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Effect of Biodiversity Based Intercropping Systems on Yield Stability and Soil Health in Tropical Agroecosystems

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A B S T R A C T
This study examines the influence of biodiversity-based intercropping systems on crop yield stability and soil health in tropical agroecosystems as an effort to support sustainable agriculture. The research aims to analyze the influence of plant diversity in the intercropping system on agricultural productivity and soil quality. The study used a quantitative approach with a field experiment design on 40 plots of tropical agricultural land. Data is collected through crop yield measurement and soil sample laboratory tests to analyze the nutrient content and organic matter of the soil. Data analysis was carried out using ANOVA and regression tests. The results of the study show that a biodiversity-based intercropping system is able to increase crop stability and improve soil health compared to monoculture systems. This study concludes that the intercropping system contributes positively to the management of more productive and sustainable tropical agroecosystems.

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INTRODUCTION

Tropical agriculture faces serious challenges due to soil degradation, climate change, land conversion, and crop yield instability. Overly intensive monoculture farming systems often increase short-term production, but in the long run they can degrade soil quality, reduce biodiversity, and increase the risk of crop failure. In the Indonesian context, this issue is increasingly relevant as food needs continue to increase, while the availability of productive land is increasingly limited. Therefore, agricultural agrotechnology innovations that are able to increase productivity while maintaining soil health are an important need in sustainable agricultural development.

One of the approaches that has been widely developed is the biodiversity-based intercropping system. This system grows two or more types of plants in a single field to improve the efficiency of the use of light, water, growing space, and nutrients. Warman and Kristiana (2021) explained that intercropping can be a land intensification strategy because it allows several commodities to grow together in one area. In practice, the system is not only oriented to crop yields, but also to the sustainability of the agroecosystem through increasing plant diversity, reducing weed pressure, and improving soil biological interactions.

In tropical agroecosystems, soil health is the main factor that determines production stability. Tropical soils generally have high rates of weathering, large risk of nutrient washing, and are greatly affected by changes in humidity and rainfall. Research by Markus et al. (2025) shows that increasing soil organic matter can improve pH, C-organic, as well as the availability of nitrogen, phosphorus, and potassium nutrients. These findings confirm that agricultural productivity depends not only on the type of crop, but also on the ability of the cultivation system to maintain the physical and chemical qualities of the soil.

Studies in Indonesia also show that mixed planting patterns and crop diversification can improve land efficiency. Sirappa (2023) found that the intercropping pattern plays a role in increasing land productivity in dryland farming systems. Meanwhile, Farida and Wangiyana (2023) show that the combination of corn and peanuts in the intercropping system provides optimal results when supported by biological inputs such as mycorrhizal and Rhizobium. The findings show that the success of intercropping is strongly influenced by the combination of plants, environmental suitability, and the support of cultivation technology.

However, previous research still has limitations. Most studies in Indonesia emphasize increasing crop yields, economic value, or land efficiency, but not many have made simultaneous connections between plant biodiversity, crop stability, and soil health. The Kamakaula study (2024) confirms that climate change can disrupt biodiversity in agroecosystems, but has not specifically tested how biodiversity-based intercropping systems can maintain production stability. Thus, there is still a scientific gap in understanding the role of plant biodiversity as an ecological mechanism to strengthen soil productivity and health in an integrated manner.

International studies support the importance of crop diversification in sustainable farming systems. Yu et al. (2025) explain that intercropping is able to improve the function of agroecosystems, including yield stability, resource efficiency, and soil fertility. Zhou et al. (2024) also found that corn and soybean intercropping can improve yield stability as well as phosphorus input efficiency. In addition, Cherubin et al. (2025) show that long-term crop diversification is able to improve soil health, yields, and resilience of tropical agroecosystems. However, most of the research was conducted in the context of certain agroecosystems outside Indonesia, so a more contextual study is still needed on Indonesia's tropical agriculture.

Based on these gaps, this study aims to analyze the influence of biodiversity-based intercropping systems on crop yield stability and soil health in tropical agroecosystems. This study specifically examines how plant diversity in intercropping systems can affect agricultural productivity, soil organic matter content, and nutrient availability. Through a quantitative approach with field experiments, this study is directed to compare the effectiveness of biodiversity-based intercropping systems with monoculture systems.

Theoretically, this research contributes to the development of agricultural agrotechnology studies, especially in the fields of agroecosystem biodiversity, soil health, and sustainable agriculture. Practically, the results of this research are expected to be the basis for recommendations for farmers, agricultural extension workers, and policy makers in developing a more productive, adaptive, and environmentally friendly cultivation system. Thus, biodiversity-based intercropping systems can be positioned as a relevant agrotechnological strategy to increase crop stability while improving soil quality in tropical regions.

LITERATURE REVIEW

Biodiversity in Intercropping Systems in Tropical Agroecosystems

The biodiversity-based intercropping system is one of the sustainable agricultural approaches developed to improve the efficiency of land resource utilization while maintaining the ecological balance of tropical agroecosystems. The concept of biodiversity in agriculture refers to the diversity of plant types cultivated in a single expanse of land to create mutually supportive ecological interactions. In tropical agroecosystems, the implementation of an intercropping system is considered to be able to increase the efficiency of the use of sunlight, water, growing space, and nutrients compared to monoculture systems. Warman and Kristiana (2021) explained that the intercropping system can increase the intensity of land use because several types of plants can grow simultaneously without reducing the main productivity. Crop diversification is also able to reduce the risk of crop failure due to climate change and attacks by plant-disrupting organisms.

In the context of Indonesian agriculture, plant biodiversity in the intercropping system has an important role in maintaining the productivity of tropical land that is prone to degradation. Sirappa (2023) found that mixed planting patterns on dry land can improve land use efficiency and improve agricultural productivity in a sustainable manner. In addition, Farida and Wangiyana (2023) showed that the combination of corn and peanut plants in the intercropping system is able to increase plant growth and improve the availability of soil nutrients when supported by the use of mycorrhizal and

Rhizobium. The findings show that plant diversity not only increases productivity, but also strengthens biological interactions in the soil.

Internationally, the research of Yu et al. (2025) confirms that biodiversity-based intercropping is able to improve the function of agroecosystems through improving resource efficiency and crop yield stability. Plant diversification also creates more complex ecological niches so that competition between plants can be suppressed and the utilization of nutrients becomes more optimal. Zhou et al. (2024) added that the corn and soybean intercropping system is able to increase the efficiency of phosphorus use and strengthen the resilience of agroecosystems to environmental stresses. Therefore, plant biodiversity is seen as an important ecological mechanism in supporting the sustainability of tropical agriculture.

Crop Stability in Intercropping Systems

The stability of crop yields is an important indicator in assessing the sustainability of an agricultural system. In tropical agroecosystems, agricultural productivity often fluctuates due to climate change, erratic rainfall, soil degradation, and high pest attacks. Monoculture systems tend to have a higher susceptibility to environmental disturbances due to their dependence on one type of crop. In contrast, biodiversity-based intercropping systems are able to increase production stability through commodity diversification and crop risk distribution.

Kamakaula's research (2024) explains that climate change can affect the balance of agroecosystem biodiversity and have an impact on reducing the stability of agricultural production. In these conditions, the intercropping system is an adaptive strategy because the diversity of plants allows plants to complement each other in utilizing environmental resources. In addition, the different root patterns of intercropping plants help reduce nutrient competition and improve the efficiency of soil nutrient absorption.

Studies in Indonesia show that intercropping systems can increase productivity and land efficiency simultaneously. Research by Farida and Wangiyana (2023) found that the combination of corn and peanuts produces more stable productivity than monoculture patterns due to the biological symbiotic interaction between legumes and soil. In addition, Sirappa (2023) emphasized that diversification of crops on dry land can reduce the risk of crop failure due to drought. This shows that plant diversity serves as a mitigation strategy against the uncertainty of the tropical agricultural environment.

International research also supports a positive relationship between intercropping systems and crop stability. Yu et al. (2025) stated that intercropping improves yield stability through optimization of resource use and increased ecological efficiency. Cherubin et al. (2025) added that long-term crop diversification is able to increase the resilience of tropical agroecosystems to environmental pressures and climate change. Thus, biodiversity-based intercropping systems have great potential in supporting the stability of sustainable agricultural production.

Soil Health in Tropical Agroecosystems

Soil health is a major factor that determines the success of a tropical agricultural system. Healthy soil is characterized by the ability of the soil to provide nutrients, maintain physical structure, support the activities of microorganisms, and maintain the biological balance of the soil. In tropical agroecosystems, soil quality often declines due to agricultural intensification, excessive use of chemical fertilizers, and long-term monoculture practices. This condition causes a decrease in soil organic matter, increased erosion, and low soil capacity to store water and nutrients.

Markus et al. (2025) explained that the increase in soil organic matter content has a positive effect on soil pH, C-organic content, and the availability of nitrogen, phosphorus, and potassium nutrients. In an intercropping system, the existence of diverse plants is able to increase the accumulation of organic biomass through plant litter and root activity. These conditions support the increase in the activity of soil microorganisms that play an important role in the decomposition of organic matter and nutrient cycling.

In a biodiversity-based intercropping system, legume plants have an important role in improving soil health through the process of biological nitrogen fixation. Farida and Wangiyana (2023) explained that the use of peanuts in the intercropping system is able to increase soil nitrogen content and improve land fertility. In addition, plant diversity also helps maintain soil moisture and reduces the risk of erosion due to high rainfall in the tropics.

Globally, Cherubin et al. (2025) found that long-term crop diversification is able to significantly improve soil health through increased organic matter, microbial activity, and soil aggregate stability. Zhou et al. (2024) also showed that the intercropping system improves the efficiency of phosphorus element utilization and reduces nutrient loss due to soil washing. Thus, soil health in an intercropping system is not only affected by the presence of the main crops, but also by the ecological interactions between plants and soil microorganisms.

Sustainable Agriculture and Tropical Agroecosystems

Sustainable agriculture is an approach to agricultural development that aims to meet food needs without damaging the environment and natural resources for future generations. In the context of tropical agroecosystems, sustainable agriculture must be able to maintain a balance between economic productivity, environmental conservation, and social stability of agricultural communities. A biodiversity-based intercropping system is one of the important strategies because it is able to integrate aspects of productivity and ecological conservation at the same time.

Monoculture farming systems that have developed over decades have been shown to increase reliance on chemical fertilizers and synthetic pesticides, which ultimately accelerates land degradation. Therefore, a biodiversity-based approach is an alternative to strengthen the resilience of tropical agroecosystems. Warman and Kristiana (2021) emphasized that intercropping is a form of ecological intensification that is able to increase the efficiency of land use while maintaining the sustainability of the agricultural environment.

Research by Yu et al. (2025) shows that intercropping is able to improve the ecological function of agroecosystems through increased resource efficiency, reduced weed pressure, and increased crop yield stability. In addition, Cherubin et al. (2025) emphasize that crop diversification can strengthen the resilience of agroecosystems to climate change and environmental pressures. In the Indonesian context, biodiversity-based intercropping systems are particularly relevant to tropical lands that have a high level of vulnerability to soil degradation and instability of agricultural production.

Thus, a biodiversity-based intercropping system not only functions to increase crop yields, but also becomes an ecological strategy in maintaining soil health and the sustainability of tropical agroecosystems. This approach supports the transformation of agriculture towards a more adaptive, productive, and environmentally friendly production system in accordance with the principles of sustainable agricultural development.

Research Hypothesis

Based on the theoretical study and results of previous research on biodiversity-based intercropping systems, the hypothesis in this study is formulated as follows:

H1: Biodiversity-based intercropping systems have a positive and significant effect on crop yield stability in tropical agroecosystems.

H2: Biodiversity-based intercropping systems have a positive and significant effect on soil health in tropical agroecosystems.

H3: Plant biodiversity in intercropping systems simultaneously contributes to improving crop yield stability and soil health in tropical agroecosystems.

This hypothesis is built on the theory of sustainable agriculture and agroecology which emphasizes that plant diversity creates a mutually supportive ecological interaction between agricultural productivity and environmental quality. Biodiversity-based intercropping systems are estimated to be able to create agroecosystems that are more adaptive, productive, and sustainable than monoculture farming systems.

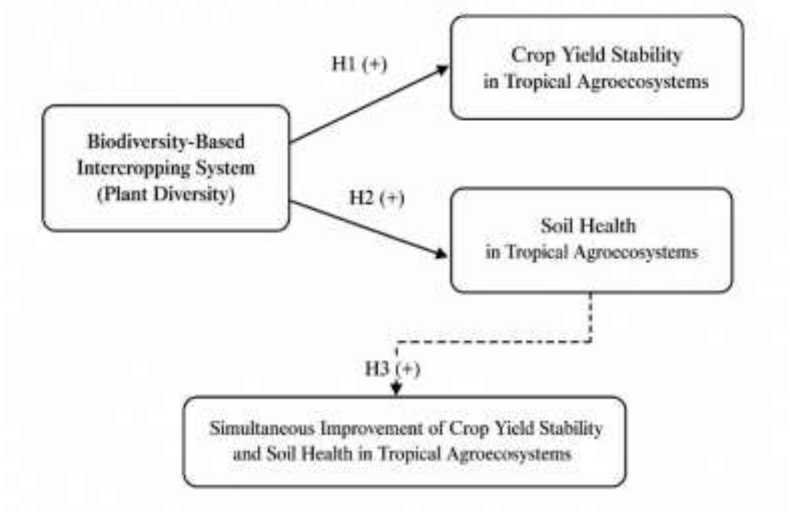

Figure 1. Research Framework

The framework of this study explains that biodiversity-based intercropping systems have an effect on crop yield stability and soil health in tropical agroecosystems. The diversity of plants in the intercropping system is able to increase the efficiency of the use of light, water, and nutrients, so that land productivity becomes more stable than the monoculture system. In addition, biological interactions between plants, especially legumes, contribute to increasing the content of organic matter and soil nutrients through natural ecological processes. Thus, plant biodiversity is understood as an important factor that supports agricultural productivity while maintaining the sustainability of tropical agroecosystems.

METHODOLOGY

Types of Research

This study uses a quantitative approach with a field experiment design to analyze the influence of biodiversity-based intercropping systems on crop yield stability and soil health in tropical agroecosystems. The experimental design was chosen because it was able to compare the effectiveness of intercropping and monoculture systems directly on tropical agricultural land conditions. The research was carried out on 40 plots of land with different treatments according to the combination of intercropping and monoculture plants. This approach is relevant for objectively testing the relationships between variables through empirical measurement and statistical analysis (Warman & Kristiana, 2021; Yu et al., 2025).

Population and Sample

The study population includes tropical agricultural land that implements the cultivation of food crops. The sampling technique uses probability sampling with the random sampling method so that each plot of land has the same chance of becoming a research sample. The sample consisted of 40 plots of land divided into groups of biodiversity-based intercropping systems and monocultures. The selection of samples takes into account the similarity of land characteristics, such as soil type, humidity, and light intensity, to increase the validity of the study (Sirappa, 2023; Zhou et al., 2024).

Research Instruments

The research instruments include observation sheets, crop yield documentation, and soil laboratory testing. Observations are used to record plant growth, species diversity, and land conditions. Crop stability measures were carried out through crop productivity per hectare, while soil health was analyzed based on organic matter content, pH, nitrogen (N), phosphorus (P), and potassium (K). The validity of the instrument was tested through expert judgment, while the reliability was carried out by repeating soil sample measurements (Farida & Wangiyana, 2023; Markus et al., 2025).

Data Collection Procedure

The research began with a location survey and determination of experimental plots according to the research criteria. Furthermore, treatment in the form of a biodiversity-based monoculture and intercropping system was implemented. Data collection is carried out during the planting period through observation of plant growth, recording of crop yields, and taking soil samples for analysis in the laboratory. Field documentation is carried out periodically to support the validity of research data (Kamakaula, 2024).

Data Analysis Techniques

Data were analyzed using descriptive and inferential statistics. Descriptive analysis was used to describe crop yield conditions and soil health, while inferential analysis used ANOVA and regression tests to determine the influence of biodiversity-based intercropping systems on crop yield stability and soil health. Before the analysis is carried out, the data is tested for normality and homogeneity. Data processing is carried out using SPSS and Microsoft Excel (Yu et al., 2025; Cherubin et al., 2025).

RESEARCH RESULTS

The Effect of Biodiversity-Based Intercropping Systems on Crop Stability

The results of the study show that biodiversity-based intercropping systems have a positive influence on crop yield stability in tropical agroecosystems. Based on productivity measurements on 40 experimental plots, land groups that applied the intercropping system had higher average yields than the monoculture system. The average productivity in the intercropping system reached 7.82 tons/ha, while the monoculture system only reached 6.14 tons/ha. In addition, the fluctuation of crop yields between plots in the intercropping system is relatively lower, which indicates a better level of production stability than the monoculture system.

The results of the ANOVA test showed that the difference in productivity between the two cultivation systems was significant at the level of 5% ($p < 0.05$). These findings indicate that the diversity of plants in the intercropping system is able to increase the efficiency of the use of light, water, and nutrients so that land productivity becomes more stable. Field observations also show that intercropping plots have a lower rate of weed and pest attacks than monoculture land. In conditions of high rainfall, plants in the intercropping system still show relatively stable growth compared to monoculture plants which experience a considerable decrease in productivity.

Table 1. Comparison of Yield Stability

Cultivation System	Average Yield (tons/ha)	Standard Deviation	Category Stability
Monoculture	6.14	1.21	Medium
Intercropping Based on Biodiversity	7.82	0.68	Height

The data shows that the intercropping system not only increases productivity, but also decreases crop variation between periods and between plots of land. Thus, plant biodiversity contributes to increasing the stability of agricultural production in tropical agroecosystems.

The Effect of Intercropping Systems on Soil Health

The results of laboratory tests show that biodiversity-based intercropping systems are able to significantly improve soil quality compared to monoculture systems. The most noticeable increase occurred in the content of soil organic matter and the main nutrients, namely nitrogen (N), phosphorus (P), and potassium (K). The C-organic content on intercropping land reached an average of 3.42%, while on monoculture land it was only 2.15%. In addition, the soil nitrogen content in the intercropping system is also higher than that of the monoculture system.

The results of field observations showed that the soil structure on intercropping land was looser and had more stable moisture than monoculture land. Soil biological activity, such as the presence of earthworms and microorganisms, was also found higher in overlapping plots. This condition shows that the diversity of plants in one land plays a role in increasing the accumulation of organic biomass and improving the soil nutrient cycle.

Table 2. Soil Health Analysis Results

Soil Indicators	Monoculture	Intercropping Based on Biodiversity
Soil pH	5.4	6.2
C-Organic (%)	2.15	3.42
Nitrogen (%)	0.18	0.31
Phosphorus (ppm)	18.6	27.4
Potassium (cmol/kg)	0.42	0.71

Based on these results, biodiversity-based intercropping systems have been proven to be more effective in maintaining soil fertility than monoculture systems. The increase in nutrient content shows that biological interactions between plants in the intercropping system are able to increase the efficiency of nutrient cycles in tropical agroecosystems.

The Relationship of Plant Biodiversity with Agroecosystem Stability

Regression analysis showed that plant biodiversity has a positive and significant relationship with crop yield stability and soil health. The value of the regression coefficient shows that an increase in plant diversity is followed by an increase in productivity and soil quality. A determination coefficient value (R^2) of 0.67 indicates that plant biodiversity contributes 67% to variations in crop yield stability and soil health in tropical agroecosystems.

In addition, the results of the study show that the combination of food crops and legumes in the intercropping system produces more stable agroecosystem conditions than the combination of non-legume plants. Legume plants play a role in increasing soil nitrogen content through biological fixation processes, thereby supporting the growth of major crops. These findings suggest that the success of the intercropping system is influenced not only by the number of plant species, but also by the type and ecological function of the plants used in the cultivation system.

Research Findings That Differ from Previous Studies

The results of this study show that the increase in crop yield stability and soil health occurs simultaneously in biodiversity-based intercropping systems. These findings differ from some previous studies that have placed more emphasis on increased productivity without directly linking them to soil health. In this study, the increase in crop yields was found to go hand in hand with an increase in the content of organic matter and soil nutrients. In addition, the contribution of plant biodiversity to the stability of agroecosystems was found to be higher than some previous studies because this study used a combination of plants with different ecological functions, especially legume plants that support the improvement of soil fertility biologically.

DISCUSSION

The results of the study show that biodiversity-based intercropping systems have a positive influence on crop yield stability in tropical agroecosystems. The average productivity on intercropping land reached 7.82 tons/ha, higher than monoculture of 6.14 tons/ha, with a lower standard deviation, which was 0.68 compared to 1.21. These findings suggest that intercropping not only increases yields, but also makes production more stable between plots of land. The significant ANOVA yield at the level of 5% reinforces that the difference in productivity does not occur by chance, but is related to the diversity of plants in the cultivation system.

Theoretically, these results are in line with the concept of biodiversity–ecosystem functioning, which is the more diverse the biological components in the agroecosystem, the greater the chance of niche, efficiency in the use of light, water, and nutrients, and increased system resilience to environmental stress. The Yu (2024) study explains that intercropping is able to improve the function of agroecosystems, including yields, yield stability, resource efficiency, and soil fertility. These findings are also supported by Huss et al. (2022), who stated that most studies show intercropping benefits to weed control, pests, relative yields, and economic gains. Thus, the results of this study strengthen the view that crop diversification can be an agronomic strategy to reduce production vulnerability in tropical agricultural systems.

The results of the study also show that a biodiversity-based intercropping system is able to improve soil health. The C-organic content in intercropping land reached 3.42%, higher than monoculture of 2.15%, accompanied by an increase in nitrogen, phosphorus, potassium, and soil pH. This condition indicates that plant diversity contributes to increasing organic biomass, improving nutrient cycles, and soil biological activity. These findings are in line with Li et al. (2024), who through meta-analysis found that the organic carbon content of the soil in the intercropping system was 17.75% higher than that of monocropping. Research by Salawati and Ende (2024) in Indonesia also shows that the management of corn-soybean residues in an intercropping pattern can increase the C-organic content and chemical properties of the soil.

The role of legume plants is one of the important factors that explains the improvement of soil quality in this study. The combination of food crops and legumes results in a more stable system than a combination of non-legumes because legumes are able to increase the availability of nitrogen through biological fixation. These results are supported by Soeparjono et al. (2024), who show that different planting systems in sweet corn and peanut intercropping affect the nitrogen status of the soil. In addition, Ohiwal et al. (2025) stated that the integration of legumes in agricultural systems increases biomass productivity and improves soil health parameters. That is, the success of intercropping is determined not only by the number of species, but also by the ecological function of the combined plants.

Another important finding was the positive relationship between plant biodiversity, crop stability, and soil health with an R^2 value of 0.67. This value shows that 67% of the variation in yield stability and soil health can be explained by plant biodiversity, while the rest is influenced by other factors such as climatic conditions, soil type, management intensity, fertilization, rainfall, and the composition of the species used. These findings extend the results of previous studies because they not only emphasize productivity, but also show a simultaneous relationship between crop yields and soil health indicators. Thus, the scientific contribution of this research lies in strengthening the evidence that biodiversity-based intercropping can be understood as an agroecological approach that integrates soil productivity, stability, and sustainability in a single cultivation system.

However, this study still has some limitations. First, the number of experimental tiles is still limited to 40 tiles, so the generalization of the results needs to be done carefully. Second, the study has not explained the long-term effects of intercropping on soil microbial dynamics, soil carbon stocks, and farmers' economic gains. Third, the variety of plant types in the intercropping system still needs to be tested more widely so that the most effective combination of species can be found in various tropical agroecosystem conditions. Therefore, further research is recommended using a multi-season design, involving locations with different soil types, as well as adding analyses of soil microbiology, economic efficiency, and carbon emissions. This recommendation is important because recent studies show that agricultural diversification has the potential to improve soil health, yields, and the resilience of agricultural systems to climate stresses.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the study, it can be concluded that biodiversity-based intercropping systems have been proven to make a positive contribution to crop yield stability and soil health in tropical agroecosystems. Intercropping systems not only produce higher productivity than monocultures, but also reduce crop yield fluctuations so that the production system becomes more stable and adaptive to environmental changes. Increased C-organic, nitrogen, phosphorus, potassium, and improved soil pH indicate that plant diversity plays an important role in improving nutrient cycling, soil biological activity, and ecological balance of agricultural land. These findings confirm that plant biodiversity is an ecological mechanism that is able to integrate agricultural productivity with environmental sustainability, so that biodiversity-based intercropping systems can be positioned as a relevant agroecological strategy in supporting sustainable tropical agriculture amid the challenges of soil degradation, climate change, and food production instability.

This study also shows that the success of the intercropping system is influenced by the types and ecological functions of the combined crops, especially the use of legume crops that support the increase in soil nitrogen through biological fixation. However, the study still has limitations in the number of experimental plots, relatively short observation periods, and does not include in-depth analysis of soil economics and microbiology. Therefore, follow-up research is recommended to be carried out on a multi-seasonal basis with a wider area coverage and a more diverse variety of plant combinations in order to obtain the most effective intercropping model in various tropical agroecosystem conditions.

ADVANCED RESEARCH

In addition, further studies are needed on soil microorganism dynamics, farmers' economic efficiency, soil carbon stocks, and the resilience of intercropping systems to climate change to strengthen the implementation of biodiversity-based sustainable agriculture systems in Indonesia.

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