Gaps and Determinants of Good Agricultural Practices Implementation in Lowland Swamp Rice Farming

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Abstract. Good Agricultural Practices (GAP) are essential guidelines to enhance productivity and ensure sustainability in rice farming, particularly in lowland swamp areas with specific environmental characteristics. This study aims to evaluate GAP implementation, identify gaps relative to the ideal standard, and analyze factors influencing sustainable GAP adoption in Awal Canal Village, Sirah Pulau Padang District, Ogan Komering Ilir Regency. A survey of 50 farmers was conducted; descriptive analysis assessed GAP implementation, one-sample t-tests measured gaps against the ideal standard, and Structural Equation Modeling–Partial Least Squares (SEM-PLS) examined determinants of sustainable adoption. Results indicate a moderate level of GAP implementation (average 71.4%) with a 28.6% gap, particularly in fertilization and water management. One-sample t-tests confirmed significant differences between current practices and the ideal standard. SEM-PLS analysis revealed that social, ecological, and technological factors significantly influence sustainable GAP adoption, with technology as the dominant determinant, while economic and institutional factors were not significant. These findings highlight the importance of improving access to and utilization of agricultural technologies to reduce gaps in GAP implementation in lowland swamp rice farming

1 Introduction

Food security is a strategic issue that is a priority at both the national and global levels, especially amidst the increasing threat of climate change and uncertainty in food production.[1]Rice, as the staple food of the majority of Indonesians, plays a vital role in maintaining national food security, making increasing its productivity an urgent need. Lowland swamps, particularly in South Sumatra Province, have significant potential to support increased rice production through sustainable use of suboptimal land. Rice productivity in lowland swamps averages 4.5 tons per hectare with one planting per year, and can be increased to 6.5–7.5 tons per hectare through the implementation of Good Agricultural Practices (GAP) and an increase in the cropping index to IP200 or IP300 [2].

Climate change has a significant impact on the agricultural sector, particularly on rice cultivation, through changes in rainfall patterns, increased temperatures, and extreme weather events such as floods and droughts that affect productivity and production stability[3]. These conditions also increase the risk of pest and disease attacks and require the use of more efficient and environmentally friendly agricultural inputs. Therefore, the implementation of Good Agricultural Practices (GAP) is becoming increasingly important as an effort to support sustainable agriculture through water management, balanced fertilization, integrated pest control, and the use of technology and rice varieties that are adaptive to climate change. In addition to increasing productivity, GAP also plays a role in strengthening the adaptive capacity of farmers and maintaining the sustainability of the agricultural environment [4].

However, the implementation of GAP in the field often does not comply with established standards because traditional practices are still dominant. Awal Terusan Village in Sirah Pulau Padang District was chosen as the study location because it has achieved IP200, but rice productivity in this area is still not optimal, which indicates a gap between actual GAP practices and expected standards.[5]. Previous studies have mostly focused on the adoption of GAP in general or on organic rice. so that the gap in GAP

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implementation in lowland swamp rice fields has not been studied systematically.[6].

Gaps in the implementation of Good Agricultural Practices (GAP) not only impact rice productivity but also the overall sustainability of the land. Suboptimal GAP practices can reduce crop yields, diminish soil quality, increase pest infestations, and reduce the efficiency of agricultural input use [7]. In this context, this study systematically assesses the dimensions of the GAP gap that have a direct impact on long-term land sustainability and productivity [8]. In addition, this research is also relevant to national policy, where the Indonesian government targets food independence through optimizing suboptimal land, including swampy land [9]The empirical data generated is expected to form the basis for formulating local policies and evidence-based intervention strategies to increase rice productivity effectively and sustainably.

The novelty of this research lies in identifying gaps in GAP implementation specifically for lowland rice cultivation in swampy areas, a specific condition, namely lowland swamps, that has not been systematically studied. Previous studies have largely focused on the level of GAP adoption in general or specifically for rice [10], so that the gap in GAP implementation in lowland swamp rice fields is still less empirically and measurably studied, especially regarding factors that influence the sustainability of agricultural practices.

This study aims to develop a structured assessment of Good Agricultural Practices (GAP) implementation in swampy rice farming by identifying multidimensional implementation gaps and examining their statistical differences across GAP components. Unlike previous studies that primarily describe GAP adoption at a descriptive or location-specific level, this research emphasizes a systematic and quantitative gap-based evaluation framework combined with an analysis of factors influencing the sustainability of GAP implementation. Furthermore, the study investigates the determinants that shape the level of sustainable GAP adoption using an explanatory approach, thereby providing empirical evidence on the structural relationships between influencing factors and GAP performance in swampy agricultural systems. The expected contribution of this research is the development of a more analytical and measurement-oriented perspective on GAP implementation, particularly in swampy land ecosystems, which can be used as a basis for designing targeted strategies to improve agricultural productivity, efficiency, and sustainability in lowland swamp rice farming systems.

2 Materials and Methods

This study was conducted in Awal Terusan Village, Sirah Pulau Padang District, Ogan Komering Ilir Regency, South Sumatra Province, Indonesia. The village was purposively selected because it is a representative lowland swamp (rawa lebak) rice farming area that has achieved a cropping intensity of 200% (IP 200), yet productivity remains suboptimal. Fieldwork was carried out from October to November 2025.

The research employed a quantitative survey design supported by descriptive and inferential analysis. Data were collected through face-to-face structured interviews using a pre-tested questionnaire that contained five items for each GAP component. The quantitative approach was used to measure the level of Good Agricultural Practices (GAP) implementation, quantify the gap between standards and actual practices, and analyze influencing factors. Structural Equation Modeling with Partial Least Squares (SEM-PLS) was applied to examine the relationship between five exogenous variables (social, economic, ecological, institutional, and technological factors) and the endogenous variable (sustainable GAP implementation)[11]. Descriptive statistics were used to present respondent characteristics and implementation levels.

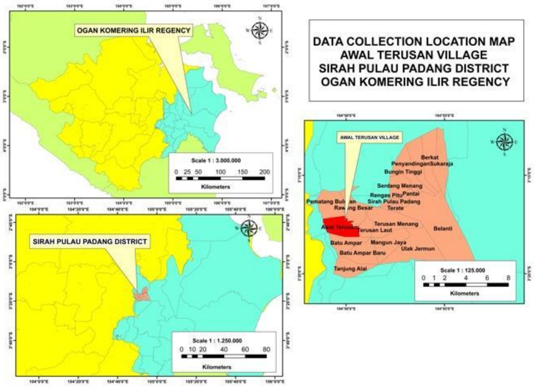

Fig. 2. Site Study Sampling: a) South Sumatra, b) Ogan Komering Ilir Subdistrict, c) Awal Terusan Village

The population of this study comprised 975 rice farmers cultivating lowland swamp areas. A simple random sampling technique was applied using Microsoft Excel's RAND() function to ensure random selection of respondents. The sample size was determined using Slovin's formula with a 15% margin of error, which was selected as a pragmatic consideration due to field constraints such as accessibility of respondents and limited research resources. This calculation resulted in a minimum sample size of 44 respondents. To ensure adequacy for structural equation modeling using Partial Least Squares (PLS-SEM) [12], the sample size was increased to 50 respondents, which satisfies the minimum requirement based on the 10-times rule for model estimation purposes. It should be noted that the 10-times rule is applied to ensure sufficient statistical power for estimating path coefficients in PLS-SEM and does not imply population representativeness. Therefore, while the sample size

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is adequate for PLS-SEM analysis, the generalization of findings should be interpreted with caution given the relatively high margin of error and limited sample size relative to the population.

Primary data were collected through structured questionnaires administered directly to farmers, while secondary data were obtained from the Central Bureau of Statistics (BPS) and relevant scholarly literature.

Table 1. Hypothetical Model Variables and Indicators

Latent Variables	Indicators (Manifest Variables)
Social Factors (X1)	X1.1. Perception of GAP
	X1.2. Trust in extension workers
	X1.3. Influence of norms and culture
	X1.4. Network
Economic Factors (X2)	X2.1. Perception of GAP Costs and Results
	X2.2. Accessibility of production facilities
	X2.3. Market support for GAP products
Ecological Factors (X3)	X3.1. Soil Quality
	X3.2. Waterlogging
	X3.3. Drainage Conditions
	X3.4. Local Climate Change
	X3.5. Presence of buffer vegetation
Institutional Factors (X4)	X4.1. Extension Worker Access
	X4.2. Market Access
	X4.3. Access to Capital Services
	X4.4. Existence of Farmer Groups
	X4.5. Access to Information and Technology
Technology Factor (X5)	X5.1. Technology Availability
	X5.2. Access to Information and Technology Services
	X5.3. Farmers' Technical Capacity/Skills
	X5.4. Adoption and Intensity of Technology Use
	X5.5. Perception of Technology Benefits
GAP Implementation Sustainable (Y)	Y1.1. Level of GAP implementation in the social aspect
	Y1.2. Level of GAP implementation in the economic aspect
	Y1.3. Level of GAP implementation in the ecological aspect
	Y1.4. Level of GAP implementation in the institutional aspect
	Y1.5. Level of GAP implementation in the technological aspect

This hypothetical model is constructed based on indicators for each variable. This model demonstrates the relationship between exogenous and endogenous variables assumed to influence the implementation of sustainable GAP.

Table 2. Operational Measurement of GAP Implementation Level

Level of Analysis	Formula	Description	Interpretation
Indicator Level	I (%) = (G / A) × 100	G = total score of each indicator, A = maximum possible score (highest scale × number of respondents)	Measures the level of GAP implementation for each indicator
Aspect Level	A (%) = (S / J) × 100	S = total score of all indicators within an aspect, J = maximum possible score for that aspect	Measures the level of GAP implementation for each aspect

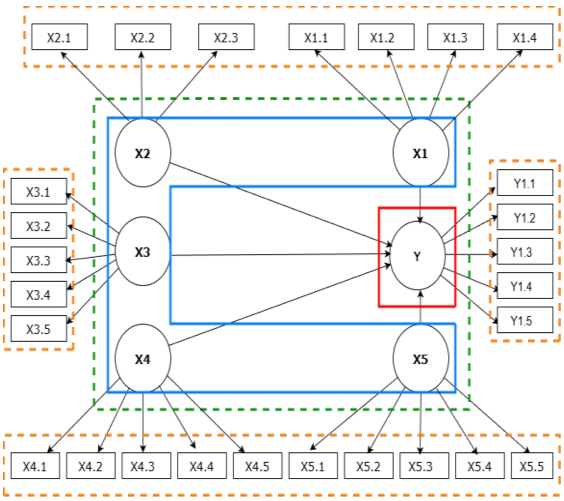

Fig. 2. Hypothetical Model

Researchers will analyze the model through several stages using goodness of fit criteria. The measurement model (outer model) will be assessed through convergent validity and reliability tests. The structural model (inner model) will be assessed by examining the R^2 and F^2 values, as well as hypothesis testing using bootstrapping analysis.

3 Results and Disucussions

3.1 Respondent characteristics

Table 3. Respondent Characteristics

	Number of people)	**Percentage (%)**
Gender		
Man	27	54
Woman	23	46
Age (Years)		
15-64	40	80
>64	10	20
Education		
Did not finish elementary school	1	2
Elementary School	28	56
JUNIOR HIGH SCHOOL	10	20
SENIOR HIGH SCHOOL	7	14
S1	4	8
Land Area (ha)		
<1	12	24
≥1	38	76
Land Ownership Status		
Rent	9	18
Profit sharing	2	4
One's own	39	78
Experience of attending training		
Once	11	22
Never	39	78

3.2 Gap Level of Good Agricultural Practices Implementation

Good Agricultural Practices (GAP) are cultivation guidelines designed to ensure safe, high-quality, and sustainable agricultural products. In Awal Terusan Village, GAP implementation in swampy rice paddies was analyzed across seven aspects: land preparation, water supply, seeds and seedbeds, planting, fertilization, protection/maintenance, and harvesting. Respondents' scores were converted into percentages and categorized as low, medium, or high, then compared against the GAP standard (100%) to identify gaps between farmer practices and ideal recommendations. The results revealed aspects that were well implemented and those that needed improvement.

Table 4. Level of GAP Implementation in Land Preparation Aspects

Aspect	**Question Indicator**	**ercentag (%)**	**Category**
PreparationLand	1. Optimal pH of rice field soil	89.0	High
	2. First pirate depth	84.5	Medium
	3. Depth of tillage	79.5	Medium
	4. Activities carried out in land processing	62.5	Medium
	5. Activities carried out during rice field mudding	79.0	Medium
	Total Average	78.9	Medium
	Gap (%)	21.1	
Provision Water	1. Flooding in the early stages of pollen formation	68.5	Medium
	2. Inundationat the stage of filling the grain - full grain	54.5	Low
	3. The water source meets irrigation water quality standards and is free from contamination.	86.5	High
	4. Regulating water levels in rice fields during the rice planting season	74.5	Medium
	5. Using water-saving irrigation methods such as AWD or periodically draining the rice fields	50.5	Low
	Total Average	66.9	Medium
	Gap (%)	33.0	
PreparationSeeds and Nurseries	1. How many seeds are recommended for the wet direct sowing system?	54.5	Low
	2. Planting rice simultaneously in one field	82.0	Medium
	3. Types of seed varieties	84.0	Medium
	4. Seed Quality	85.0	Medium
	5. Nurseries are carried out in land that is easy to monitor and well managed.	95.5	High
	Total Average	80.2	Medium
	Gap (%)	19.8	
Planting	1. Planting distance	78.0	Medium
	2. Plant density at 15 days after planting	60.5	Low
	3. Planting is carried out by paying attention to the season and the correct planting distance.	94.0	High
	4. Methodplanting used in the land	50.0	Low
	5. Land health is taken into account during planting	91.5	High

	(e.g., weed-free, sufficient water)		
	Total Average	74.8	Medium
	Gap (%)	25.2	
Fertilization	1. Recommended dose of urea	38.0	Low
	2. Provide basic N fertilizer with the following initial N fertilizer requirements: 50 kg N/ha 14 days after planting	61.5	Medium
	3. Provide basic P fertilizer (TSP) with the initial P2O5 fertilizer requirement: 50-75 kg P2O5/ha at the same time as planting.	52.5	Low
	4. Provide basic K fertilizer with the provisions of KCl Fertilizer: 30-50 kg / ha together 14 HST	46.5	Low
	5. Fertilizerorganic is used in fertilization	58.0	Low
	Total Average	51.3	Low
	Gap (%)	48.7	
Protection and Maintenance	1. Frequency of pest and disease monitoring	98.5	High
	2. Weeding is done 30-35 days after planting and the water is removed. After that, water is added again 40 days after planting.	68.5	Medium
	3. Activitywhich is done to control HPT	54.0	Low
	4. The most appropriate time to start spraying drugs (pesticides) on rice plants	77.5	Medium
	6. Try non-chemical control methods before using chemical pesticides.	55.5	Low
	Total Average	70.8	Medium
	Gap (%)	29.2	
Harvest and Post-Harvest	1. Timethe right time to start the rice harvest	91.5	High
	2. Ideal moisture content of grain at harvest	86.5	High
	3. Productivitycultivated land	38.0	Low
	4. Handlingcrop residue after harvest	80.0	Medium
	5. Is burning of crop residues on land permitted according to GAP standards?	88.5	High
	Total Average	76.9	Medium
	Gap (%)	23.1	

Source: Processed Data, 2026

Implementation gap represents not only technical deficiencies but also the tension between farmers' solid social capacity and persistent limitations in technological access and ecological constraints.

To address these issues, targeted interventions are essential. Priority must focus on fertilization through enhanced training on dosage, timing, and appropriate fertilizer types aligned with GAP standards. Intensified extension programs, demonstration plots, and continuous field mentoring by agricultural extension officers can reduce misapplication and improve nutrient-use efficiency.

Water management, currently in the moderate category, requires strengthening via training on Alternate Wetting and Drying (AWD) techniques and improved irrigation scheduling to optimize water use while supporting crop growth. For land preparation, planting, and crop protection—also at moderate levels but with several weak indicators—greater access to simple technologies such as soil pH meters, proper planting systems, and Integrated Pest Management (IPM) training is recommended to decrease reliance on chemical pesticides.

Post-harvest practices, which already show relatively good performance, should be reinforced by enforcing maturity standards, proper residue management without open burning, and the adoption of basic post-harvest tools to minimize losses. Institutional strengthening through regular farmer group meetings and closer collaboration with agricultural agencies will facilitate sustained technology transfer. Village government support in the form of timely production input assistance, irrigation network rehabilitation, and agricultural machinery facilitation remains crucial.

Through integrated improvements in technical practices, institutional capacity, and governmental backing, GAP implementation in Awal Canal Village can advance significantly. Such progress will enhance productivity and promote the long-term sustainability of tidal lowland rice farming.

3.3 GAP Implementation Gap Significance Test

This study used a One Sample T-Test to determine whether the level of Good Agricultural Practices (GAP) implementation achieved by farmers differed significantly from the ideal standard value. The test value used was 100, which represents the condition of GAP implementation fully in accordance with the established standards. This test compares the average value of the GAP implementation level with the standard value, thus producing a clear picture of the magnitude of the gap between actual farmer practices and GAP guidelines, which were analyzed statistically.

Table 5. One Sample T-Test Results

One-Sample Test				
Test Value= 100				
	T	Df	*Sig. (2-tailed)*	*Mean Difference*
Implementation Level GAP	-25,220	49	0,000	-28,640

The results of the One Sample T-Test showed a t-value of –25.220 with a degree of freedom (df) of 49 and a p-value (Sig. 2-tailed) of 0.000. Because the significance value is less than 0.05, the null hypothesis stating that there is no significant difference between farmers' GAP implementation and the standard value is rejected. Thus, there is a real gap between the level of GAP implementation carried out by farmers and the ideal standard. The mean difference value of –28.640 (95% CI: –30.92 to –26.36) confirms that the average GAP implementation is far below the value of 100.

3.4 Measurement Model Assessment (Outer model)

Figure 3 shows the initial measurement model used in the Partial Least Squares (PLS) analysis. This initial model was then evaluated by examining the outer loading values of each indicator against the latent construct being measured.

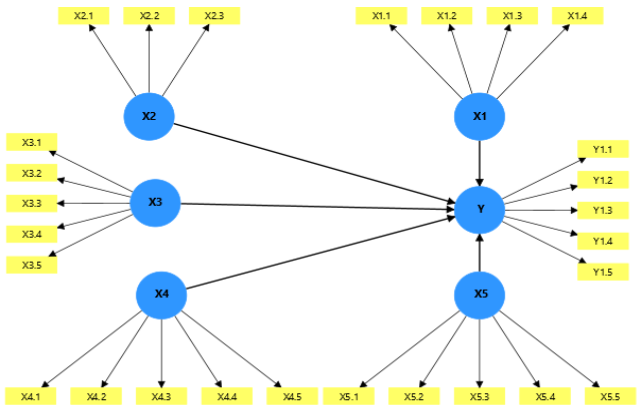

Fig. 3. Initial Measurement Model (Hypothetical)

PLS Algorithm estimation of the research model after elimination. The values listed for each indicator indicate the magnitude of the outer loading on the measured latent construct. Furthermore, to provide a more systematic explanation, the outer loading values are presented in tabular form in Table 5.

Table 6. Outer Loading Values of the Research Model

Variables	Indicator	*Outer Loading*	Decision
Social Factors (X1)	X1.1.	0.905	Valid
	X1.3.	0.816	Valid
	X1.4.	0.729	Valid
Economic Factors (X2)	X2.1.	0.892	Valid
	X2.2.	0.892	Valid
Ecological Factors (X3)	X3.1.	0.853	Valid
	X3.2.	0.776	Valid
	X3.4.	0.866	Valid
Institutional Factors (X4)	X4.1.	0.770	Valid
	X4.2.	0.914	Valid
	X4.4.	0.950	Valid
Technology Factor (X5)	X5.1.	0.929	Valid
	X5.2.	0.795	Valid
	X5.4.	0.891	Valid
	X5.5.	0.833	Valid
Good Agricultural Practices Compliance Level (Y1)	Y1.1.	0.730	Valid
	Y1.2.	0.812	Valid
	Y1.3.	0.742	Valid
	Y1.4.	0.771	Valid
	Y1.5.	0.900	Valid

All indicators in the latest research model have an outer loading value of ≥ 0.7. This indicates that each indicator retained in the model adequately represents the latent construct and has a strong correlation with the measured variables. Outer loading values that meet this threshold indicate that the indicators used have good convergent validity in explaining the latent constructs in the research model.

Table 7. Average Variance Extracted (AVE) Value

Latent Variables	**AVE**	**Decision**
Social Factors (X1)	0.673	Valid
Economic Factors (X2)	0.795	Valid
Ecological Factors (X3)	0.693	Valid
Institutional Factors (X4)	0.777	Valid
Technology Factor (X5)	0.746	Valid
Sustainable GAP Implementation (Y1)	0.630	Valid

Based on Table 6, all latent constructs in this study have AVE values above 0.5. This indicates that each latent construct is able to explain more than 50% of the variance in the indicators that reflect it. An AVE value that meets the minimum threshold indicates that the indicators used in each construct have a good level of fit in representing the latent variable being measured.

Table 8. Cronbach's Alpha and Composite Reliability

Variables	*Cronbach's Alpha*	Composite Reliability	Decision
Social Factors (X1)	0.751	0.860	Reliable
Economic Factors (X2)	0.742	0.886	Reliable

Ecological Factors (X3)	0.780	0.871	Reliable
Institutional Factors (X4)	0.857	0.912	Reliable
Technology Factor (X5)	0.885	0.921	Reliable
Sustainable GAP Implementation(Y)	0.852	0.894	Reliable

Based on the reliability test results, all latent variables had a Cronbach's Alpha value ≥ 0.6. This indicates that the indicators within each construct have sufficient consistency in measuring the same concept. Thus, the research instrument can be said to be stable and capable of producing relatively consistent measurements.

The analysis results show that the R^2 value obtained is 0.607. This value indicates that the social, economic, ecological, institutional, and technological factors have a fairly good ability to explain variations in the implementation of sustainable GAP, so that the model formed is included in the moderate category. Substantively, the R^2 value of 0.607 indicates that 60.7% of the variation in the implementation of sustainable GAP among farmers can be explained by the combination of factors used in the research model.

The $f2$ value describes the size of the influence or effect given by the independent variable on the dependent variable. The threshold value is around $f2 \leq 0.02$ for a small influence, $0.02 < f2 \leq 0.15$ for a medium influence, and $f2 > 0.15$ for a large influence. The $f2$ value is presented in the following table.

Table 9. F-Square Value

Variables	*F-Square*	Information
X1 → Y	0.103	Intermediate
X2 → Y	0.011	Small
X3 → Y	0.075	Intermediate
X4 → Y	0.059	Intermediate
X5 → Y	0.187	High

Based on the effect size (f^2) analysis, each exogenous variable contributes differently to explaining sustainable GAP implementation. The smallest effect is found in the economic factor (X2 → Y), with an f^2 value of 0.011, indicating a weak contribution. In contrast, the technological factor (X5 → Y) shows the strongest effect, with an f^2 value of 0.187, making it the most dominant variable in the model.

The social factor (X1) has a moderate effect size of 0.103, suggesting that social aspects contribute meaningfully to sustainable GAP implementation. The ecological factor (X3), with an f^2 value of 0.075, also shows a moderate contribution, indicating the importance of environmental conditions in supporting sustainable farming practices. Similarly, the institutional factor (X4) has a moderate effect size of 0.059, showing that institutional support, such as access to information, assistance, and facilities, helps improve GAP implementation.

Overall, technology is the most influential factor in explaining sustainable GAP implementation, while economic factors provide the weakest additional explanatory power in the model.

Table 10. Hypothesis Testing Results Table

Variables	*Path coefficient*	*P-Value*
Social Factors of GAP Implementation→	0.241	0.024Sig.
Economic Factors□ GAP Implementation	0.072	0.562
Ecological Factors□ GAP Implementation	0.194	0.044Sig.
Institutional Factors□GAP Implementation	0.214	0.168
Technology Factors□ GAP Implementation	0.386	0.006Sig.

Social Factors → Sustainable GAP Implementation

Social factors play a crucial role in driving the implementation of sustainable GAP because farmers' behavior in implementing cultivation practices is influenced not only by technical aspects but also by the surrounding social environment. Interactions between farmers, prevailing customs within the community, and perceptions of the importance of sustainable agriculture shape how farmers make decisions in their farming operations. Farmers who are active in groups or have good communication with other farmers tend to be more open to innovation and more receptive to the implementation of GAP. Conversely, strong traditional habits cause some farmers to maintain old cultivation methods, especially in aspects of fertilization and water management. This condition indicates that changes in farmer behavior are strongly influenced by social support and collective learning processes at the farming community level. Community-based education and training: Community-based interventions that improve farmers' knowledge, attitudes, and practices have proven effective in increasing the adoption of sustainable practices. Cross-sector collaboration: Cooperation between governments, NGOs, and other stakeholders can strengthen social and technical support for farmers as well as research [13].

Economic Factors → Sustainable GAP Implementation

Economic factors have not been a primary consideration for farmers in implementing sustainable GAP. Farmers tend to focus more on short-term production sustainability than on the long-term benefits of GAP implementation. Implementing GAP often requires additional investments in labor, resources, and infrastructure, which many farmers perceive as not yielding immediate financial returns. For example, higher production costs in GAP farms compared to conventional farms have been noted, with often lower profitability due to added costs like certification and compliance. Furthermore, implementing some GAP components requires additional costs, labor, and production inputs that are not considered capable of providing direct benefits to farmers. This condition causes farmers to still choose conventional cultivation practices, which are considered simpler and more suited to their economic capabilities. This indicates that without tangible economic benefits or immediate incentives, farmers tend to be difficult to motivate to implement GAP optimally. Farmers are more likely to adopt GAP when they perceive direct economic benefits, such as increased market access, higher crop prices, or reduced input costs. For instance, farms with third-party food safety audits or those selling to wholesale markets reported higher financial benefits.

Ecological Factors → Sustainable GAP Implementation

Ecological factors play a significant role in the implementation of sustainable GAP, as the success of GAP implementation is highly dependent on the conditions of the farming environment. Water availability, land quality, and climate conditions are factors that determine a farmer's ability to implement cultivation practices according to GAP standards in swampy areas, changing water conditions and seasonal uncertainties often force farmers to adapt cultivation practices to field conditions. As a result, the application of GAP, particularly in water management and fertilization, is crucial, becoming inconsistent. This condition indicates that even though farmers are willing to implement GAP, environmental limitations often become obstacles that are difficult for farmers to control independently.

Institutional Factors → Sustainable GAP Implementation

Institutional factors have not been able to provide a strong influence on the implementation of sustainable GAP because the role of existing institutions still tends to be administrative and has not touched on the practical needs of farmers in line with research [14]. The existence of farmer groups, extension workers, and access to information have not fully helped farmers improve their technical skills or gain economic benefits from GAP implementation. Farmers have not seen any real difference in profits between farms that implement GAP and those that do not. Furthermore, the lack of ongoing support has resulted in farmers being less motivated to change their cultivation practices. This situation suggests that institutions would be more effective if they function not only as a means of coordination but also provide technical solutions, market access, and tangible economic support for farmers.

Technology Factors → Sustainable GAP Implementation

The technological factor is the most determining factor in the implementation of sustainable GAP because technology functions as a link between knowledge and practice in the field [15]. The implementation of GAP requires technological support that can help farmers manage their farming more effectively, particularly in aspects of fertilization, water management, and adaptation to climate change. When technology and supporting facilities are available, farmers more easily implement cultivation practices according to GAP standards. Conversely, technological limitations cause farmers to continue using conventional methods that are easier to implement even though they do not comply with GAP principles. This shows that the successful implementation of GAP is not sufficient only through extension or increased knowledge, but also requires technological support that can be directly used by farmers in their farming activities.

Conclusion

The implementation of Good Agricultural Practices (GAP) in swamp rice farming in Awal Terusan Village is still not optimal and shows a gap between GAP standards and farmer cultivation practices in the field, especially in the aspects of fertilization and water management. The results of the study indicate that technological, social, and ecological factors have a significant influence on the implementation of sustainable GAP. Technological factors are the most dominant factor because they play a direct role in supporting farmers' ability to implement cultivation practices according to GAP standards. Social factors also influence GAP implementation through interactions between farmers and social learning processes, while ecological factors are related to the conditions of the farming environment, especially water availability and the characteristics of the swamp land. Conversely, economic and institutional factors have not shown a significant influence because the economic benefits and institutional support have not been felt by farmers in the implementation of sustainable GAP.

Suggestion

Improving the implementation of sustainable GAP requires more targeted technological support and technical assistance, particularly on balanced fertilization and water management in swampy areas. The government and relevant parties need to strengthen the provision of agricultural technology tailored to local conditions to facilitate farmers' implementation of GAP standards in the field. Furthermore, strengthening the role of farmer groups is crucial as a learning medium, information exchange, and improvement of farmers' technical skills in implementing sustainable cultivation practices. Further research is recommended to conduct broader studies and develop more comprehensive analytical models, particularly regarding institutional strengthening and the integration of technological support in promoting the implementation of sustainable GAP.

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References

1. A. M. Abduh *et al.*, "Rice crop management to increase productivity and reduce methane emissions in Indonesia," *Chil. J. Agric. Res.*, vol. 86, no. 1, pp. 140–153, 2026, doi: 10.4067/s0718-58392026000100140.
2. B. E. Ayamba *et al.*, "Increasing lowland rice yields of smallholder farmers through the adoption of good agricultural practices in the forest agro-ecological zone of Ghana," *Plant Prod. Sci.*, vol. 26, no. 4, pp. 335–349, 2023, doi: 10.1080/1343943X.2023.2251180.
3. M. Yamin *et al.*, "Analysis of Climate-Smart Agriculture (CSA) Adoption Level on Tidal Land and Its Effect on Household Food Security," *Research on World Agricultural Economy*, vol. 6, no. 2 SE-Research Article, pp. 499–513, Mar. 2025, doi: 10.36956/rwae.v6i2.1736.
4. M. Rahman, Md. M. Rahman, N. Khatun, and A. K. M. K. Pervez, "Analysing Research on Good Agricultural Practices (GAP): A Bibliometric Approach to Global Trends," *Journal of Agriculture and Ecology Research International*, vol. 25, no. 6, pp. 242–255, 2024, doi: 10.9734/jaeri/2024/v25i6655.
5. E. Istiyanti, A. Huda Aditya Darmawan, and K. Keothoumma, "The factors of affecting level of implementation Standard Operational Procedure-Good Agriculture Practice (SOP-GAP) organic rice farming," in *E3S Web of Conferences*, 2023. doi: 10.1051/e3sconf/202344402025.
6. A. S. Kumar and S. C.S., "Knowledge heterogeneity in Integrated Pest Management and its impact on yield gap: An empirical study among rice farmers in Kerala, India," *Crop Protection*, vol. 201, 2026, doi: 10.1016/j.cropro.2025.107498.
7. R. R. Rachmawati *et al.*, "Regional Variability in Climate-Rice Yield Relationships Across Java, Indonesia: A 30-Year Spatial-Temporal Analysis," *International Journal of Design and Nature and Ecodynamics*, vol. 20, no. 8, pp. 1815–1825, 2025, doi: 10.18280/ijdne.200812.
8. R. Darma, P. O'Connor, R. Akzar, A. N. Tenriawaru, and R. Amandaria, "Enhancing Sustainability in Rice Farming: Institutional Responses to Floods and Droughts in Pump-Based Irrigation Systems in Wajo District, Indonesia," *Sustainability (Switzerland)*, vol. 17, no. 8, 2025, doi: 10.3390/su17083501.
9. N. Herlina, H. Wahyuni, F. P. Winahyu, and K. Anwar, "The Movement to Maintain Food Security Through Technological Advancements and Local Diversification: Ministry of Agriculture Republic of Indonesia," *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan*, vol. 14, no. 3, pp. 555–565, 2024, doi: 10.29244/jpsl.14.3.555.
10. S. P. Oo and K. Usami, "Farmers' perception of good agricultural practices in rice production in Myanmar: A case study of Myaungmya District, Ayeyarwady Region," *Agriculture (Switzerland)*, vol. 10, no. 7, pp. 1–20, 2020, doi: 10.3390/agriculture10070249.
11. F. Magno, F. Cassia, and C. M. Ringle, "A brief review of partial least squares structural equation modeling (PLS-SEM) use in quality management studies," *TQM Journal*, vol. 36, no. 5, pp. 1242–1251, 2024, doi: 10.1108/TQM-06-2022-0197.
12. G. Dash and J. Paul, "CB-SEM vs PLS-SEM methods for research in social sciences and technology forecasting," *Technol. Forecast. Soc. Change*, vol. 173, 2021, doi: 10.1016/j.techfore.2021.121092.
13. S. Pawar and R. M. Channaveer, "Impact of community education interventions on adopting sustainable agriculture practices among smallholder farmers in Vaijapur Village, Karnataka, India," *Discover Global Society*, vol. 3, no. 1, 2025, doi: 10.1007/s44282-025-00287-1.
14. A. M. Azis, M. Irjayanti, and Y. R. Murti, "Advancing traceability and sustainability through a digital information system in Indonesia's rice supply chain," *Discover Sustainability*, vol. 7, no. 1, 2026, doi: 10.1007/s43621-025-02544-4.

15. Y. Apriyana *et al.*, “The Transformation of Rice Crop Technology in Indonesia: Innovation and Sustainable Food Security,” *Agronomy*, vol. 13, no. 1, 2023, doi: 10.3390/agronomy13010001.