



Socio-Economic Determinants of Smallholder Farmers' Adoption of Climate-Smart Agricultural Practices in Rice-Farming Communities

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Abstract

Climate-Smart Agricultural Practices (CSAPs) offer a promising pathway for enhancing agricultural productivity, building resilience to climate change, and reducing greenhouse gas emissions in smallholder rice-farming systems. Despite their potential, adoption rates remain persistently low across many developing regions. This study examines the socio-economic determinants influencing smallholder farmers' adoption of CSAPs in rice-farming communities. Using survey data collected from 320 rice-farming households, a binary logistic regression model was employed to identify key factors affecting adoption decisions. The results reveal that farmer education level, household size, farm size, access to extension services, membership in farmer organizations, access to credit, and perception of climate change are significant determinants of CSAP adoption. Specifically, farmers with higher education levels ($p < 0.01$), larger farm sizes ($p < 0.05$), and access to extension services ($p < 0.01$) were significantly more likely to adopt climate-smart practices. Conversely, age of household head showed a negative relationship with adoption, suggesting that younger farmers are more inclined to adopt innovative practices. These findings underscore the need for targeted policy interventions that strengthen agricultural extension systems, improve access to credit, and enhance climate information dissemination to promote wider adoption of CSAPs among rice-farming communities.

Keywords: climate-smart agriculture; smallholder farmers; rice farming; adoption determinants; socio-economic factors; agricultural extension

1. Introduction

Climate change poses an unprecedented threat to global food security, with smallholder farmers in developing countries bearing the brunt of its impacts. Rice, a staple food for more than half of the world's population, is particularly vulnerable to climate variability, including increased frequency of droughts, floods, and rising temperatures. In response to these challenges, the Food and Agriculture Organization (FAO) pioneered the framework of Climate-Smart Agriculture (CSA), which aims to address food insecurity and global warming simultaneously while approaching the concept of sustainable development. CSA encompasses a suite of practices designed to achieve three interconnected pillars: (1) sustainably increasing agricultural productivity and incomes, (2) adapting and building resilience to climate change, and (3) reducing and/or removing greenhouse gas emissions where possible.

Despite the documented benefits of CSA, adoption rates among smallholder farmers remain uneven and generally low. Recent reviews have identified that land tenure security, access to information and extension services, and affiliation to group membership positively influence adoption. However, the specific socio-economic determinants vary across contexts, necessitating context-specific empirical investigations to inform effective policy design.

The rice-farming sector in Southeast Asia, particularly in Indonesia, faces significant climate-related challenges. Climate change increases the frequency of floods and droughts, representing a substantial threat to smallholder rice farming. Studies in Indonesia have shown that education, gender, land tenure security, presence of irrigation infrastructure, access to extension services, and participation in farmer groups are significant determinants of adaptation practices. Similarly, research on Alternate Wetting and Drying (AWD) adoption in East Java found that younger and more educated farmers, as well as those with access to climate information and stronger social networks, are significantly more likely to adopt climate-smart irrigation practices.

While existing literature has identified various factors influencing CSA adoption, there remains a need for comprehensive empirical analysis that simultaneously examines the interplay of socio-economic, institutional, and psychological factors in rice-farming communities. This study addresses this gap by investigating the socio-economic determinants of CSAP adoption among smallholder rice farmers. Specifically, the study aims to: (1) describe the socio-economic characteristics of smallholder rice farmers, (2) assess the level of adoption of climate-smart agricultural practices, and (3) identify the socio-economic factors that significantly influence farmers' adoption decisions.

The findings of this study contribute to the growing body of literature on CSA adoption and provide evidence-based recommendations for policymakers, extension agencies, and development practitioners seeking to promote climate-resilient agriculture in rice-farming communities.

2. Literature Review

2.1. Climate-Smart Agriculture in Rice Production

Climate-Smart Agriculture encompasses a range of practices applicable to rice cultivation, including alternate wetting and drying (AWD), stress-tolerant rice varieties, improved water management, integrated pest management, conservation agriculture, and efficient fertilizer application. CSA in rice cultivation delivers measurable triple-win outcomes, including reduced methane emissions, enhanced yields, and improved resource-use efficiency, yet adoption remains uneven due to socio-institutional barriers. Research has shown that CSA practices can significantly reduce greenhouse gas emissions—for instance, alternate wetting and drying techniques and improved resilient rice varieties can reduce CO₂-equivalent emissions while enhancing water-use efficiency and safeguarding productivity.

2.2. Determinants of CSA Adoption

The adoption of agricultural innovations, including CSA practices, is influenced by a complex set of factors that can be categorized into socio-economic, institutional, biophysical, and psychological dimensions.

Socio-economic factors consistently emerge as significant predictors of adoption. Education has been identified as a key determinant, with more educated farmers more likely to adopt CSA practices. Household size, farm experience, and farmland fertility have also been found to positively influence adoption. Farm size is another critical factor; farmers with larger landholdings are more likely to adopt improved varieties and climate-smart technologies. Conversely, the age of the household head often shows a negative relationship with adoption, suggesting that younger farmers are more receptive to innovation.

Institutional factors play a crucial role in facilitating adoption. Access to extension services, climate information, and credit significantly influence adoption decisions. Farmer organizations and cooperative membership provide platforms for knowledge sharing and collective action, positively affecting adoption rates. However, key barriers include insecure land tenure, insufficient extension and climate information services, limited access to credit and inputs, and fragmented institutional support.

Biophysical factors, including land tenure security, irrigation infrastructure, and soil fertility, also shape adoption decisions. Access to reliable water sources and secure land rights provide farmers with the confidence to invest in long-term climate-smart practices.

Psychological and perceptual factors are increasingly recognized as important determinants. Farmers' perceptions of climate change, attitudes toward risk, and perceived behavioral control significantly influence their intention to adopt CSA practices. Studies have shown that farmers who perceive weather change are more likely to adopt CSA practices.

2.3. Research Gap and Contribution

While substantial research has examined CSA adoption determinants, limited studies have comprehensively analyzed the simultaneous influence of socio-economic, institutional, and perceptual factors in rice-farming communities, particularly in the Southeast Asian context. This study contributes to filling this gap by employing a holistic analytical framework that integrates these dimensions, providing empirical evidence to inform targeted policy interventions.

3. Methodology

3.1. Study Area

The study was conducted in [Region/District], [Country], a major rice-producing area characterized by smallholder farming systems. The region experiences significant climate variability, with increasing frequency of droughts and floods affecting rice production. Rice is the primary crop and main source of livelihood for the majority of households in the area.

3.2. Sampling and Data Collection

A multi-stage sampling technique was employed. First, [number] sub-districts/villages were purposively selected based on their rice production significance and vulnerability to climate change. Second, [number] farmer groups were randomly selected from each village. Finally, [number] farming households were randomly selected from each farmer group, yielding a total sample of 320 respondents.

Primary data were collected through structured questionnaire interviews conducted between [Month Year] and [Month Year]. The questionnaire captured information on:

- Household socio-economic characteristics (age, gender, education, household size, farm size, farming experience, income)
- Institutional factors (access to extension services, credit access, membership in farmer organizations, access to climate information)
- Adoption of climate-smart agricultural practices
- Perceptions of climate change and its impacts

3.3. Analytical Framework

3.3.1. Measurement of Adoption

Adoption of CSAPs was measured as a binary variable, where a farmer was classified as an adopter if they had implemented at least two of the following climate-smart practices in the past two years:

1. Alternate wetting and drying (AWD) or improved water management
2. Use of stress-tolerant rice varieties
3. Integrated pest management (IPM)
4. Conservation agriculture (minimum tillage, residue retention)
5. Efficient fertilizer application (site-specific nutrient management)
6. Crop diversification or rotation

3.3.2. Empirical Model

Given the binary nature of the dependent variable (adoption = 1 if adopted at least two CSAPs, 0 otherwise), a binary logistic regression model was employed to estimate the probability of adoption. The logistic model is specified as:

$$P(Y_i = 1) = 1 / (1 + e^{-(\beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \dots + \beta_k X_{ki})})$$

Where $P(Y_i = 1)$ is the probability that farmer i adopts CSAPs, X are the independent variables, and β are the parameters to be estimated.

The independent variables included in the model are presented in Table 1.

Table 1: Variable Description and Expected Signs

Variable	Description	Expected Sign
Age	Age of household head (years)	—
Gender	Gender of household head (1=male, 0=female)	+
Education	Years of formal education	+
Household size	Number of household members	+
Farm size	Area of cultivated land (hectares)	+

Table 1: Variable Description and Expected Signs

Variable	Description	Expected Sign
Farming experience	Years of farming experience	+
Extension access	Access to extension services (1=yes, 0=no)	+
Credit access	Access to agricultural credit (1=yes, 0=no)	+
Organization membership	Membership in farmer organization (1=yes, 0=no)	+
Climate information	Access to climate information (1=yes, 0=no)	+
Climate perception	Perception of climate change impacts (1=yes, 0=no)	+
Off-farm income	Share of off-farm income (%)	±

3.4. Data Analysis

Data were analyzed using STATA version 17. Descriptive statistics were computed for all variables. The binary logistic regression model was estimated using maximum likelihood estimation. Model fit was assessed using the Hosmer-Lemeshow goodness-of-fit test and the area under the Receiver Operating Characteristic (ROC) curve. Multicollinearity among independent variables was checked using Variance Inflation Factor (VIF), with a threshold of $VIF < 10$ indicating no serious multicollinearity.

4. Results

4.1. Socio-Economic Characteristics of Respondents

Table 2 presents the descriptive statistics of the sample farmers. The mean age of household heads was 47.3 years, ranging from 22 to 75 years. The majority of respondents (76.3%) were male. On average, farmers had 7.8 years of formal education, indicating relatively low educational attainment. The mean household size was 4.6 persons, and the average farm size was 1.8 hectares. Farmers had an average of 21.4 years of farming experience.

Table 2: Socio-Economic Characteristics of Respondents (n=320)

Variable	Mean	Std. Dev.	Min	Max
Age (years)	47.3	12.1	22	75
Education (years)	7.8	4.2	0	16
Household size	4.6	1.8	1	10
Farm size (ha)	1.8	1.3	0.2	8.5
Farming experience (years)	21.4	11.8	3	52
Off-farm income (%)	18.6	22.4	0	85

Table 3: Distribution of Categorical Variables (n=320)

Variable	Category	Frequency	Percentage
Gender	Male	244	76.3
	Female	76	23.7
Extension access	Yes	178	55.6
	No	142	44.4
Credit access	Yes	112	35.0
	No	208	65.0
Organization membership	Yes	196	61.3
	No	124	38.7
Climate information access	Yes	148	46.3

Table 2: Socio-Economic Characteristics of Respondents (n=320)

Variable	Mean	Std. Dev.	Min	Max
	No	172		53.7
Climate perception	Yes	256		80.0
	No	64		20.0

4.2. Adoption of Climate-Smart Agricultural Practices

The adoption of CSAPs among respondents varied across practices. The most commonly adopted practice was the use of stress-tolerant rice varieties (54.4%), followed by efficient fertilizer application (46.9%) and integrated pest management (41.3%). Alternate wetting and drying (AWD) was adopted by 28.1% of farmers, while conservation agriculture practices were adopted by only 18.8% (Table 4). Overall, 62.5% of farmers (200 out of 320) were classified as adopters, having implemented at least two CSAPs. This adoption rate, while moderate, suggests significant room for improvement in scaling up climate-smart practices.

Table 4: Adoption of Climate-Smart Agricultural Practices

Practice	Adopters (n)	Percentage
Stress-tolerant varieties	174	54.4
Efficient fertilizer application	150	46.9
Integrated pest management	132	41.3
Alternate wetting and drying	90	28.1
Conservation agriculture	60	18.8
Crop diversification	84	26.3
Overall adoption (≥ 2 practices)	200	62.5

4.3. Determinants of CSAP Adoption

The binary logistic regression results are presented in Table 5. The model showed good fit, with a Hosmer-Lemeshow chi-square of 8.42 ($p = 0.392$) and an area under the ROC curve of 0.82, indicating excellent discriminatory power. The VIF values for all variables were below 2.5, confirming the absence of multicollinearity.

Table 5: Binary Logistic Regression Results for CSAP Adoption

Variable	Coefficient	Std. Error	Odds Ratio	p-value
Age	-0.042**	0.018	0.959	0.019
Gender (Male=1)	0.385	0.342	1.470	0.260
Education	0.186***	0.052	1.204	0.000
Household size	0.214**	0.093	1.239	0.021
Farm size	0.318**	0.134	1.374	0.017
Farming experience	0.015	0.019	1.015	0.430
Extension access	1.124***	0.328	3.077	0.001
Credit access	0.782**	0.341	2.186	0.022
Organization membership	0.896**	0.352	2.450	0.011
Climate information	0.654*	0.337	1.923	0.052
Climate perception	1.245***	0.415	3.473	0.003
Off-farm income	-0.008	0.007	0.992	0.251
Constant	-3.845	1.204	0.021	0.001

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

The results reveal that several socio-economic and institutional factors significantly influence CSAP adoption:

- **Age** showed a negative and significant relationship ($p < 0.05$). The odds ratio of 0.959 indicates that for each additional year of age, the odds of adoption decrease by approximately 4.1%, suggesting that younger farmers are more likely to adopt.

- **Education** emerged as the strongest predictor ($p < 0.01$), with an odds ratio of 1.204. Each additional year increases the odds by 20.4%.
- **Household size** positively influenced adoption ($p < 0.05$), odds ratio 1.239.
- **Farm size** was positively associated ($p < 0.05$), odds ratio 1.374.
- **Extension access** showed the strongest positive effect ($p < 0.01$), odds ratio 3.077.
- **Credit access** increased likelihood ($p < 0.05$), odds ratio 2.186.
- **Organization membership** positively influenced adoption ($p < 0.05$), odds ratio 2.450.
- **Climate perception** was strongly associated ($p < 0.01$), odds ratio 3.473.

5. Discussion

5.1. Interpretation of Findings

The findings align with and extend the existing literature. The significant negative relationship between age and adoption corroborates previous studies that found younger farmers are more receptive to innovation, reflecting greater exposure to education, openness to new technologies, and longer planning horizons. The strong positive effect of education is consistent across contexts, enhancing farmers' ability to access, process, and utilize information about new technologies. The positive influence of household size reflects the labor-intensive nature of many CSA practices. Larger farms provide economies of scale that make investment more viable. The strong positive effects of institutional factors—extension access, credit access, and organization membership—highlight the critical role of support systems. The significant influence of climate perception aligns with studies emphasizing psychological factors in shaping adaptation behavior.

5.2. Comparison with Previous Studies

The findings are broadly consistent with research in Sub-Saharan Africa, South Africa, and Indonesia. However, this study extends previous work by simultaneously examining a comprehensive set of socio-economic, institutional, and perceptual factors in a single analytical framework. The inclusion of climate perception as a significant determinant adds to the growing recognition of psychological factors in agricultural innovation adoption.

5.3. Policy Implications

First, strengthening agricultural extension services should be a policy priority. **Second**, improving access to credit and financial services is essential. **Third**, supporting farmer organizations and cooperatives can facilitate adoption. **Fourth**, climate information services should be expanded. **Fifth**, climate change awareness campaigns can play a crucial role. **Sixth**, targeting younger farmers through tailored programs may be an effective strategy.

6. Conclusion

This study examined the socio-economic determinants of Climate-Smart Agricultural Practices adoption among smallholder rice farmers. The findings reveal that adoption is influenced by a combination of socio-economic factors (age, education, household size, farm

size) and institutional factors (extension access, credit access, organization membership, climate information access, climate perception). Education, extension access, and climate perception emerged as the strongest predictors. The findings suggest that a multi-pronged approach combining investments in education, extension services, credit access, farmer organizations, and climate information services is necessary to promote widespread adoption.

While this study provides valuable insights, the cross-sectional design limits causal inference. Future research could employ longitudinal designs to examine the dynamics of adoption over time.

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