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Sustainability of Rice Farming in the Northern Coastal Area of Batang Regency, Central Java, Indonesia, Using Rice Check Indicators

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ABSTRACT: Rice cultivation on saline soils in the coastal region of the northern coast of Java is crucial for ensuring food availability for coastal communities. Indonesian farmers have recently encountered environmental challenges, including more frequent tidal flooding and increased soil salinity due to seawater intrusion, which have led to reduced crop fertility. This study aimed to analyze the factors influencing the sustainability of rice cultivation in this region. Primary data were collected through interviews with 154 rice farmers. The data were analyzed using the Rice Check method, as specified by the Ministry of Agriculture, with indicators expressed in the Farmer Sustainability Index (FSI), which was subsequently examined through regression analysis. The findings revealed that the average FSI score was 71.75%, with a range from 46.43% to 96.43%. These results suggest that most farms are classified as sustainable, although sustainability performance varies among farmers. Education level and farmer's experience significantly impact the sustainability of farming operations. These findings highlight the critical role of farmers' capacity and skills in managing their farms, emphasizing the importance of their ability to adapt to changing environmental conditions.

1. INTRODUCTION

Rice serves as a primary source of nutrition for half of the global population and is a fundamental food item in Asia, particularly in Indonesia. Consequently, rice farming is crucial to a nation's strategy for ensuring food security. Nonetheless, farmers encounter growing challenges in sustaining rice cultivation over the long term. These challenges include the extensive use of chemicals such as fertilizers, pesticides, fungicides, and herbicides; degradation of land and scarcity of water; and poor management of natural resources, all contributing to a decline in ecosystem health and productivity [1]. Additionally, rapid and unpredictable climate changes exacerbate the socioeconomic difficulties associated with shifting from traditional to sustainable agricultural practices [2], [3].

In Indonesia, the reliance on chemical fertilizers in rice cultivation diminishes plant nutrition and heightens susceptibility to pest and disease outbreaks, leading to an increase in pesticide application [4]. Reports indicate that several rice production areas in Indonesia excessively use fertilizers like nitrogen, phosphorus, and potassium, which can degrade soil quality and contribute to greenhouse gas emissions, raising sustainability concerns in rice farming [5]. To address this, the Indonesian government, through the Ministry of Agriculture, launched the Rice Check system in 2017 [6]. This initiative, modeled after the Rice Check Australia program, aims to assess agricultural practices, promote sustainable farming, and assist farmers in adhering to a series of guidelines covering seed selection, fertilizer application, pest control, and water management [7].

Research conducted previously on farmer adherence to the Rice Check system in nations like Malaysia, Vietnam, and Indonesia has demonstrated enhancements in both production results and environmental conditions [8], [9], [10]. This research aims to examine the Rice Check system within rice agriculture along the northern coast of Java. Farmers in these coastal regions encounter challenges such as saltwater intrusion into rice paddies, inadequate irrigation, and improper fertilization, all

contributing to nutrient imbalances that diminish rice yields [11]. A lack of comprehensive farm management knowledge can hasten land degradation, further reducing crop productivity. There is a need for empirical analysis to assess the sustainability performance of rice farms in the coastal area using rice check indicators, while also pinpointing the key factors influencing farmer adherence to sustainable rice farming practices. The findings from this study are anticipated to offer insights into the sustainability status of rice farming in Java's northern coastal region, which could inform policy decisions and extension initiatives aimed at enhancing sustainability prospects for rice agriculture.

2. MATERIALS AND METHODS

This study was conducted in the coastal region of Batang District, situated in Batang Regency, Central Java Province, Indonesia, from April to June 2025. The selection of this area was deliberate due to its vulnerability to tidal flooding and seawater intrusion, which contribute to flooding and increased soil salinity. These conditions pose significant challenges to rice yield, soil fertility, and the long-term sustainability of rice agriculture [11–13]. A quantitative research methodology was employed, involving the collection of primary data through direct, in-person interviews with 154 randomly selected rice farmers. The sampling was conducted using random sampling based on farmer groups within the study area, which were crucial in identifying the population of rice farmers from which participants were randomly selected. The participants were rice farmers actively engaged in rice cultivation in the study area during the research period. Data collection was facilitated through a structured questionnaire that examined farmers' socioeconomic characteristics, including education, age, household size, cultivated land area under cultivation, and farmer's experience. The questionnaire also collected information on rice farming practices, such as the types of rice seed varieties used, seed quantity, fertilizers, pesticides, land preparation, irrigation, pest and weed control, harvesting, and post-harvest processes. Direct interviews with the selected farmers provided insights into their actual farming practices and socioeconomic profiles.

2.1 Research Framework

The Rice Check Indonesia framework, developed by the Ministry of Agriculture, was employed to evaluate the sustainability of rice farming practices. This framework includes recommended practices for rice production across various stages of the production cycle. In this study, 22 indicators were selected and adapted to align with the agroecological conditions of coastal rice farming. These indicators encompass seedling management, land preparation, fertilizer application, weed management, pest management, water management, and harvesting and post-harvest handling, as detailed in Table 1. Each indicator was scored based on the farmer's adherence to the recommended practices. A score of +1 was assigned if the farmer adhered to the recommended practice, 0 if the farmer did not adhere, and –1 if the farmer adopted a practice deemed detrimental to sustainable rice cultivation. The scoring criteria and recommended thresholds for each indicator are outlined in Table 1.

Table 1. Components of Rice Check

Rice Check Indicators	Amount of Frequency	Max Score	Min Score
Rice Check 1,2,3 (Seedling)			
Planting time	December-March = 1, Not following = 0	1	0
Block-wise synchronized planting	Following = 1, Not following = 0	1	0
Variety	Salinity-tolerant varieties = 1, Not following = 0	1	0
Varietal Characteristic	Improved and adaptive rice varieties with tolerance to saline soils, endemic pests, and diseases = 1, Not following = 0	1	0
Amount of seeds	10-20 kg.ha ⁻¹ = 1, <10 kg.ha ⁻¹ = 0, >20kg.ha ⁻¹ = -1	1	-1
Seed sowing	19–23 days prior to transplanting = 1, Not following = 0	1	0
Rice Check 4,6 (Land Preparation)			

Depth (20-40cm), followed by the repair of bunds	Following = 1, Not following = 0	1	0
Soil moisture status	Moist but not flooded = 1, Not following = 0	1	0
Plant spacing	20 x 20 cm or 25 x 25 cm = 1, Not following = 0	1	0
Rice check 7 (Fertilizer)			
Timing			
1 st application	Basal fertilizer was applied at the time of transplanting = 1, Not following = 0	1	0
2 nd application	Within 15 – 20 days after planting = 1, Not following = 0	1	0
3 rd application	Within 35 - 40 days after planting = 1, Not following = 0	1	0
Organic fertilizer	Application according to the recommended rate of 1 ton ha ⁻¹ = 1, Application below the recommended rate (<1 ton ha ⁻¹) = 0, and No organic fertilizer application = -1	1	-1
Amount of Fertilizer	Fertilizer application according to recommendation (225 kg ha ⁻¹ of urea and 250 kg ha ⁻¹ of Phonska) = 1, Fertilizer application outside the recommended rate = 0, and No fertilizer application = -1	1	-1
Rice Check 9 (Weed Management)			
Weed management	Regular manual weeding = 1, No weeding = 0	1	0
Rice Check 10 (Pest Management)			
Pest Management	Proper pest monitoring and targeted pesticide application = 1, Inadequate or mistargeted pesticide application = 0, and No pest monitoring or pesticide application = -1	1	-1
Rice Check 8, 12, 13 (Water Management)			
Irrigation management	Following irrigate schedule = 1, Not following = 0	1	0
Flooding depth (flowering–grain filling)	Water depth 20-25 cm = 1, Water depth <20cm = 0, and Water depth >25 cm = -1	1	-1
Flooding depth (grain-filling–ripening)	Water depth 5–10 cm = 1, Water depth <5 cm = 0, Water depth >10 cm = -1	1	-1
Drainage	Field drainage conducted approximately 10 days before harvest, when the grains started to turn yellow = 1, Not following = 0	1	0
Rice Check 14, 15 (Harvesting and Post-Harvest)			
Harvesting	Harvest conducted when the grains were yellow, hard, and fully matured = 1, Not following = 0	1	0
Post-Harvest handling	Harvested paddy was immediately cleaned and sun-dried to a moisture content of 16–18% = 1, Not following = 0	1	0
Total		22	-6

The Farmer Sustainability Index (FSI) was determined by compiling the scores derived from 22 rice check indicators. As outlined in Table 1, the unadjusted FSI scores spanned from -6 to +22. These minimum and maximum scores denote the theoretical lower and upper boundaries established by the scoring framework of the chosen indicators. To facilitate comparison among farmers, the unadjusted scores were normalized to a 0–100 scale using the following equation:

$$FSI_i = \frac{S_i - S_{min}}{S_{max} - S_{min}} \times 100$$

where (FSI_i) is the normalized Farmer Sustainability Index of farmer (i), (S_i) is the total unadjusted score obtained by farmer (i), (S_{min}) is the minimum possible score (-6), and (S_{max}) is the maximum possible score (+22).

The normalized Farmer Sustainability Index (FSI) quantifies the extent to which farmers adhere to the recommended rice farming practices. An elevated FSI signifies increased compliance with these practices, thereby reflecting enhanced sustainability performance as measured by the Rice Check indicators employed in this study. Conversely, a reduced FSI denotes a greater divergence from the recommended practices. The FSI values were categorized into sustainability levels according to the classification system proposed in a prior study [14]. The criteria for this classification are detailed in Table 2.

Table 2. Criteria for the Farmer Sustainability Index

Sustainability index value (%)	Sustainability Category
>70 to 100	Sustainable
>60 to ≤70	Somewhat sustainable
>50 to ≤60	Intermediate sustainable
>40 to ≤50	Possibly quite unsustainable
>20 to ≤40	Possibly unsustainable
≤20	Possibly very unsustainable

The second stage of the analysis employed multiple linear regression utilizing the ordinary least squares (OLS) method to determine the socioeconomic factors influencing the sustainability performance of rice farmers. The normalized Farm Sustainability Index (FSI) served as the dependent variable, whereas education, age, household size, cultivated land area, and farmer's experience were incorporated as explanatory variables. The OLS model was chosen due to the normal distribution of FSI values within the 0–100 range, thereby satisfying the requisite assumptions for regression analysis [15], [16]. The regression model is specified as follows:

$$FSI_i = \beta_0 + \beta_1 EDU_i + \beta_2 AGE_i + \beta_3 FAM_i + \beta_4 LAN_i + \beta_5 EXP_i + \varepsilon_i$$

where (FSI_i) represents the farmer sustainability index of farmer (i); (EDU_i) is the farmer's formal education; (AGE_i) is the farmer's age; (FAM_i) is the number of household members; (LAN_i) is the cultivated land area; (EXP_i) is farmer's experience in rice farming; (β_0) is the intercept; (β_1 – β_5) are the estimated regression coefficients; and (ε_i) is the error term.

Education, farmer's experience, and cultivated land area were hypothesized to have positive effects on FSI ($\beta_1, \beta_4, \beta_5 > 0$) because higher educational attainment, greater farming experience, and larger cultivated areas may enhance farmers' capacity to implement recommended farming practices. In contrast, age and household size were hypothesized to have negative effects on FSI ($\beta_2, \beta_3 < 0$), as older farmers or households with greater family responsibilities may face differences in their capacity and resource allocation for adopting recommended practices [9]. The operational definitions and measurement units of the variables used in the regression model are listed in Table 3.

Table 3. Operational Definitions and Measurement Units of the Variables

Variables	Definition	Unit
FSI_i	Normalized Farmer Sustainability Index based on 22 Rice Check Indicators	%
EDU_i	Formal Education of the farmer	Years
AGE_i	Age of the Farmer	Years
FAM_i	Number of Household Members	Persons
LAN_i	Cultivated Land Area	Hectares
EXP_i	Farmer's Experience in Rice Farming	Years

Several diagnostic procedures were conducted to assess the suitability of the OLS regression model. Multicollinearity among the explanatory variables was assessed using the variance inflation factor (VIF). Heteroscedasticity was examined using the Breusch–Pagan test. These diagnostic procedures were conducted before interpreting the regression coefficients to assess whether multicollinearity and unequal error variances could affect the reliability of the estimated relationships. The regression analysis was performed using STATA version 14. The statistical significance of individual regression coefficients was evaluated at the 1%, 5%, and 10% significance levels, corresponding to ($p < 0.01$), ($p < 0.05$), and ($p < 0.10$), respectively.

3. RESULTS AND DISCUSSION

3.1. Socio-Economic Characteristics of Rice Farmers

The socio-economic characteristics of rice farmers (Table 4) provide an overview of the farmers' potential to adopt sustainable agricultural practices.

Table 4. Respondent Characteristics of Maize Farmers

Variables	Mean	Std. Deviation
Education (years)	10.52	3.75
Age (years)	53.73	12.16
Household size (individual)	4.67	3.57
Cultivated Land Area (ha)	1.15	1.25
Farmer's experience (years)	14.94	14.57

Source: Primary data processed, 2025

The respondents' average education level was 10.52 years, suggesting that the majority of farmers in the coastal area of Batang Regency have completed junior high school. The mean age of 53.73 years implies that the farmers managing their farms are relatively older, which may affect productivity. On average, each farmer's household comprised 4.67 members, indicating a reliance on family labor for rice-farming activities. The average cultivated land area was 1.15 hectares, reflecting the predominance of smallholder farmers in this region. Furthermore, the average farming experience among rice farmers was 14.94 years, demonstrating that they generally possess substantial experience and an understanding of agroecological conditions, which enhances their capacity to sustain productivity amidst increasing environmental challenges.

3.2 Rice farmer's Production Input

Table 5 presents the production inputs of rice farmers, revealing that the average seed usage in the coastal area was 65.54 kg ha⁻¹, which surpasses the recommended amount (25 kg ha⁻¹). This excessive seed usage is attributed to the failure of many rice seeds to germinate due to pest infestations or tidal flooding, necessitating replanting. The average application of nitrogen

fertilizer was 232.97 kg ha⁻¹, significantly higher than the applications of phosphorus and potassium fertilizers, each at 58.54 kg ha⁻¹. This pattern suggests a preference for nitrogen-dominant fertilization, a prevalent practice among rice farmers in Indonesia. Additionally, the average pesticide usage was 1.87 litre ha⁻¹, primarily employed to combat pest infestations, notably the brown planthopper, at the study site.

Table 5. Production Input of Rice Farmers

Production Input	Mean	Std. Deviation
Seed (kg.ha ⁻¹)	65.54	59.27
N fertilizer (kg.ha ⁻¹)	232.97	223.07
P fertilizer (kg.ha ⁻¹)	58.54	49.03
K fertilizer (kg.ha ⁻¹)	58.54	49.03
Pesticide (litre.ha ⁻¹)	1.87	1.84

Source: Primary data processed, 2025

3.3. Sustainability Performance of Rice Farming

The sustainability performance of rice farming in the coastal areas of Batang Regency, as evaluated by the Farmer Sustainability Index (FSI) detailed in Table 6, reveals varied outcomes. The average FSI value is 71.75%, with individual scores ranging from 46.43% to 96.43%. These findings imply that most farmers have adopted key practices within the Rice Check system, such as proper land preparation, seed management, nutrient application, and pest control. This pattern indicates that the majority of farmers have implemented Rice Check indicators, thereby demonstrating a moderate to high level of sustainability.

Table 6. Sustainability Assessment of Rice Farming Practices

Measure	Value (%)
Mean	71.75
Median	75
Mode	75
Min-Max	46.43-96.43

Source: Primary data processed, 2025

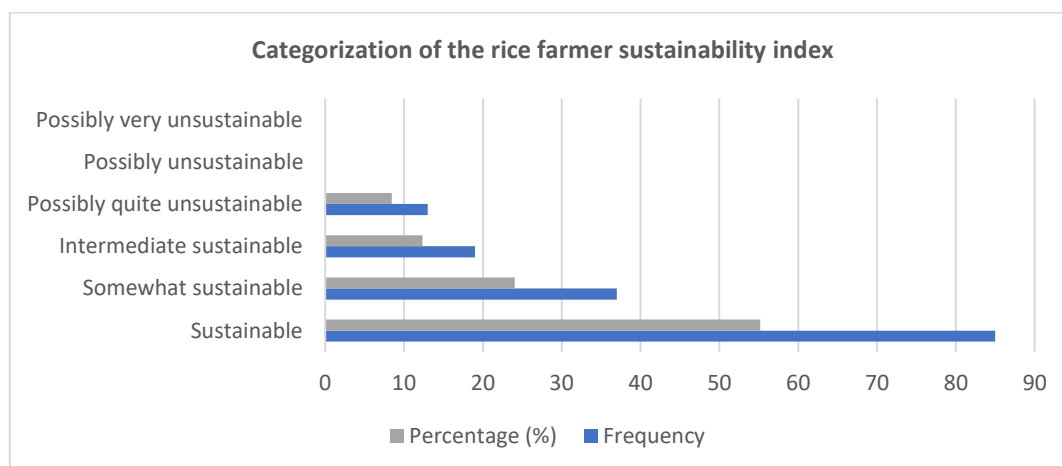


Figure 1 Categorization of the rice farmer sustainability index

The mean FSI value of 71.75% suggests that rice production in coastal regions exemplifies sustainable agricultural practices. As illustrated in Figure 1, an FSI value below the 50% threshold signifies that a minority of farmers continue to encounter significant challenges, particularly concerning water management and salinity control. These two elements are essential for achieving sustainable agriculture in coastal areas. Factors affecting the sustainability of rice cultivation practices are discussed.

Tabel 7. Factors influencing the sustainability of rice farming practices in coastal area

Variables	Coefficients	Std. Error	t-stat	P	VIF
Constant	0.548	0.048	11.29	0.000	
Education	0.023	0.002	11.72	0.000	1.14
Age	-0.002	0.001	-2.55	0.012	1.64
Household Size	0.001	0.002	0.90	0.369	1.07
Cultivated Land Area	-0.000	0.000	-2.28	0.024	1.06
Farmer's Experience	0.001	0.000	2.01	0.047	1.49
R ²	0.567				
Adj R ²	0.553				
F table	38.80				
Breusch-Pagan test	0.8901				

Source: Primary data processed, 2025

To investigate the factors contributing to this variability, a regression analysis was performed to identify the socioeconomic determinants significantly affecting the farm sustainability index (FSI) (refer to Table 7). Diagnostic tests confirmed that the regression model was free from significant multicollinearity and heteroscedasticity issues. The variance inflation factor (VIF) values for the explanatory variables ranged from 1.06 to 1.64, indicating a low correlation among the independent variables and no problematic multicollinearity. The heteroscedasticity test yielded a p-value of 0.8901, exceeding the 5% significance threshold. Consequently, the null hypothesis of homoscedasticity could not be rejected, suggesting no statistical evidence of heteroscedasticity in the regression model. These findings validate the use of ordinary least squares (OLS) estimates for interpreting the relationships between farmers' socioeconomic characteristics and the FSI. The model achieved an R² value of 0.567, indicating that approximately 56.7% of the variance in the sustainability score was explained by the demographic and agricultural characteristics of the farmers. The F statistic of 38.80 ($p < 0.01$) confirms that the selected variables collectively provide a statistically robust explanation of sustainability outcomes among coastal rice farmers. Among the explanatory variables, education exhibited a positive and statistically significant effect on the FSI ($t = 11.72$, $p = 0.000$). Age demonstrated a negative and statistically significant effect on the FSI ($t = -2.55$, $p = 0.012$). Cultivated land area also had a small but statistically significant negative effect on the FSI ($t = -2.28$, $p = 0.024$). Farmer's experience showed a positive and statistically significant effect on the FSI ($t = 2.01$, $p = 0.047$). In contrast, household size did not exhibit a statistically significant effect on the FSI ($t = 0.90$, $p = 0.369$). Overall, the results indicate that education and farmer's experience were positively correlated with the FSI, whereas age and cultivated land area were negatively correlated. Household size did not demonstrate a statistically significant correlation with the FSI.

3.4. Discussion

The socioeconomic characteristics of rice farmers in the coastal areas of Batang Regency significantly influence their ability to manage rice farming and address the challenges of sustainable rice production. The study reveals that these farmers generally possess a low level of formal education, are of advanced age, have extensive farming experience, and come from families of varying sizes. These attributes are intricately connected to their access to information, capacity to adopt agricultural innovations, availability of family labor, and responsiveness to sustainable farming practices. This underscores the importance of human capital as a vital intangible asset in agricultural performance. Specifically, the education level of rice farmers in this region is

comparable to that of junior high school graduates, which is crucial for accessing information, comprehending innovations, and adopting new technologies in rice production [17]. Additionally, the age of rice farmers is relatively high, as the younger generation shows less interest in agriculture [18]. While older farmers possess more farming experience, they are generally less responsive to sustainable agricultural practices [2]. Furthermore, larger household sizes often impact labor availability, thereby influencing the efficiency and sustainability of rice farming [19].

The utilization of production inputs illustrates the influence of farmers' socioeconomic conditions and the distinct environmental characteristics of coastal rice farming on farm management practices. In the study area, the seed usage surpassed the recommended rate of 25 kg ha⁻¹. This elevated seed rate suggests that rice production in coastal regions should not be equated with rice farming in non-coastal environments. Tidal flooding poses a significant production constraint, potentially damaging newly established rice plants and, in some instances, necessitating replanting from the seedling stage. Consequently, farmers may employ additional seeds as a risk management strategy to mitigate potential crop losses. This observation aligns with the findings of Wibowo et al. (2024), who emphasized the importance of optimizing seed density to enhance rice productivity in coastal and peri-urban areas with heterogeneous soil fertility [20]. Fertilizer application was also notably high, particularly when compared to the recommended balanced fertilization practices. The persistent use of elevated fertilizer rates indicates that some farmers have not fully embraced nutrient management based on balanced N, P, and K requirements. While fertilizer application aims to sustain crop productivity, excessive nitrogen application may escalate production costs and pose environmental risks. Therefore, a more balanced supply of N, P, and K is crucial for maintaining soil nutrient availability and supporting sustainable rice production. Conversely, disproportionate nutrient application over the long term may lead to nutrient imbalance and soil degradation, thereby diminishing the efficiency and sustainability of rice production.

Contrary to routine application, pesticide use generally adhered to recommended thresholds. Farmers appeared to adjust pesticide application based on pest and disease pressures, rather than applying pesticides indiscriminately. This practice indicates that farmers have integrated economic and biological considerations into pest management, particularly by aligning pesticide application with perceived pest pressure and economic thresholds [17]. Such an approach can mitigate unnecessary pesticide use, reduce production costs, and minimize potential environmental impacts while ensuring crop protection. Overall, the pattern of input use suggests that farmers have developed adaptive practices in response to coastal production risks. However, improvements in seed efficiency and balanced nutrient management remain crucial for enhancing the sustainability of rice farming in the coastal area of Batang Regency.

The evaluation of rice cultivation practices yielded an average Farmer Sustainability Index (FSI) of 71.75%, suggesting that rice farmers in the coastal region of Batang Regency generally adhere to sustainable rice production principles. Nevertheless, the FSI scores exhibited significant variability among farmers, indicating disparities in their ability to implement sustainable practices. Over half of the farmers were deemed sustainable, whereas fewer than 10% were considered potentially quite unsustainable. This variability implies that sustainability performance is influenced not only by the coastal production environment but also by differences in farmers' socioeconomic characteristics and farming experience. Coastal rice farming faces unique environmental challenges, such as salinity, tidal intrusion, and soil fertility fluctuations, which can hinder the application of standardized best management practices [20]. Similar disparities in the adoption of sustainable practices have been observed in other coastal farming regions of Indonesia, where variations in access to institutional support, credit, and agricultural extension services contribute to differences in sustainability performance [17].

The regression analysis indicates that within the socioeconomic variables incorporated in the model, education and farming experience exerted significant positive influences on the Farm Sustainability Index (FSI), whereas age and cultivated land area exhibited significant negative impacts. Conversely, household size did not demonstrate a statistically significant effect on FSI. These results imply that sustainability performance is linked not only to farm characteristics but also to the human capital and accumulated farming experience of farmers. Nonetheless, these relationships should be interpreted with caution, as other environmental, institutional, technological, and economic factors, which were not examined in this study, may also contribute to variations in sustainability performance.

The significant positive effect of education on FSI underscores the critical role of human capital in promoting sustainable rice farming. Farmers with higher educational attainment may possess enhanced abilities to access and interpret agricultural information, comprehend extension recommendations, evaluate new technologies, and make informed decisions regarding input use and farm management. These skills are particularly pertinent in coastal rice farming, where farmers must adapt to

changing conditions such as salinity, tidal flooding, and soil fertility variation. This finding aligns with the studies by Amandaria et al. (2025) and Chang et al. (2024), which highlighted the importance of education in enhancing farmers' absorptive capacity and facilitating the adoption of sustainable agricultural practices [2], [21]. Therefore, enhancing farmers' knowledge and learning capacity through extension services and farmer training may contribute to improved sustainability performance.

Farmer's experience in rice farming significantly influences the FSI positively. This observation indicates that accumulated experience equips farmers with essential local knowledge for managing the unique conditions of coastal rice production in the region. Through successive farming cycles, farmers may gain a comprehensive understanding of local hydrological conditions, tidal patterns, pest and disease dynamics, soil responses, and the optimal timing of agricultural activities. Such experiential knowledge facilitates more adaptive decision-making and supports the implementation of sustainable practices. Nevertheless, farming experience alone may not guarantee continuous sustainability improvements. Its advantages are likely enhanced when local knowledge is integrated with new information, adaptive learning, and access to suitable technologies, such as salinity-tolerant varieties, improved nutrient management, and organic soil amendments [23].

In contrast, age exerted a significant negative impact on FSI. This finding suggests that older farmers in the study area exhibited lower sustainability performance. A plausible explanation is that older farmers may encounter more obstacles in accessing or adopting new information, technologies, and institutional programs, despite the fact that farming experience can simultaneously offer valuable local knowledge. Thus, the divergent effects of age and experience are noteworthy: while accumulated experience positively influences sustainability, advancing age may correlate with slower adaptation to evolving technologies and management strategies. Similar evidence from rice-producing regions in Asia emphasizes the necessity of generational renewal and increased involvement of younger farmers to facilitate the transition toward more adaptive and sustainable agricultural practices [18], [22]. This observation highlights the need to enhance intergenerational knowledge transfer while ensuring that older farmers have access to extension services, training, and technologies tailored to their requirements.

Cultivated land area was found to have a notable adverse effect on the FSI, indicating that larger cultivated areas are linked to decreased sustainability. This suggests that merely increasing land area does not guarantee enhanced sustainable outcomes. In coastal areas, larger farms may face more pronounced spatial variations in factors such as salinity, irrigation conditions, soil fertility, and tidal flooding exposure, which complicate uniform management practices. Moreover, the complexity of monitoring and implementing site-specific management practices may increase with larger land area. Kartikawati et al. (2024) also reported that sustainability efficiency might decline beyond certain land area due to heightened management complexity and environmental heterogeneity [13]. Therefore, sustainability strategies in coastal rice farming should consider land area and spatial variability, rather than applying uniform recommendations across all farms.

Analysis of household size revealed no statistically significant impact on the FSI, suggesting that the mere number of household members does not inherently affect the sustainability of rice farming. Although larger households might offer more family labor, the effectiveness of household members in sustainable farm management is contingent upon the distribution of labor, knowledge, and decision-making roles. The lack of a significant effect implies that the quality of farm management and the decision-making capabilities of farmers may be more critical to sustainability than household size itself. This interpretation aligns with Yunianti et al. (2022), who emphasized the role of household decision-making autonomy and risk-sharing mechanisms in influencing sustainability-related outcomes [24].

The findings indicate that a relatively high average Farm Sustainability Index (FSI) of 71.75% is accompanied by considerable variability in sustainability performance among individual farmers. Education and farming experience are identified as significant positive influences, whereas age and cultivated land area correlate with a lower FSI, and household size does not exhibit a significant relationship. These results imply that enhancing the sustainability of coastal rice farming necessitates strategies that bolster farmers' human capital and adaptive capacity, while considering variations in farmer age and the complexity of farm-scale management. Consequently, extension programs, farmer training, and technology dissemination should be tailored not only to advance sustainable practices but also to address the socioeconomic and environmental diversity of coastal rice farmers.

Several limitations must be considered when interpreting these findings. Firstly, the study relied on interview-based self-reported data regarding farmers' management practices and socioeconomic characteristics. Although direct interviews were employed for data collection, self-reported responses may be influenced by recall bias or respondents' inclination to report practices in line with perceived recommendations. Secondly, the study was geographically confined to rice farmers in the coastal area of

Batang District, Batang Regency, Central Java. Consequently, the findings should not be generalized to all coastal rice farming areas without accounting for variations in agroecological and socioeconomic conditions. Specifically, factors such as soil salinity, tidal exposure, irrigation conditions, and soil fertility may differ among farms, yet these environmental characteristics were not directly measured at the farm level in this study. Such spatial heterogeneity may partially contribute to variations in farmers' sustainability performance but cannot be explicitly quantified from the current dataset. Thirdly, the regression model incorporated selected socioeconomic characteristics, namely education, age, household size, cultivated land area, and farmer's experience, while excluding other potentially relevant environmental, institutional, technological, and economic factors. As a result, the explanatory power of the model should not be interpreted as encompassing all determinants of sustainability performance. Future studies should include direct measurements of soil salinity, tidal exposure, soil and water conditions, access to extension and institutional support, technology adoption, and other pertinent socioeconomic factors. Finally, validation using larger samples and data from other coastal rice farming regions is necessary to evaluate whether the observed relationships and the applicability of the Farmer Sustainability Index are consistent across different coastal agroecosystems.

4. CONCLUSION

This study illustrates that coastal rice farming in Batang Regency has generally achieved sustainable performance, as evidenced by an average farmer sustainability index (FSI) of 71.75%. However, FSI scores among farmers varied significantly, ranging from 46.43% to 96.43%, indicating disparities in farmers' abilities to implement and sustain sustainable rice farming practices in coastal environments. Regression analysis reveals that education and farming experience significantly enhance sustainability performance, while age and cultivated land area exert significant negative effects, and household size is not statistically significant. These findings underscore the necessity of enhancing farmers' human capital, experiential learning, and adaptive capacity through targeted and participatory extension services. Sustainability interventions should also account for variations in farm scale and the specific environmental challenges associated with coastal rice production. Considering the cross-sectional design and limited coverage of environmental and institutional factors, future research should incorporate longitudinal data and a broader range of ecological, climatic, market, and institutional variables to provide a more comprehensive understanding of the sustainability of coastal rice farming.

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AUTHOR CONTRIBUTIONS

Restie Novitaningrum: Conceptualization, Design, Data Collection, Statistical Analysis.

Nur Indah Cahyaningtyas: Data Collection, Statistical Analysis, Writing—Review & Editing.

Levana Masitajasmin Putri: Design, Literature Research, Writing—Review & Editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ETHICS STATEMENT

This is not applicable to the present study.

DATA AVAILABILITY STATEMENT

Data supporting the findings of this study are available from the corresponding author upon request.

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