBK) and Helopeltis sp. infestation, while the El Nino phenomenon causes drought resulting in cocoa pod fall and crop failure. Extreme rainfall fluctuations due to the La Nina and El Nino phenomena cause disruptions in the cocoa growth cycle, ranging from pest and disease attacks to fruit and flower loss. This condition has resulted in a significant decrease in cocoa farming productivity (4). The negative impacts of climate change are a serious challenge for cocoa farmers in Suruh Village, so adaptation is needed to reduce these negative impacts and maintain cocoa farming productivity. Adaptation to climate change involves adjusting cultivation techniques to reduce damage and increase resilience to climate change which ultimately contributes to increasing the productivity of cocoa farming in Trenggalek. Based on preliminary observations, cocoa farmers in Suruh Village have adapted to climate change based on their knowledge and experience, especially through the farmer group "Tunggal Jaya". However, the implementation of adaptation by farmers is still not maximized and evenly distributed.

Recent research on climate change adaptation in the agricultural sector has largely concentrated on two main areas: the identification of available adaptation strategies and technologies, and the analysis of socio-economic determinants influencing farmers' adoption of these strategies. For example, studies in Indonesia and other tropical countries have documented a range of adaptation practices among smallholder farmers, such as crop diversification, adjustment of planting calendars, use of improved varieties, and agroforestry (5,6). In the context of cocoa farming, adaptation strategies also include the substitution of crops, biological pest management, and water and soil conservation techniques. Despite these valuable insights, most existing literature remains descriptive or focuses on the drivers of adaptation adoption, often neglecting the quantitative relationship between the intensity of adaptation implementation and actual farm productivity, especially in vulnerable agro-ecological zones. For instance, research in Indonesia and Ghana has highlighted the widespread use of adaptation strategies among cocoa farmers, but has not directly analyzed how the level of adaptation correlates with yield outcomes. Similarly, studies in West Africa have shown that while climate change significantly threatens cocoa production, the adoption of adaptation technologies is not universal, and the direct impact of these technologies on productivity is rarely quantified (7).

Empirical evidence from Ghana and Nigeria suggests that farmers who adopt a greater number of adaptation strategies, such as agroforestry, improved varieties, and crop diversification tend to achieve higher yields and greater resilience to climate shocks (8,9). However, such quantitative analyses remain scarce in the Indonesian context, particularly for smallholder cocoa farmers facing dual climate extremes like La Niña and El Niño. For example, studies in Bali and Sulawesi have documented significant yield losses and increased tree mortality during extreme climate events, but have not systematically linked these outcomes to the intensity of adaptation measures implemented. Therefore, there is a critical research gap regarding the direct, quantitative relationship between the level of adaptation and cocoa productivity in Suruh Village. This study aims to 1) determine the adaptation strategies of cocoa farmers in facing climate change; 2) the level of productivity of cocoa farming; and 3) the relationship between climate change adaptation strategies and the level of productivity of cocoa farming in Suruh Village, Trenggalek Regency.

2 Research Methods

The research was conducted in Suruh Village, Trenggalek Regency, which was purposively selected because it is the center of cocoa production in Suruh Sub-district with the highest area of 60 hectares. However, Suruh Village will experience a 52% decrease in cocoa production by 2022 due to climate change. The research method used was descriptive analytic with primary and secondary data. Primary data were collected through observations, interviews, and questionnaires, while secondary data were obtained from BPS, the Ministry of Agriculture, BMKG, and other relevant agencies. Cocoa farmers were used as respondents, namely all members of the "Tunggal Jaya" Farmer Group, totaling 111 farmers.

Data analysis methods used to describe climate change adaptation strategies are descriptive analysis and percentage. Descriptive analysis is used to explain the forms of climate change adaptation carried out by cocoa farmers, while percentage calculation is used to determine the level of adaptation of cocoa farmers in Suruh Village, Trenggalek Regency in facing climate change. Systematically, the percentage calculation formula is as follows.

$$X = \frac{n}{N} x\ 100\% \qquad (1)$$

Description:
X = The level of adaptation of cocoa farmers in facing climate change
n = Total of forms of climate change adaptation by cocoa farmers
N = Total of forms of climate change adaptation by cocoa farmers
Decision criteria:
a. High adaptation level, if the percentage value of the adaptation level of cocoa farmers is above average.
b. Low adaptation level, if the percentage value of the adaptation level of cocoa farmers is below average.

The analysis used to calculate the productivity value of cocoa farming uses the following formula.

$$Productivity = \frac{Total\ Cocoa\ Output\ (ton)}{Land\ Area\ (ha)} \qquad (2)$$

Decision-making criteria related to the level of productivity of cocoa farming in Suruh Village, Trenggalek Regency, are using the following interval categories.
a. 0.100 – 0.441 = Low
b. 0.442 – 0.782 = Medium
c. 0.783 – 1.125 = High

The relationship between climate change adaptation strategies and cocoa farming productivity in Suruh Village, Trenggalek Regency was analyzed using Pearson product moment correlation with the following formula.

$$r_{xy} = \frac{\sum x_i y_i}{\sqrt{\sum x_i^2}\sqrt{\sum y_i^2}} \qquad (3)$$

Description:
x = Variables of climate change adaptation strategies in Suruh Village, Trenggalek Regency
y = Cocoa farm productivity variable in Suruh Village, Trenggalek Regency
Pearson product moment correlation analysis was assisted by the IBM SPSS Statistics 20 application with the following hypothesis.
$H_0 = r_{xy} = 0$; there is no significant relationship between climate change adaptation strategies and cocoa farming productivity in Suruh Village, Trenggalek Regency
$H_1 = r_{xy} \neq 0$; there is a significant relationship between climate change adaptation strategies and cocoa farming productivity in Suruh Village, Trenggalek Regency
The decision-making criteria with a level of 0.05, namely:
- If significance > 0.05 then H_0 is accepted and H_1 is rejected
- If the significance ≤ 0.05 then H_0 is rejected and H_1 is accepted
The categories of correlation coefficient values are as follows.
a. $0.00 \leq r_{xy} \leq 0.20$; very weak correlation
b. $0.20 < r_{xy} \leq 0.40$; weak correlation
c. $0.40 < r_{xy} \leq 0.60$; medium correlation

d. $0.60 < r_{xy} \leq 0.80$; strong correlation
e. $0.80 < r_{xy} \leq 1.00$; very strong correlation

3 Results and Discussion

3.1 Farmer’s Characteristic

The research was conducted in Suruh Village, Suruh Sub-district, Trenggalek Regency, an area with topographical characteristics suitable for plantation crops. The village's land use is dominated by agricultural land, primarily in the form of smallholder plantations and mixed gardens. This characteristic emphasizes the community's reliance on a rainfed agricultural system, where farmers are highly dependent on rainfall patterns for irrigation, making them vulnerable to climate variability such as La Nina and El Nino. This vulnerability is critical, as recent spatial analysis in the neighboring Bondowoso Regency confirmed that El Nino events significantly increase land surface temperature (LST) and induce vegetation stress in agricultural areas (10). Furthermore, bioclimatic modeling on similar plantation crops (coffea arabica) indicates that climatic variables, particularly precipitation seasonality and temperature, are the most decisive factors determining crop distribution and productivity outcomes (11). Farming, especially cocoa cultivation, constitutes the main livelihood for the majority of residents in Suruh Village. The leading commodity is cocoa, which is often cultivated in mixed farming systems alongside other perennial crops as a strategy to diversify income. The characteristics of the farmers who participated as respondents in this study are presented in Table 1.

Table 1. Characteristics of cocoa farmer respondents in the Trenggalek Distric.

General Characteristics	Range	Total (Farmer)	Average
Land Area (ha)	≤ 0.25	102	0.15
	> 0.25 – < 0.5	8	
	≥ 0.5	1	
Total		**111**	
Farmer Age (years)	25-44	11	58
	45-54	23	
	≥ 55	77	
Total		**111**	
Farming Experience (years)	11 – 20	16	26
	21 – 30	95	
	31 – 40	0	
Total		**111**	
Education (years)	Elementary and Junior High School	79	Elementary School
	Senior High School	19	
	Bachelor's Degree	13	
Total		**111**	
Total of Climate Change Adaptation Implemented	0 – 2	7	4
	3 – 5	78	
	≥ 6	26	
Total		**111**	

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3.2 Climate Change Adaptation Strategy

The results showed that 111 cocoa farmers in Suruh Village, Trenggalek Regency who are members of the "Tunggal Jaya" farmer group have adapted to climate change based on knowledge and experience. There are seven forms of climate change adaptation as show in Table 2.

Table 2. Forms of Adaptation of Cocoa Farmers in Suruh Village in Facing Climate Change

	Form of Adaptation	Application		Percentage Applicability (%)	
		Yes	No	Yes	No
1	Worm Palace Making	55	56	49.55	50.45
2	**Rorak Making**	**108**	**3**	**97.30**	**2.70**
3	Anthill Making	58	53	52.25	47.75
4	Spraying Botanical Pesticides	38	73	34.23	65.77
5	**Increased Use of Organic Fertilizer**	**79**	**32**	**71.17**	**28.83**
6	**Pruning Management**	**95**	**16**	**85.59**	**14.41**
7	Wrapping the Cocoa Fruits	59	52	53.15	46.85

Source: Primary data processed, 2025

Based on Table 2, it is known that there are seven forms of climate change adaptation carried out by cocoa farmers in Suruh Village, Trenggalek Regency, namely worm palace making, making rorak, making ant nests, spraying botanical pesticides, increasing the use of organic fertilizers, pruning management, and cocoa sheathization. The most common form of adaptation practiced by cocoa farmers is rorak making by 108 cocoa farmers or 97.30%, while the least practiced form of adaptation is botanical pesticides spraying by 38 cocoa farmers or 34.23%. Rorak making is the most widely used form of adaptation, because it is the easiest form of adaptation with quite a lot of benefits compared to other forms of adaptation. Praying botanical pesticides is the least used form of adaptation, because this form of adaptation is considered less effective in dealing with climate change, meaning that this form of adaptation does not provide enough benefits to reduce the negative impacts of climate change. A description of each form of adaptation practiced by cocoa farmers in Suruh Village is as follows.

3.2.1 Worm Palace Making

Fig. 2. Appearance of Worm Palace

Research shows that 67.5% of cocoa farmers in Suruh Village, Trenggalek Regency make worm palace while 32.5% do not. Worm palace making are holes next to cocoa trees to place organic matter and serve as drainage. It helps cope with drought (El Nino) by storing water

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reserves, thus reducing water demand. This adaptation is effective because it reduces water evaporation and ensures the roots of the cacao plant remain hydrated, improving nutrient uptake. Worm activity creates soil pores that make it easier for plant roots to reach deeper for water and nutrients, strengthening drought resistance (12).

3.2.2 Rorak Making

Fig. 3. Rorak apperance

A total of 92.5% of cocoa farmers in Suruh Village made rorak, while 7.5% did not. Rorak is a hole next to the cocoa plant to place organic fertilizer and function as drainage. Roraks help collect water during droughts and accelerate the shrinkage of rainwater that pools during the rainy season (La Nina). This adaptation is effective because it helps cacao plants survive drought and high rainfall conditions, and increases nutrient absorption from cacao plant waste placed inside the rorak.

3.2.3 Anthill Making

Fig. 4. Appearance of the Anthill

57.5% of cocoa farmers in Suruh Village make ant nests, while 42.5% do not. Ant nests are folds of dried coconut leaves to increase the population of black ants (*Dolichoderus thoracicus*), a natural predator of PBK pests, and fruit-sucking lady bugs. This adaptation is effective in controlling pests biologically, low cost, sustainable, and environmentally friendly. Black ants can control pest populations more efficiently, keeping cocoa production stable.

3.2.4 Spraying Botanical Pesticides

Fig. 5. Appearance of Botanical Pesticides

Research shows that 77.5% of cocoa farmers in Suruh Village use otanical pesticides, while 22.5% do not. Botanical pesticides contain active ingredients that repel, kill, and inhibit the development of PBK and fruit-sucking ladybugs. Some of the ingredients used include galangal, neem leaves, betel leaves, clove leaves, and lemongrass. Spraying is done regularly, once a week or depending on the intensity of pest infestation, and has been shown to significantly reduce the percentage of PBK and fruit-sucking ladybird infestation (13).

3.2.5 Increased Use of Organic Fertilizer

35% of cocoa farmers in Suruh Village increased their use of organic fertilizer, while 65% did not. Organic fertilizers improve soil fertility, nutrients, and cocoa plant resistance to PBK and fruit- sucking ladybugs, which increase during high rainfall. Increased use of organic fertilizers also reduces the use of chemical fertilizers, reducing chemical residues or GHGs. Farmers are increasing the dose and frequency of fertilization, with current doses reaching 2-3 kg per tree more than twice a year.

3.2.6 Pruning Management

As many as 90% of cocoa farmers in Suruh Village conduct pruning management, while 10% do not. Pruning is done in the rainy season to increase light intensity and air circulation, stimulate flower formation, and accelerate pollination. During the long dry season, shade trees are left overgrown to protect the cocoa from drought. Shade crop pruning also reduces high humidity that triggers PBK pests and diseases (14).

3.2.7 Wrapping the Cocoa Fruit

Fig. 6. Appearance Cocoa Fruit Wrap

Total of 62.5% of cocoa farmers in Suruh Village shaded their cocoa pods, while 37.5% did not. Shading fruit using plastic prevents PBK from laying eggs and fruit -sucking ladybugs from attacking cocoa. This adaptation effectively protects cocoa pods from pest attacks that increase during high rainfall.

Based on the calculation results, the average percentage of climate change adaptation level of cocoa farmers in Suruh Village, Trenggalek Regency is 63%. The category of adaptation level of cocoa farmers in facing climate change can be seen in Table 3.

Table 3. Adaptation Level of Cocoa Farmers in Suruh Village in Facing Climate Change

No	Description	Total of Farmers	Percentage
1	High adaptation level	52	46.85%
2	Low adaptation level	59	53.15%
Total of Respondents		111	**100.00%**

Source: Primary data processed, 2025

Based on Table 3, it is known that the majority of cocoa farmers in Suruh Village, Trenggalek Regency, have a low level of adaptation, accounting for 53.15% or 59 people. Meanwhile, the remaining 46.85% or 52 people have a high level of adaptation. This result leads to the conclusion that the overall adaptation level of cocoa farmers in Suruh Village in facing climate change is still categorized as low, as more than half of the respondents have not yet implemented a sufficient number of adaptation strategies. This finding suggests that although farmers may have a basic awareness of climate change, as observed in the field, this awareness has not yet fully translated into concrete and comprehensive adaptation actions to mitigate the negative impacts of climate change.

3.3 Cocoa Farm Productivity

The productivity analyzed in this study is the cocoa yield during 2025, including monthly harvests conducted by respondent farmers. The productivity level of cocoa farming in Suruh Village, Trenggalek Regency can be seen in Table 4.

Table 4. Productivity Level of Cocoa Farming

No.	Productivity Level (ton/ha/year)	Category	Total of Farmers (person)	Percentage (%)
1	0.100 - 0.441	Low	46	41.44
2	0.442 - 0.782	Medium	44	39.64
3	0.783 - 1.125	High	21	18.92
Total			111	100.00
Average = 0.54 ton/ha/year				

Source: Primary data processed, 2025

Table 4 shows the productivity level of cocoa farming divided into three categories: low, medium, and high. Based on cocoa production per hectare per year, the total of cocoa farmers in Suruh Village, Trenggalek Regency with low productivity (0.100 – 0.441) is 46 people (41.44%), medium productivity (0.442 – 0.782) is 44 people (39.64%), and high productivity (0.783 – 1.125) is 21 people (18.92%). The average productivity of cocoa farming in Suruh Village is 0.54 tons/hectare/year which is included in the medium category.

This moderate level of productivity is due to the fact that many cocoa farmers are members of farmer groups, one of which is the "Tunggal Jaya" farmer group. This group aims to mobilize farmers to run sustainable cocoa farms and adhere to the correct cocoa cultivation methods. However, not all farmers are active in group activities, so the benefits of farmer groups are not optimally applied in cocoa farming practices. In addition, the 28-29 year old cocoa plants in Suruh Village also contribute to the decline in productivity. This study is in line with the finding that cocoa less than 15 years old has higher productivity than cocoa that has entered the unproductive age of more than 15 years. The average productivity of productive age cocoa is 744.20 kg/ha, while unproductive age is 588.41 kg/ha (15).

3.4 Relationship of Climate Change Adaptation Strategies with Cocoa Farm Productivity

The implementation of climate change adaptation strategies is expected to help farmers mitigate risks and subsequently maintain or enhance the productivity of their farms. To analyze the direct impact of these actions, this study examines the relationship between the level of adaptation implemented by cocoa farmers and the resulting farm productivity. A cross-tabulation analysis was conducted to categorize farmers based on their adaptation level (high or low) and their productivity level (low, medium, or high). The detailed distribution of farmers across these categories is presented in Table 5.

Table 5. Cross-Tabulation of Adaptation Level and Cocoa Farm Productivity

Adaptation Level	Productivity (ton/ha)		
	Low	Medium	High
High Adaptation Level	17 (15.32%)	21 (18.92%)	14 (12.61%)
Low Adaptation Level	29 (26.13%)	23 (20.72%)	7 (6.31%)
Average Adaptation Level: 63% (equivalent to 4 forms of adaptation)			
Average Productivity: 0.54 (ton/ha)			

Source: Primary data processed, 2025

The correlation between climate change adaptation strategies and cocoa farming productivity in Suruh Village, Trenggalek Regency was analyzed using Pearson product moment correlation. The analysis results obtained with the help of IBM SPSS Statistics 20 application can be seen in Table 6.

Table 6. Correlation Analysis of Climate Change Adaptation Strategies with Cocoa Farm Productivity

		Productivity
Correlation between Adaptation Level and Productivity	Pearson Correlation	0.740**
	Sig. (2-tailed)	0.000
	N	111

Notes: **) Significant at α = 0,01 level (2-tailed)
Source: Primary data processed, 2025

The relationship between climate change adaptation strategies implemented by cocoa farmers and cocoa farming productivity in Suruh Village, Trenggalek Regency, is 0.740 which means it has a strong correlation. This positive correlation value indicates that the more forms of climate change adaptation applied by farmers, the higher cocoa farm productivity will be, and vice versa. Sig. (2-tailed) of 0.000 is smaller than the significance level of 0.05 ($0.000 < 0.05$), so H_0 is rejected and H_1 is accepted. This shows that there is a significant relationship at the 0.01 significance level between climate change adaptation strategies and cocoa farming productivity in Suruh Village, Trenggalek Regency. This study supports the results of previous research which states that cocoa farmers who adopt climate change adaptation technologies record significantly higher farm productivity and income compared to farmers who do not adopt such technologies (7).

The results show that cocoa farmers who adopted climate change adaptation techniques, such as worm palace making, rorak making, anthill making, botanical pesticides spraying, increased use of organic fertilizers, pruning management, and cocoa scabbarding to increase resilience to extreme weather, were able to significantly increase cocoa productivity. These adaptations not only helped in mitigating the negative impacts of extreme temperatures and erratic rainfall, but also improved soil health and fertility which ultimately contributed to higher cocoa productivity. This strong relation between adaptation strategies and productivity confirms the importance of a proactive approach to climate change challenges for the sustainability of cocoa farming.

4 Conclusions and Recommendation

There are seven climate change adaptation strategies implemented by cocoa farmers in Suruh Village, Trenggalek Regency, namely worm castings, rorak, ant nests, spraying plant-based pesticides, increasing the use of organic fertilizers, pruning management, and cocoa sarungisasi. The three most popular forms of adaptation among cocoa farmers are rorak making, pruning management, and increased use of organic fertilizer. The level of adaptation of cocoa farmers in Suruh Village in facing climate change is considered high, with an average adaptation rate of 63% or equivalent to 4 adaptation options. The average productivity of cocoa farming in Suruh Village is 0.54 tons/hectare/year, which is classified as moderate. The results of the analysis show that there is a correlation between the level of adaptation to climate change and the level of cocoa farm productivity in Suruh Village, with a correlation coefficient of 0.740, which indicates a strong correlation.

Climate change has a significant impact on cocoa farming in (name of region). Therefore, farmers need to have the right strategies to respond to and anticipate these impacts. Currently, the average form of adaptation of horticultural farmers to climate change reaches around 63%, or equivalent to 4-5 types of adaptation measures. However, these adaptation efforts still need to be improved to be more diverse and tailored to the actual conditions of climate change in the field. Properly implemented adaptation has been proven to significantly increase cocoa productivity. To expand the range of adaptation options, it is necessary to enhance farmers' knowledge and skills in applying various adaptation strategies, which sometimes require technical expertise or specialized understanding.

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Author contribution: Yuli Hariyati (conceptualized the research framework, supervised the overall study, and revised the final manuscript), Vina Yunita Ria (contributed to data analysis, interpretation, and preparation of the discussion section), Wafik Aziza Nur Aini (was responsible for field coordination and data collection), Indah Ibanah (managed data validation and visualization for descriptive analysis), Rena Yunita Rahman (participated in literature review and preparation of the results section), Setiyono (provided methodological guidance and critical revision of the manuscript), Didik Suharijadi (assisted in data interpretation, refinement of the theoretical framework, and final proofreading of the article).
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