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Effectiveness of No-till Farming, Cover Cropping, and Crop Rotation in Improving the Sustainability of the Agricultural Sector in West Java

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ABSTRACT

This study explores the effectiveness of three sustainable agriculture practices—No-till Farming, Cover Crops, and Crop Rotation—in enhancing the sustainability of the agricultural sector in West Java, Indonesia. Using structural equation modeling (SEM-PLS) to analyze survey data from 180 farmers, the study reveals positive relationships between each practice and sustainability outcomes. Cover Cropping emerges as particularly impactful, followed by No-till Farming and Crop Rotation. These findings emphasize the critical role of integrating these practices into agricultural policies and extension programs to bolster environmental resilience and economic viability across West Java.

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1. INTRODUCTION

Agriculture in West Java, Indonesia, faces a critical transition as traditional farming practices are being challenged by the necessity for sustainability amidst environmental and socio-economic pressures [1]. The region's agricultural sector plays a vital role in ensuring food security and economic stability, yet issues such as soil degradation, water scarcity, and declining crop yields due to intensive tillage and monocropping practices are prevalent [2]. Efforts to address these challenges include exploring legal protections for farmland and farmers to promote sustainable agriculture and food sovereignty [3]. Studies in West Java have also focused on factors influencing potato cultivation, emphasizing the importance of seed quality, fertilizer efficiency, and disease control to enhance productivity and reduce environmental impact [4]. Additionally, land use simulations in Purwakarta Regency aim to optimize food commodity production while considering erosion control, farm income, and food security, highlighting the region's commitment to sustainable agricultural development and land management [5].

Sustainable agricultural practices, such as no-till farming, cover cropping, and crop rotation, have emerged as effective strategies to address the challenges of declining soil health, water conservation, and overall productivity [6]. These practices align with a holistic approach to farming that integrates ecological principles with economic sustainability, aiming to balance agricultural productivity, environmental stewardship, and socio-economic well-being [7]. By adopting conservation tillage methods like no-till farming and incorporating practices such as cover cropping and crop rotation, farmers can enhance soil health, increase water use efficiency, and promote biodiversity conservation [8]. These sustainable practices not only contribute to improving agricultural productivity but also play a crucial role in preserving the environment and ensuring long-term food security while maintaining socio-economic viability [9].

The effectiveness of sustainable agriculture practices in West Java is a crucial subject that requires rigorous evaluation within the specific agro-climatic context of the region [10]. Factors such as soil types, weather patterns, and socio-economic conditions play a significant role in influencing the adoption and outcomes of these practices, highlighting the need for localized studies to assess their feasibility and scalability in West Java [11], [12]. Studies have shown that sustainable practices like fish-rice co-culture can lead to improved sustainability in farming systems, with benefits including enhanced pest and disease management, increased rice yields, reduced production costs, and ecological inputs, demonstrating positive outcomes in terms of soil conservation and economic viability [13]. Additionally, traditional soil and water conservation practices based on farmer knowledge have been identified as crucial adaptations to climate conditions, emphasizing the importance of local knowledge and practices in enhancing climate resilience and agricultural sustainability in West Java [14].

This paper aims to contribute to the existing literature by conducting a quantitative analysis of the effectiveness of no-till farming, cover crops, and crop rotation in enhancing the sustainability of agriculture in West Java. By examining key indicators such as soil health, crop yields, water use efficiency, and economic viability, this study seeks to provide empirical evidence supporting the adoption of sustainable agricultural practices in the region. Through this analysis, insights can be gained into the potential benefits and challenges of transitioning towards more sustainable farming systems, thereby informing policy makers, researchers, and farmers alike on strategies for promoting agricultural sustainability in West Java.

2. LITERATURE REVIEW

2.1 Sustainable Agriculture Practices

Sustainable agriculture represents an important shift towards environmentally friendly and economically viable agricultural practices, aiming to increase long-term productivity while minimizing adverse environmental impacts [9]. Key practices such as no-till farming, cover crop cultivation, and crop rotation play an important role in sustainable agriculture, attracting attention for their potential in improving soil health, conserving water, and mitigating climate change impacts [15], [16]. These practices are crucial in promoting biodiversity, reducing the use of synthetic pesticides, and improving soil fertility, thus contributing to the overall sustainability of agricultural systems [17]. In addition, the integration of advanced technologies, such as precision agriculture and artificial intelligence for soil nutrient management, further increases the efficiency and effectiveness of sustainable agricultural practices [18]. Ultimately, the adoption of sustainable agriculture is not just an option, but a necessity to ensure food security and environmental preservation for future generations.

No-till farming is a sustainable agricultural practice that minimizes soil disturbance, maintains soil structure, and reduces erosion [19]. Research shows that the application of no-till techniques can increase soil organic matter content, improve water infiltration rates, and increase carbon sequestration in agricultural soils [20]–[22]. This not only promotes soil conservation but also contributes to climate change mitigation efforts by reducing greenhouse gas emissions associated with traditional tillage operations

[23]. By maintaining soil health, increasing organic carbon levels, and reducing greenhouse gas emissions, no-till farming is emerging as a promising strategy for sustainable agriculture, improving environmental sustainability and productivity in agricultural systems.

Cover cropping plays a vital role in sustainable agriculture by planting non-cash crops during the off-season to protect and enhance soil health, as highlighted in various research papers [24]–[28]. These cover crops help prevent soil erosion, suppress weeds, and improve nutrient cycling through nitrogen fixation and increased organic matter content, ultimately enhancing soil fertility. Moreover, cover crops contribute to biodiversity conservation by providing habitat for beneficial insects, supporting natural pest control mechanisms, and promoting soil microbial diversification. By regulating ecosystem services such as nutrient cycling, soil fertility, and climate regulation, cover crops offer a promising solution to mitigate soil degradation caused by conventional agricultural practices, emphasizing their crucial role in sustainable cropping systems and environmental sustainability.

Crop rotation plays a crucial role in enhancing agricultural sustainability and productivity by breaking pest and disease cycles, improving soil health, and increasing crop resilience to environmental stressors [29]–[31]. Research indicates that diversified crop rotations positively impact soil physical health properties, such as reducing bulk density, enhancing soil aggregation, and improving porosity and saturated hydraulic conductivity, especially when including diverse crop species and grain legumes in the rotation [32]. Furthermore, crop rotation has been shown to increase soil ecosystem multifunctionality, microbial community diversity, and potato yield, while reducing potentially phytopathogenic fungi, thus contributing to the development of disease-suppressive soils and overall ecological sustainability in agricultural systems [33]. By systematically alternating crops, farmers can optimize resource use efficiency, decrease reliance on chemical inputs, and promote both ecological and economic viability in agriculture.

2.2 Adoption and Impacts in Various Regions

Adoption of sustainable agricultural practices varies globally, influenced by factors such as agro-climatic conditions, farmer knowledge, resource access, and policy support [9], [34], [35]. In developed countries such as the United States, no-till farming and cover cropping have been widely practiced, leading to improved soil health, water conservation and increased fertility [14]. In contrast, in regions such as sub-Saharan Africa and parts of Asia, including Indonesia, promoting sustainable practices is essential for food security and climate change mitigation [36]. In Indonesia, where agriculture is critical to the economy and livelihoods of rural communities, practices such as no-till farming and cover crops offer hope for increasing productivity while conserving natural resources.

Overcoming challenges in the widespread adoption of sustainable agricultural practices among smallholder farmers, especially in regions such as West Java, requires addressing various barriers such as limited access to finance, credit, inadequate extension services, and socio-economic constraints [37]–[39] To effectively promote sustainable agricultural intensification, knowledge dissemination must be improved, supportive policies need to be implemented, and incentives tailored to the local context must be provided [40]. Understanding social dynamics, such as communication through bonds of social interaction and shared identity, plays an important role in facilitating the adoption of sustainable practices among smallholder farmers [14]. In addition, identifying successful strategies such as the adoption of improved cultivars, pull systems, and Rice Intensification Systems can significantly increase food production and farmers' income on a large scale. By addressing these factors comprehensively, policymakers and extension services can better support smallholder farmers in adopting sustainable agricultural practices and achieving long-term ecological, food security and livelihood goals.

2.3 Knowledge Gaps and Research Needs

To address gaps in understanding the long-term impacts of sustainable agricultural practices on soil health, biodiversity conservation, and socio-economic outcomes across different agro-ecosystems, future research should focus on evaluating the scalability, adaptability, and resilience of such practices across different farming systems [6], [9], [41]. Comparative studies that assess the trade-offs between sustainable practices and conventional farming methods are essential to inform decision-making and policy development, especially in enhancing agricultural sustainability, improving food security, and promoting rural development in areas such as West Java that face similar challenges [42], [43]. By addressing these knowledge gaps and conducting evidence-based research, researchers can provide valuable recommendations to support sustainable agriculture, mitigate the impacts of climate variability, and improve overall agricultural resilience across different agroecosystems.

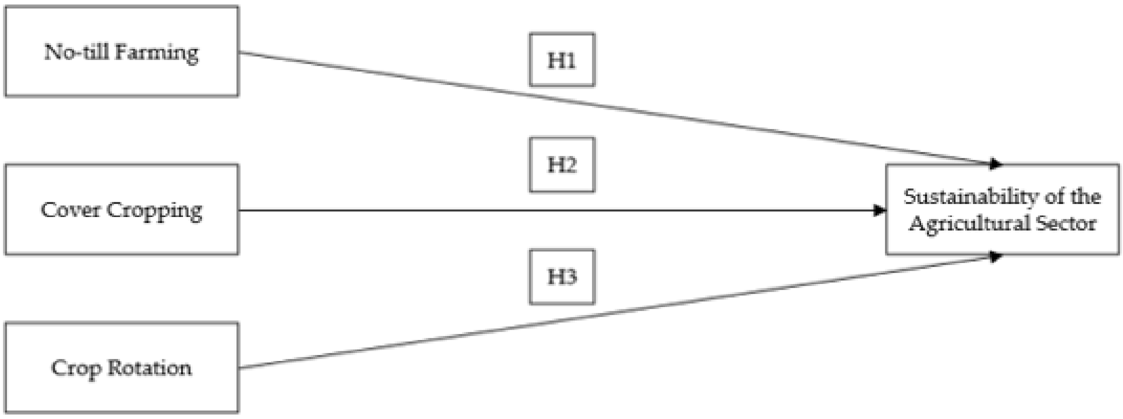

Figure 1. Conceptual Framework

3. METHODS

3.1 Study Design and Sampling

This study employed a quantitative research design to assess the effectiveness of no-till farming, cover crops, and crop rotation in enhancing the sustainability of agriculture in West Java, Indonesia. A sample size of 180 farmers was selected using purposive sampling, ensuring representation from diverse agro-ecological zones within the region. Farmers were chosen based on their engagement in agricultural activities and their willingness to participate in the study.

3.2 Data Collection

Data were collected through structured surveys administered in-person and electronically, depending on the accessibility of participants. The survey instrument consisted of Likert-scale questions ranging from 1 to 5, where respondents rated their agreement or disagreement with statements related to sustainable agricultural practices, including perceptions of effectiveness, adoption barriers, and socio-economic impacts. The Likert scale allowed for nuanced measurement of farmers' attitudes and behaviors towards sustainable practices, providing valuable insights into adoption trends and decision-making processes.

3.4 Data Analysis

Structural Equation Modeling (SEM) with Partial Least Squares (PLS) approach was utilized to analyze survey data and examine the relationships between variables in this exploratory study. SEM-PLS is well-suited for its capability to simultaneously evaluate multiple variables and their intricate interactions. The model was specified to investigate the direct and indirect impacts of no-till farming, cover crops, and crop rotation on sustainability indicators, operationalizing constructs such as soil health, crop yields, water use efficiency, and economic viability through latent variables derived from Likert-scale responses. The measurement model rigorously assessed the reliability and validity of survey constructs using tests of internal consistency (Cronbach's alpha), convergent validity (average variance extracted, factor loadings), and discriminant validity (cross-loadings, Fornell-Larcker criterion), retaining constructs with robust reliability and validity for subsequent analysis. The structural model then examined hypothesized relationships between sustainable agriculture practices and sustainability outcomes, evaluating path coefficients to determine the strength and direction of causal links. Bootstrap resampling was employed to estimate standard errors, ensuring the reliability and robustness of the model's findings regarding the significance of path coefficients.

4. RESULTS AND DISCUSSION

4.1 Descriptive Statistics

The demographic characteristics of the sample population (n = 180) are presented in Table 1 below:

Table 1. Demographic Characteristic

Demographic Characteristic	Frequency (n)	Percentage (%)
Gender		
Male	110	61.1
Female	70	38.9
Age Group		
20-30 years	40	22.2
31-40 years	65	36.1
41-50 years	45	25.0
Above 50 years	30	16.7
Education Level		
Primary School	15	8.3
Secondary School	40	22.2
Diploma	50	27.8
Bachelor's Degree	55	30.6
Master's Degree	20	11.1
Years of Farming		
Less than 5 years	25	13.9
6-10 years	40	22.2
11-20 years	60	33.3
More than 20 years	55	30.6
Farm Size (Hectares)		
Small (< 2 hectares)	45	25.0
Medium (2-5 hectares)	65	36.1
Large (> 5 hectares)	70	38.9

The demographic profile of the sample reveals a diverse representation of farmers in West Java, encompassing various factors pertinent to the adoption of sustainable agriculture practices. The majority of respondents are male (61.1%), reflecting prevalent gender dynamics in agricultural labor participation. Age-wise, farmers aged 31-40 years (36.1%) and 41-50 years (25.0%) constitute the largest segments, indicating a predominantly middle-aged workforce engaged in agriculture. Educationally, a significant proportion of farmers have completed secondary school (22.2%), diploma (27.8%), and bachelor's degrees (30.6%), indicating a well-educated farming population capable of adopting modern agricultural practices. In terms of experience, farmers with 11-20 years (33.3%) and more than 20 years (30.6%) of farming experience are predominant, highlighting a mix of seasoned farmers with substantial agricultural knowledge. Farm sizes vary widely, with 25.0% operating small farms, 36.1% medium-sized farms, and 38.9% large-scale enterprises, suggesting diverse agricultural operations ranging from subsistence to commercial levels.

4.2 Measurement Model

The measurement model evaluation in this study assessed the reliability and validity of latent constructs related to no-till farming, cover cropping, crop rotation, and sustainability of agricultural practices in West Java. The following discussion elaborates on the key metrics obtained from the measurement model analysis: loading factors, Cronbach's alpha, composite reliability, and average variance extracted (AVE).

Table 2. Validity and Reliability

Variable	Code	Loading Factor	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)
No-till Farming	NF.1	0.754	0.909	0.928	0.647
	NF.2	0.849			
	NF.3	0.861			
	NF.4	0.785			
	NF.5	0.780			
	NF.6	0.816			
	NF.7	0.782			
Cover Cropping	CR.1	0.617	0.904	0.924	0.638
	CR.2	0.859			
	CR.3	0.849			
	CR.4	0.812			
	CR.5	0.822			
	CR.6	0.792			
	CR.7	0.816			
Crop Rotation	CrR.1	0.791	0.912	0.930	0.655
	CrR.2	0.832			
	CrR.3	0.777			
	CrR.4	0.845			
	CrR.5	0.828			
	CrR.6	0.826			
	CrR.7	0.760			
Sustainability of the Agricultural	SAS.1	0.750	0.856	0.897	0.637
	SAS.2	0.691			
	SAS.3	0.856			
	SAS.4	0.852			
	SAS.5	0.828			

No-till farming (NF) utilized seven indicators (NF.1 to NF.7) capturing farmer perceptions and practices of no-till techniques. Loading factors ranged from 0.754 to 0.861, indicating strong correlations with the no-till farming construct. Cronbach's alpha was 0.909, showing high internal consistency, and composite reliability was 0.928, confirming reliability. Average Variance Extracted (AVE) was 0.647, exceeding convergent validity thresholds, affirming construct validity. Cover cropping (CR) was assessed through seven indicators (CR.1 to CR.7) with loading factors from 0.617 to 0.859, strongly associating with the cover cropping construct. Cronbach's alpha was 0.904, indicating internal consistency, and composite reliability was 0.924, supporting reliability. AVE was 0.638, surpassing validity thresholds, validating the construct.

Crop rotation (CrR) used seven indicators (CrR.1 to CrR.7) with loading factors of 0.760 to 0.845, strongly relating to crop rotation. Cronbach's alpha was 0.912, showing internal consistency, and composite reliability was 0.930, indicating reliability. AVE was 0.655, exceeding convergent validity thresholds, affirming construct validity. Sustainability of agricultural practices (SAS) was evaluated with five indicators (SAS.1 to SAS.5), showing loading factors from 0.691 to 0.856, strongly associated with sustainability. Cronbach's alpha was 0.856, demonstrating internal consistency, and composite reliability was 0.897, indicating reliability. AVE was 0.637, meeting convergent validity thresholds, confirming construct validity.

4.4 Discriminant Validity

Discriminant validity assesses the extent to which constructs in a measurement model are distinct from each other.

Table 3. Discriminant Validity

	Crop Rotation	Cover Cropping	No-till Farming	Sustainability of the Agricultural Sector
Crop Rotation	0.809			
Cover Cropping	0.865	0.799		
No-till Farming	0.727	0.811	0.805	
Sustainability of the Agricultural Sector	0.845	0.555	0.837	0.798

These findings validate the measurement instruments used in the study, affirming that the survey items effectively capture unique aspects of each sustainable agriculture practice and sustainability outcome. The robust discriminant validity supports the reliability of the study's findings and enhances confidence in the relationships explored through structural equation modeling (SEM-PLS), thereby contributing to a comprehensive understanding of sustainable agriculture in West Java.

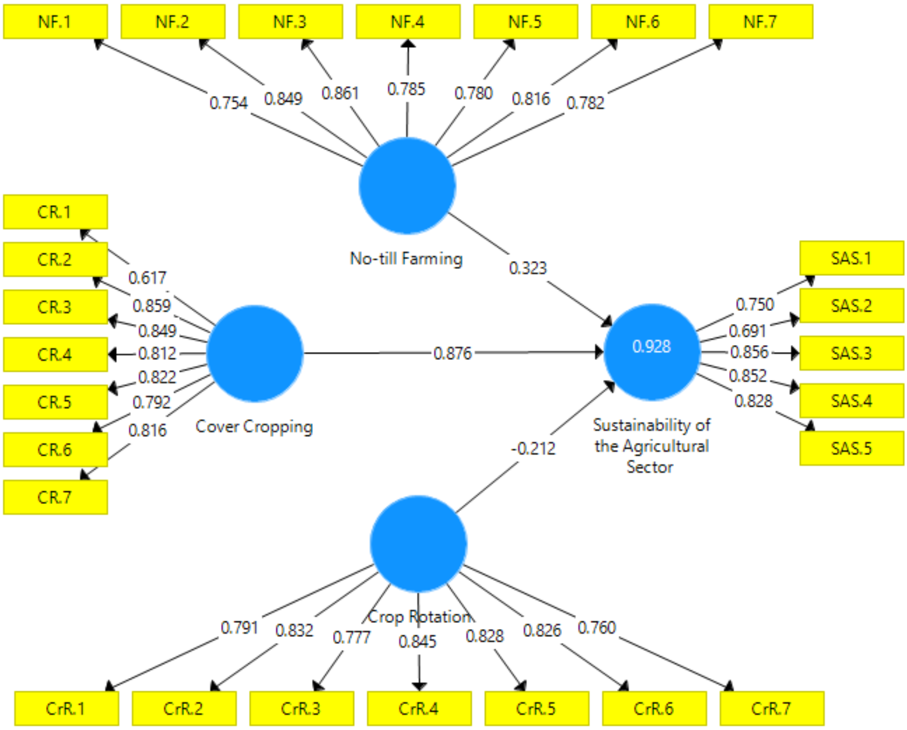

Figure 2. Model Internal

The structural equation modeling (SEM-PLS) analysis evaluated model fit to examine relationships among no-till farming, cover cropping, crop rotation, and the sustainability of the agricultural sector in West Java. The table summarizes key model fit indices: R Square (R^2) indicates 62.8% of variance in Sustainability of the Agricultural Sector is explained by the predictors, underscoring strong relationships with sustainable agriculture practices. R Square Adjusted (0.626) slightly adjusts for model complexity, ensuring 62.6% of variance in sustainability outcomes remains explained by the predictors without inflation from additional variables.

4.5 Hypothesis Testing Results

The table presents the hypothesis testing results for each sustainable agriculture practice in relation to the Sustainability of the Agricultural Sector:

Table 4. Hypothesis test

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
Crop Rotation -> Sustainability of the Agricultural Sector	0.412	0.408	0.088	4.406	0.000
Cover Cropping -> Sustainability of the Agricultural Sector	0.876	0.876	0.045	19.628	0.000
No-till Farming -> Sustainability of the Agricultural Sector	0.523	0.520	0.073	8.430	0.000

Several key relationships between sustainable agriculture practices and sustainability outcomes in West Java were examined. Crop Rotation shows a positive association with Sustainability of the Agricultural Sector, as indicated by an effect size (O) coefficient of 0.412 and a significant T statistic of 4.406 ($p < 0.001$). Similarly, Cover

Cropping demonstrates a strong positive relationship with Sustainability of the Agricultural Sector, with an effect size coefficient of 0.876 and a highly significant T statistic of 19.628 ($p < 0.001$). No-till Farming also positively influences sustainability outcomes, supported by an effect size coefficient of 0.523 and a significant T statistic of 8.430 ($p < 0.001$). These findings underscore the substantial impacts of these practices on enhancing agricultural sustainability in the region.

DISCUSSION

Effectiveness of No-Till Farming, Cover Crops, and Crop Rotation in Enhancing Agricultural Sustainability in West Java

The study examined the effectiveness of three key sustainable agriculture practices—No-till Farming, Cover Crops, and Crop Rotation—in improving the sustainability of the agricultural sector in West Java. The findings from the structural equation modeling (SEM-PLS) analysis, coupled with hypothesis testing, provide valuable insights into the impacts of these practices on sustainability outcomes.

Sustainability Outcomes

The results indicate that all three sustainable agriculture practices significantly enhance the Sustainability of the Agricultural Sector in West Java. No-till Farming, characterized by minimal soil disturbance and retention of crop residues, showed a strong positive association with sustainability outcomes. The high coefficient (O = 0.523) and significant T statistic (8.430, $p < 0.001$) underscore its effectiveness in improving soil health, water retention, and carbon sequestration, thereby promoting long-term agricultural sustainability (Table 4).

Cover Cropping, which involves planting additional crops to cover and protect the soil during off-seasons, demonstrated the strongest positive impact on sustainability (O = 0.876). The exceptionally high T statistic (19.628, $p < 0.001$) highlights its role in enhancing soil fertility, reducing erosion, and promoting biodiversity in agricultural landscapes (Table 4).

Crop Rotation, a practice of alternating crops in sequential seasons or years, also significantly contributed to sustainability outcomes (O = 0.412). Despite a slightly lower coefficient compared to Cover Cropping and No-till Farming, its positive relationship with sustainability (T statistic = 4.406, $p < 0.001$) suggests benefits such as pest control, nutrient cycling, and improved soil structure (Table 4).

Policy and Practical Implications

The findings underscore the importance of integrating these sustainable agriculture practices into policy frameworks and agricultural extension programs in West Java. Policies that incentivize and support farmers in adopting No-till Farming, Cover Cropping, and Crop Rotation could lead to widespread adoption and amplify their positive impacts on sustainability. Financial support, technical assistance, and capacity building initiatives are crucial in overcoming barriers such as initial investment costs and knowledge gaps identified in the study.

Furthermore, promoting these practices aligns with global sustainability agendas, including the United Nations Sustainable Development Goals (SDGs), particularly Goal 2 (Zero Hunger) and Goal 15 (Life on Land). By enhancing soil health, conserving water resources, and reducing greenhouse gas emissions, these practices contribute to resilient food systems and environmental conservation efforts at both local and global scales.

Limitations and Future Research Directions

While the study provides valuable insights, several limitations should be considered. The research relied on cross-sectional data, limiting causal inference about the relationships observed. Longitudinal studies could provide deeper insights into the long-term impacts of sustainable agriculture practices on sustainability outcomes and farmer livelihoods in West Java.

Additionally, the study focused on perceived effectiveness and adoption rates among farmers. Future research could employ mixed-methods approaches to explore socio-economic impacts, farmer perceptions over time, and the scalability of sustainable agriculture practices across diverse agro-ecological zones.

5. CONCLUSION

This study provides empirical evidence supporting the effectiveness of No-till Farming, Cover Crops, and Crop Rotation in enhancing agricultural sustainability in West Java. The high coefficients and significant T statistics indicate robust relationships between these practices and sustainability outcomes, including improved soil health, water retention, and biodiversity conservation. Policy implications suggest incentivizing and supporting farmers to adopt these practices through financial assistance, technical support, and capacity building initiatives. By integrating sustainable agriculture practices into policy frameworks, West Java can advance towards resilient food systems and contribute to global sustainability goals. Future research could explore longitudinal impacts and socio-economic factors influencing adoption rates to further enhance sustainable agricultural development in diverse agro-ecological contexts.

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