**West Science Agro**
Vol. 4, No. 02, May 2026, pp. 165~178

# Enhancing Climate-Resilient Farming in Indonesia: The Roles of Crop Diversification, Agroforestry Adoption, Environmental Literacy, and Farmer Cooperative Participation

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**Article Info**

***Article history:***

Received May, 2026
Revised May, 2026
Accepted May, 2026

***Keywords:***

Climate-Resilient Agriculture
Crop Diversification
Agroforestry Implementation
Environmental Literacy
Farmer Cooperative Participation

**ABSTRACT**

This study examines the role of crop diversification, agroforestry implementation, environmental literacy, and farmer cooperative participation in promoting climate-resilient agriculture in Indonesia. Climate change has increasingly affected agricultural productivity, environmental sustainability, and farmer livelihoods through droughts, floods, irregular rainfall patterns, and land degradation. A quantitative research approach was employed using a survey of 250 farmers from several agricultural regions in Indonesia. Data were collected using structured questionnaires with a five-point Likert scale and analyzed using Structural Equation Modeling–Partial Least Squares (SEM-PLS 4). The findings indicate that crop diversification positively and significantly influences climate-resilient agriculture Agroforestry implementation was found to have the strongest influence. Environmental literacy also demonstrated a significant positive effect, while farmer cooperative participation significantly affected climate-resilient agriculture. The model showed strong explanatory power with an R-square value of 0.742, indicating that the independent variables explained 74.2% of the variance in climate-resilient agriculture. The results highlight the importance of integrating sustainable farming practices, environmental awareness, and institutional collaboration to strengthen agricultural resilience and sustainability in Indonesia.



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## 1. INTRODUCTION

Climate-resilient agriculture has become increasingly important in Indonesia due to the growing impact of climate change on agricultural productivity, food security, and rural livelihoods [1]. Indonesia's agricultural sector remains highly vulnerable to environmental disturbances such as rising temperatures, prolonged droughts, floods, soil degradation, and unpredictable rainfall patterns [2], [3]. These challenges directly affect crop yields, farmer income, and the sustainability of agricultural systems, particularly because many farming communities still rely on traditional cultivation methods and possess limited adaptive capacity. As climate variability intensifies, the development of sustainable and adaptive agricultural systems is essential to ensure long-term food production and rural economic stability.

One important strategy for strengthening climate resilience in agriculture is crop diversification. Crop diversification refers to the cultivation of various crops or agricultural commodities within the same farming system to reduce dependence on a single commodity. This approach helps farmers minimize risks associated with climate uncertainty, pest attacks, and market instability while simultaneously improving biodiversity, soil fertility, and land-use efficiency [4], [5]. Diversified agricultural systems also contribute to more stable farmer income and increased adaptive capacity under changing environmental conditions. However, many Indonesian farmers still practice monoculture farming systems, particularly in rice cultivation and plantation sectors, making agricultural production more vulnerable to extreme climate events and crop failure.

Another essential component of climate-resilient agriculture is the implementation of agroforestry systems. Agroforestry combines trees, crops, and sometimes livestock within integrated land management practices to create ecological and economic benefits simultaneously [6], [7]. The integration of trees into agricultural landscapes contributes to soil conservation, water retention, carbon sequestration, biodiversity protection, and microclimate regulation. Agroforestry systems also provide additional income sources for farmers through timber, fruits, medicinal plants, and non-timber forest products [8], [9]. In many rural regions of Indonesia, agroforestry has been recognized as a sustainable agricultural approach capable of reducing environmental degradation and strengthening ecosystem resilience. Nevertheless, its adoption remains relatively limited because some farmers perceive agroforestry as requiring greater labor, longer investment periods, and more complex management systems.

Environmental literacy also plays a significant role in supporting climate-resilient agriculture. Environmental literacy refers to the level of knowledge, awareness, attitudes, and behaviors related to environmental sustainability and conservation. Farmers with higher environmental literacy are generally more capable of understanding climate-related risks, adopting sustainable farming practices, managing natural resources efficiently, and responding effectively to environmental changes [10], [11]. In agricultural communities, environmental literacy influences important decisions regarding pesticide application, water management, soil conservation, and farming innovation. However, many Indonesian farmers still have limited access to environmental education, sustainability training, and climate information. This condition reduces their ability to adapt to climate-related challenges and slows the transition toward more sustainable agricultural systems.

In addition to individual awareness, institutional support through farmer cooperatives is considered essential for strengthening agricultural resilience. Farmer cooperatives facilitate collective action among farmers by providing access to agricultural inputs, farming technologies, financial assistance, market distribution channels, and climate adaptation information. Cooperative participation also enhances social capital and strengthens collaboration within rural communities [12]–[14]. Through collective institutions, farmers can improve their bargaining power, reduce economic vulnerability, and accelerate the adoption of sustainable agricultural innovations. Although the Indonesian government has increasingly promoted cooperatives as part of agricultural modernization and rural development programs, the effectiveness of cooperative participation remains inconsistent due to variations in organizational capacity, management quality, and farmer engagement.

Previous studies have separately examined the influence of crop diversification, agroforestry systems, environmental literacy, and cooperative participation on sustainable agriculture and climate adaptation [15]–[17]. Research findings generally indicate that diversified farming systems improve farmer resilience, agroforestry enhances ecosystem sustainability, environmental literacy encourages sustainable agricultural behavior, and cooperatives strengthen rural economic resilience. Nevertheless, limited research has comprehensively integrated these environmental, educational, and institutional factors within a single analytical framework, particularly in the Indonesian agricultural context. Therefore, this study aims to investigate the combined influence of crop diversification, agroforestry implementation, environmental literacy, and farmer cooperative participation in promoting climate-resilient agriculture in Indonesia. The findings are expected to contribute theoretically to sustainable agriculture literature and practically to the development of policies and strategies that support environmental sustainability, food security, and rural welfare.

## 2. LITERATURE REVIEW

### *2.1 Climate-Resilient Agriculture*

Climate-resilient agriculture refers to agricultural systems that are able to maintain productivity, adapt to climate variability, and minimize environmental degradation while supporting long-term sustainability. The concept emphasizes adaptive farming practices that strengthen ecological balance, improve resource efficiency, and enhance farmers' capacity to respond to climate-related risks such as droughts, floods, irregular rainfall, and declining soil quality [18], [19]. Closely associated with sustainable development and environmental management, climate-resilient agriculture integrates environmental protection, economic viability, and social sustainability through practices such as sustainable land management, biodiversity conservation, and efficient resource use [20], [21]. Based on resilience theory, agricultural resilience reflects the ability of farming systems to absorb disturbances, adapt to environmental changes, and recover from climate-related shocks without losing their core functions. Common indicators of climate-resilient agriculture include adaptive farming practices, environmental conservation behavior, productivity stability, and the ability to recover from environmental disruptions.

### *2.2 Crop Diversification*

Crop diversification refers to the practice of cultivating multiple crop varieties or combining different agricultural commodities within a farming system to reduce farming risks, improve biodiversity, and strengthen resilience against climate variability. Ecologically, crop diversification contributes to soil fertility, pest and disease control, and environmental sustainability by reducing dependence on monoculture systems that are vulnerable to environmental disturbances [5], [22], [23]. Economically, diversified farming systems help farmers stabilize income, improve food security, and reduce vulnerability to market fluctuations and crop failure. In the context of climate resilience, crop diversification is considered an adaptive agricultural strategy because different crops respond differently to environmental stress, thereby reducing the risk of total production loss during extreme weather events [24], [25]. In Indonesia, the continued dominance of monoculture farming among smallholder farmers has increased vulnerability to climate-related disruptions, making crop diversification an important strategy for promoting sustainable and climate-resilient agriculture.

H1: Crop diversification positively influences climate-resilient agriculture.

### 2.3 *Agroforestry Implementation*

Agroforestry refers to a land management system that integrates trees, crops, and sometimes livestock within the same agricultural area to generate ecological, economic, and social benefits simultaneously. This system contributes to environmental sustainability through soil conservation, carbon sequestration, water retention, erosion control, biodiversity preservation, and microclimate regulation, making it highly relevant for sustainable agriculture in tropical countries such as Indonesia [7], [26]. Economically, agroforestry provides additional income sources for farmers through timber, fruits, medicinal plants, and non-timber forest products, thereby improving rural livelihood resilience and reducing economic vulnerability. Agroforestry is also closely associated with climate change mitigation and adaptation because trees help absorb carbon dioxide and diversified land systems improve resilience against droughts, floods, and extreme temperatures [6]–[8]. Although agroforestry offers significant environmental and economic advantages, its adoption among Indonesian farmers remains limited due to barriers such as limited technical knowledge, resource constraints, long-term investment perceptions, and insufficient institutional support.

H2: Agroforestry implementation positively influences climate-resilient agriculture.

### 2.4 *Environmental Literacy*

Environmental literacy refers to an individual's knowledge, awareness, attitudes, and behaviors related to environmental sustainability and ecological protection, which play an important role in shaping sustainable farming practices. In the agricultural sector, farmers with higher environmental literacy are generally more capable of understanding climate change impacts, conserving natural resources, and adopting environmentally friendly agricultural methods such as efficient water management, soil conservation, and sustainable pesticide use [27], [28]. Environmental literacy is also strengthened through environmental education, agricultural training, extension services, and access to climate information, which help farmers improve their adaptive capacity toward environmental challenges [6], [29]. In Indonesia, environmental literacy among farming communities remains uneven due to differences in education, access to information, institutional support, and socio-economic conditions, affecting the implementation of climate-resilient agricultural practices.

H3: Environmental literacy positively influences climate-resilient agriculture.

### 2.5 *Farmer Cooperative Participation*

Farmer cooperatives are community-based organizations that support collective agricultural activities, improve farmer welfare, and strengthen bargaining power through participation in training, resource sharing, financial support, agricultural marketing, and collective decision-making. Cooperative participation helps farmers gain better access to agricultural inputs, technologies, information, markets, and extension services, while also reducing production costs and strengthening social capital within rural communities [12], [13]. Through collaboration and knowledge sharing, cooperatives encourage the adoption of sustainable agricultural practices, environmental conservation, and climate adaptation strategies. In the context of climate resilience, cooperatives contribute by improving farmers' access to climate information, agricultural innovation, and coordinated risk management systems [14], [30]. In Indonesia, cooperatives play an important role in agricultural development programs, although their effectiveness often depends on management quality, institutional capacity, and the level of member participation.

H4: Farmer cooperative participation positively influences climate-resilient agriculture.

## 3. METHODS

### 3.1 Research Design

This study employed a quantitative research approach with a causal explanatory design to examine the influence of crop diversification, agroforestry implementation, environmental literacy, and farmer cooperative participation on climate-resilient agriculture in Indonesia. Data were collected through a cross-sectional survey using structured questionnaires distributed to farmers in several regions vulnerable to climate variability and environmental changes. The survey method was selected because it allows efficient and systematic data collection from large agricultural communities. Furthermore, the study utilized Structural Equation Modeling–Partial Least Squares (SEM-PLS 4) as the analytical technique because it is suitable for analyzing complex relationships among latent variables, accommodating non-normal data distributions, and supporting predictive research models with multiple constructs and indicators.

### 3.2 Population and Sample

The population of this study consisted of farmers engaged in agricultural activities across several agricultural regions in Indonesia. The target respondents included farmers involved in crop cultivation, agroforestry practices, farmer cooperatives, and sustainable agricultural activities because they possess direct experience related to climate change impacts and agricultural adaptation strategies. This study applied a purposive sampling technique, which was selected because the research required respondents who met specific criteria relevant to the study objectives. The criteria included farmers who had been actively involved in agricultural activities for at least three years, were members of agricultural communities or farmer cooperatives, were familiar with sustainable agricultural practices, and were located in areas affected by climate variability.

Based on these criteria, a total of 250 respondents were selected as the research sample. The sample size was considered sufficient for Structural Equation Modeling–Partial Least Squares (SEM-PLS) analysis because it exceeded the minimum sample requirement for structural equation modeling involving multiple latent variables and indicators. The use of purposive sampling also ensured that the selected respondents possessed adequate knowledge and practical experience related to climate-resilient agriculture, thereby supporting the accuracy and relevance of the research findings. The demographic characteristics of respondents included gender, age, education level, farming experience, and cooperative membership.

Table 1. Respondent Characteristics

| Characteristics | Category | Frequency | Percentage (%) |
|---|---|---|---|
| Gender | Male | 168 | 67.2 |
| | Female | 82 | 32.8 |
| Age | 20–30 years | 39 | 15.6 |
| | 31–40 years | 71 | 28.4 |
| | 41–50 years | 86 | 34.4 |
| | >50 years | 54 | 21.6 |
| Education | Elementary School | 42 | 16.8 |
| | Junior High School | 58 | 23.2 |
| | Senior High School | 109 | 43.6 |
| | Bachelor Degree | 41 | 16.4 |
| Farming Experience | <5 years | 36 | 14.4 |
| | 5–10 years | 77 | 30.8 |
| | 11–15 years | 83 | 33.2 |
| | >15 years | 54 | 21.6 |
| Cooperative Membership | Yes | 191 | 76.4 |
| | No | 59 | 23.6 |

Table 1 shows that the majority of respondents were male farmers, accounting for 67.2% of the total sample, while female respondents represented 32.8%, indicating that agricultural activities in the surveyed regions are still predominantly managed by men. In terms of age, most respondents were between 41–50 years old (34.4%), followed by 31–40 years old (28.4%), suggesting that the agricultural sector is largely dominated by middle-aged farmers with considerable farming maturity and experience. Regarding educational background, most respondents had completed senior high school education (43.6%), while a smaller proportion possessed bachelor degrees (16.4%), indicating moderate educational attainment among farmers. The results also reveal that most respondents had farming experience between 11–15 years (33.2%) and 5–10 years (30.8%), reflecting substantial practical knowledge in agricultural activities. Furthermore, a large majority of respondents (76.4%) were members of farmer cooperatives, demonstrating relatively strong institutional involvement and collective participation among farmers in supporting agricultural and climate adaptation activities.

### 3.3 Data Collection Technique

Primary data in this study were collected through structured questionnaires distributed directly to respondents and designed based on indicators derived from previous literature related to climate-resilient agriculture, sustainable farming practices, environmental literacy, and cooperative participation. The questionnaire consisted of two sections, where the first section gathered respondent demographic information such as age, education level, farming experience, farm size, and cooperative membership status, while the second section measured the research variables using statement items assessed through a five-point Likert scale ranging from 1 = Strongly Disagree to 5 =

Strongly Agree. Prior to large-scale distribution, a pilot study was conducted involving several respondents to ensure the clarity, validity, and reliability of the research instrument.

### 3.4 Operational Definition of Variables

This study consisted of four independent variables and one dependent variable. Crop Diversification (X1) refers to the practice of cultivating multiple crop varieties or agricultural commodities within a farming system to reduce agricultural risks and improve sustainability, measured through indicators such as crop variety, crop rotation, mixed farming implementation, dependency reduction on a single crop, and diversification-based risk management. Agroforestry Implementation (X2) refers to the integration of trees and crops within the same land management system to improve ecological and economic sustainability, measured through tree-crop integration, soil conservation, water retention, environmental conservation activities, and long-term land sustainability. [7], [31], [32] Environmental Literacy (X3) refers to farmers' knowledge, awareness, attitudes, and understanding regarding environmental sustainability and climate-related issues, measured through awareness of climate change impacts, understanding of sustainable farming, environmental conservation knowledge, participation in environmental education, and environmentally responsible farming behavior [27], [28]. Farmer Cooperative Participation (X4) refers to farmers' involvement in cooperative activities related to agricultural development, knowledge sharing, and collective action, measured through active participation in cooperatives, agricultural training involvement, knowledge sharing, access to agricultural resources, and collective problem-solving activities [33]. Meanwhile, Climate-Resilient Agriculture (Y) refers to the ability of agricultural systems and farmers to adapt to climate variability while maintaining productivity and sustainability, measured through adaptation to climate variability, sustainable agricultural productivity, efficient natural resource management, reduction of environmental risks, and long-term agricultural sustainability [16], [33].

### 3.5 Data Analysis Technique

The data analysis in this study was conducted using Structural Equation Modeling–Partial Least Squares (SEM-PLS 4), which consisted of two main stages: evaluation of the measurement model (outer model) and evaluation of the structural model (inner model) [34]. The outer model evaluation aimed to assess the validity and reliability of the measurement indicators used in the study. Convergent validity was evaluated using factor loading and Average Variance Extracted (AVE) values, where indicators were considered valid if the loading factor exceeded 0.70 and AVE values were greater than 0.50. Discriminant validity was assessed using the Fornell-Larcker Criterion and cross-loading analysis to ensure that each construct was distinct from other constructs. In addition, construct reliability was measured using Composite Reliability (CR) and Cronbach's Alpha, with acceptable values exceeding 0.70, indicating satisfactory internal consistency and reliability of the constructs.

The inner model evaluation was conducted to examine the relationships among latent variables and test the research hypotheses. The coefficient of determination ($R^2$) was used to evaluate the predictive capability of the independent variables toward the dependent variable, where higher R-square values indicated stronger explanatory power of the model. Predictive relevance was assessed using the Q-square ($Q^2$) value, with values greater than zero indicating that the model possessed predictive relevance. Furthermore, path coefficient analysis was performed to determine the strength and direction of relationships among variables. Hypothesis testing was conducted using the bootstrapping procedure in SEM-PLS 4, where hypotheses were considered supported if the T-statistic exceeded 1.96 and the P-value was below 0.05.

## 4. RESULTS AND DISCUSSION

### 4.1 Measurement Model Evaluation (Outer Model)

The outer model evaluation was conducted to assess the validity and reliability of the measurement indicators used in this study through convergent validity, discriminant validity, composite reliability, and Cronbach's alpha testing. Convergent validity was evaluated using factor loading and Average Variance Extracted (AVE), where indicators were considered valid if the loading values exceeded 0.70 and the AVE values were greater than 0.50, indicating that the indicators were able to adequately explain their respective constructs.

Table 2. Factor Loading and AVE

| Variable | Indicator | Loading Factor |
|---|---|---|
| Crop Diversification | CD1 | 0.812 |
| | CD2 | 0.845 |
| | CD3 | 0.798 |
| | CD4 | 0.834 |
| | CD5 | 0.821 |
| Agroforestry Implementation | AI1 | 0.876 |
| | AI2 | 0.852 |
| | AI3 | 0.819 |
| | AI4 | 0.841 |
| | AI5 | 0.826 |
| Environmental Literacy | EL1 | 0.801 |
| | EL2 | 0.836 |
| | EL3 | 0.854 |
| | EL4 | 0.813 |
| | EL5 | 0.828 |
| Farmer Cooperative Participation | FC1 | 0.824 |
| | FC2 | 0.845 |
| | FC3 | 0.867 |
| | FC4 | 0.816 |
| | FC5 | 0.839 |
| Climate-Resilient Agriculture | CRA1 | 0.871 |
| | CRA2 | 0.853 |
| | CRA3 | 0.824 |
| | CRA4 | 0.846 |
| | CRA5 | 0.862 |

Table 2 shows that all indicators used in this study achieved loading factor values above the recommended threshold of 0.70, indicating strong convergent validity for each construct. The Crop Diversification variable demonstrated loading values ranging from 0.798 to 0.845, while Agroforestry Implementation showed the highest loading values overall, ranging from 0.819 to 0.876. Environmental Literacy indicators also exhibited satisfactory loading values between 0.801 and 0.854, followed by Farmer Cooperative Participation with loading values ranging from 0.816 to 0.867. Similarly, the Climate-Resilient Agriculture construct demonstrated strong indicator reliability with loading values between 0.824 and 0.871. These findings indicate that all measurement indicators were capable of explaining their respective latent constructs adequately and met the requirements for convergent validity in SEM-PLS analysis.

Table 3. Average Variance Extracted (AVE)

| Variable | AVE |
|---|---|
| Crop Diversification | 0.675 |
| Agroforestry Implementation | 0.709 |
| Environmental Literacy | 0.683 |
| Farmer Cooperative Participation | 0.701 |
| Climate-Resilient Agriculture | 0.728 |

Table 3 shows that all constructs achieved Average Variance Extracted (AVE) values above the recommended threshold of 0.50, indicating satisfactory convergent validity for all variables in the study. Climate-Resilient Agriculture obtained the highest AVE value at 0.728, followed by Agroforestry Implementation (0.709), Farmer Cooperative Participation (0.701), Environmental Literacy (0.683), and Crop Diversification (0.675). These results demonstrate that each construct was able to explain more than 50% of the variance of its indicators, confirming that the measurement model possesses adequate validity and that the indicators appropriately represent their respective latent variables.

Reliability testing was conducted using Composite Reliability and Cronbach's Alpha.

Table 4. Reliability Test Results

| Variable | Cronbach's Alpha | Composite Reliability |
|---|---|---|
| Crop Diversification | 0.879 | 0.912 |
| Agroforestry Implementation | 0.897 | 0.924 |
| Environmental Literacy | 0.884 | 0.915 |
| Farmer Cooperative Participation | 0.891 | 0.921 |
| Climate-Resilient Agriculture | 0.906 | 0.931 |

Table 4 indicates that all constructs demonstrated strong reliability and internal consistency, as reflected by Cronbach's Alpha and Composite Reliability values exceeding the recommended threshold of 0.70. Climate-Resilient Agriculture showed the highest reliability values with a Cronbach's Alpha of 0.906 and Composite Reliability of 0.931, followed by Agroforestry Implementation with values of 0.897 and 0.924, respectively. Farmer Cooperative Participation, Environmental Literacy, and Crop Diversification also achieved high reliability values, confirming that the measurement indicators consistently represented their respective latent constructs. These findings indicate that all variables used in the study possess satisfactory reliability and are appropriate for further structural model analysis in SEM-PLS.

### 4.2 Structural Model Evaluation (Inner Model)

The inner model evaluation was conducted to assess the structural relationships among variables using R-square, Q-square, path coefficient analysis, and hypothesis testing. The R-square analysis was used to evaluate the explanatory power of the independent variables toward the dependent variable in the structural model. Based on the analysis results, the Climate-Resilient Agriculture variable obtained an R-square value of 0.742, indicating that the model possessed substantial predictive capability. This result demonstrates that the combination of crop diversification, agroforestry implementation, environmental literacy, and farmer cooperative participation significantly contributed to explaining variations in climate-resilient agriculture.

The R-square value of 0.742 indicates that 74.2% of the variance in Climate-Resilient Agriculture could be explained collectively by the four independent variables included in the study, while the remaining 25.8% was influenced by other variables outside the research model. According to SEM-PLS evaluation criteria, this result reflects strong explanatory power and suggests that the structural model was capable of adequately explaining the relationships among the studied variables. Therefore, the model can be considered robust and appropriate for further hypothesis testing and structural relationship analysis.

Table 5. Q-Square Results

| Variable | SSO | SSE | $Q^2$ (=1-SSE/SSO) |
|---|---|---|---|
| Climate-Resilient Agriculture | 1250.000 | 498.212 | 0.601 |

Table 5 presents the Q-square ($Q^2$) results for the Climate-Resilient Agriculture variable, which obtained a value of 0.601. This result indicates that the structural model possesses strong predictive relevance because the $Q^2$ value is greater than zero. The findings demonstrate that the model has substantial predictive capability in explaining the observed data related to climate-resilient agriculture. In SEM-PLS analysis, higher Q-square values indicate better model accuracy and predictive performance; therefore, the $Q^2$ value of 0.601 confirms that the combination of crop diversification, agroforestry implementation, environmental literacy, and farmer cooperative participation provides meaningful predictive contributions to climate-resilient agriculture.

Hypothesis testing was conducted using bootstrapping analysis in SEM-PLS 4. The significance criteria used were T-statistics > 1.96 and P-values < 0.05.

Table 6. Path Coefficient and Hypothesis Testing

| | Relationship | Path Coefficient | T-Statistic | P-Value | Result |
|---|---|---|---|---|---|
| H1 | Crop Diversification → Climate-Resilient Agriculture | 0.281 | 4.832 | 0.000 | Supported |
| H2 | Agroforestry Implementation → Climate-Resilient Agriculture | 0.326 | 5.417 | 0.000 | Supported |
| H3 | Environmental Literacy → Climate-Resilient Agriculture | 0.214 | 3.928 | 0.000 | Supported |
| H4 | Farmer Cooperative Participation → Climate-Resilient Agriculture | 0.297 | 5.104 | 0.000 | Supported |

Table 6 shows that all proposed hypotheses were supported, as each relationship obtained a T-statistic value above 1.96 and a P-value of 0.000. Agroforestry Implementation had the strongest effect on Climate-Resilient Agriculture with a path coefficient of 0.326, indicating that agroforestry practices play the most dominant role in improving agricultural resilience. Farmer Cooperative Participation also showed a strong positive effect with a coefficient of 0.297, followed by Crop Diversification with 0.281 and Environmental Literacy with 0.214. These results indicate that ecological practices, institutional support, diversified farming systems, and farmers' environmental awareness all significantly contribute to strengthening climate-resilient agriculture.

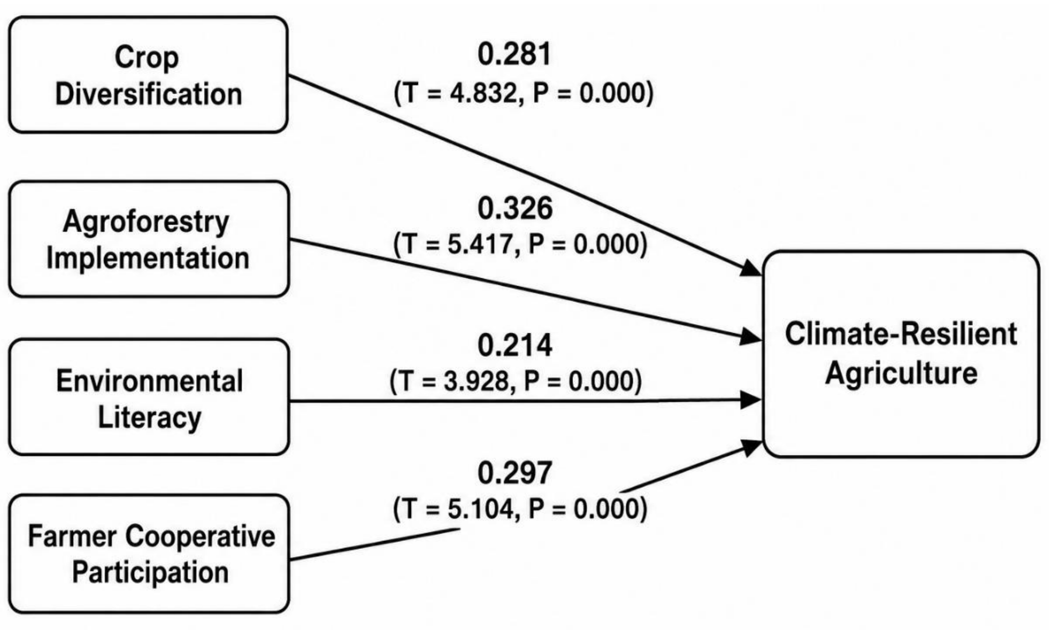


Figure 1. Hypothesis Testing

**Discussion**

The results of this study indicate that crop diversification has a positive and significant effect on climate-resilient agriculture, demonstrating that farmers who implement diversified farming systems tend to possess stronger adaptive capacity toward climate variability and environmental uncertainty. Diversified agricultural practices reduce farmers' dependence on a single commodity, thereby minimizing the risks associated with droughts, floods, pest attacks, and market fluctuations. In addition, crop diversification contributes to soil fertility improvement, biodiversity enhancement, and long-term ecosystem sustainability. In the Indonesian agricultural context, diversified farming systems also provide alternative income sources and strengthen household food security, which are essential for improving resilience among rural farming communities. These findings support previous studies stating that diversified agricultural systems are more adaptive and resilient compared to monoculture systems under changing climate conditions. [18], [22], [35]

The findings further reveal that agroforestry implementation positively and significantly influences climate-resilient agriculture, indicating that agroforestry practices play an important role in strengthening environmental sustainability and agricultural resilience. Agroforestry systems improve ecological stability through soil conservation, water retention, biodiversity preservation, and carbon sequestration, while the integration of trees within agricultural landscapes helps regulate microclimates and reduce environmental degradation caused by extreme climate conditions. Farmers implementing agroforestry systems are generally better prepared to cope with droughts, erosion, and declining soil productivity. Economically, agroforestry also enhances farmer resilience by providing additional agricultural outputs such as timber, fruits, and non-timber forest products, thereby reducing economic vulnerability among farming households. This finding confirms previous research emphasizing agroforestry as one of the most effective sustainable agricultural approaches for climate adaptation in tropical regions such as Indonesia [7], [26].

Environmental literacy was also found to positively and significantly affect climate-resilient agriculture, suggesting that farmers with greater environmental awareness and knowledge are more likely to adopt sustainable farming practices and adaptive agricultural strategies.

Environmental literacy enables farmers to understand climate-related risks, environmental conservation principles, and sustainable resource management practices. Farmers with higher environmental literacy tend to manage water resources more efficiently, apply environmentally responsible farming methods, and demonstrate greater awareness regarding soil conservation and pesticide use. The findings support the Theory of Planned Behavior, which explains that knowledge and awareness influence attitudes and behavioral intentions. Therefore, farmers who possess stronger environmental understanding are generally more willing to implement environmentally friendly agricultural practices that support long-term sustainability and climate adaptation [27], [28].

The study also demonstrates that farmer cooperative participation positively and significantly influences climate-resilient agriculture, indicating the importance of collective institutions in strengthening agricultural resilience among rural communities. Farmer cooperatives facilitate access to agricultural information, training programs, financial support, farming technologies, and market opportunities that assist farmers in responding to environmental challenges more effectively. Cooperative participation also strengthens social capital, encourages collective problem-solving, and enhances knowledge sharing related to climate adaptation and sustainable farming practices. Farmers who actively participate in cooperative activities generally possess better access to agricultural innovation and climate-related information, which contributes to stronger adaptive capacity and improved agricultural sustainability. These findings support previous studies emphasizing that institutional collaboration and collective action are critical factors in promoting resilient agricultural systems and rural community empowerment in Indonesia.

Overall, the findings of this study confirm that ecological practices, environmental awareness, and institutional participation collectively play important roles in promoting climate-resilient agriculture in Indonesia. Crop diversification and agroforestry implementation strengthen ecological sustainability and reduce environmental vulnerability, while environmental literacy improves farmers' adaptive behavior toward climate change. At the same time, farmer cooperative participation strengthens collective resilience by improving access to resources, knowledge, and agricultural innovation. The integration of these environmental, educational, and institutional dimensions demonstrates that climate resilience in agriculture cannot be achieved solely through technological adaptation but also requires behavioral transformation, social collaboration, and sustainable resource management. Therefore, policymakers and agricultural institutions should prioritize integrated strategies that promote sustainable farming systems, environmental education, and cooperative empowerment to strengthen long-term agricultural resilience and rural sustainability in Indonesia.

## 5. CONCLUSION

This study concludes that crop diversification, agroforestry implementation, environmental literacy, and farmer cooperative participation significantly contribute to climate-resilient agriculture in Indonesia. The findings indicate that sustainable farming practices and institutional collaboration strengthen farmers' adaptive capacity toward climate change and environmental uncertainty. Agroforestry implementation emerged as the strongest factor influencing climate-resilient agriculture, while cooperative participation improved resilience through collective action, knowledge sharing, and access to agricultural resources. In addition, environmental literacy encouraged sustainable farming behavior, and crop diversification reduced agricultural vulnerability and improved farming stability. Overall, the study highlights the importance of integrating ecological sustainability, environmental awareness, and institutional support in strengthening agricultural resilience, food security, and rural welfare in Indonesia.

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