Jurnal Manajemen & Agribisnis, Vol. 23 No. 1, March 2026
Permalink/DOI: http://dx.doi.org/10.17358/jma.23.1.126

Available online at
http://journal.ipb.ac.id/index.php/jmagr

CLIMATE ADAPTATION STRATEGIES AND REVENUE IMPLICATIONS IN SMALLHOLDER PADDY FARMING: EVIDENCE FROM KLATEN REGENCY

Putriesti Mandasari[*)1], Desy Mayasari[,***)], Nabittun Nahar[****)]**

[*)] Study Program of Agribusiness, Faculty of Agriculture, Sebelas Maret University
Jl. Ir. Sutami 36 A, Surakarta City, Indonesia
[**)] Study Program of Digital Marketing, Vocational School, Sebelas Maret University
Jl. Kol. Sutarto 150 K, Surakarta City, Indonesia
[***)] Indonesian Agribusiness Association
Jl. Kamper, Wing 4, Bogor City, Indonesia
[****)] Study Program of Agricultural Economics, School of Economic Sciences, Washington State University
255 E Main Street, Pullman, Washington, United States

Article history:

Received
20 February 2026

Revised
12 March 2026

Accepted
30 March 2026

Available online
31 March 2026

Abstract

Background: Climate variability increasingly affects paddy production, exposing smallholder farmers to revenue instability. This challenge is also evident in Klaten Regency, Central Java, Indonesia. Although climate adaptation strategies are widely adopted, evidence on their revenue implications remains limited.
Purpose: This study examines the adoption rates of climate adaptation strategies (shifting planting dates, constructing ridges, and income diversification), compares log farm revenue between adopters and non-adopters, and evaluates whether differences persist after controlling for farmer, farm, and district characteristics.
Design/methodology/approach: Using primary survey data from 271 paddy farmers, adoption patterns are described using summary statistics and the mean comparison test (Welch's t-test). Revenue associations with adaptation strategies are estimated using ordinary least squares (OLS) with three specifications. First, a baseline model that only considers adaptation indicators. Second, an OLS model with control variables (farmer and farm characteristics). Third, an OLS model with control variables and fixed effects (land tenure categories and district) to explain institutional arrangements and spatial heterogeneity.
Findings/Results: Farmers who shift planting dates tend to have higher revenue. Mean comparisons indicate higher log revenue among farmers who shift planting dates and lower log revenue among ridge users. These t-test results align with the OLS results. However, once controls are included in the OLS model, the estimated coefficients become smaller and statistically weaker, suggesting that revenue differences partly reflect farmer sorting and contextual conditions rather than direct causal effects.
Conclusion: Revenue implications are heterogeneous and context-dependent.
Originality/value (State of the art): This study contributes to the limited empirical evidence on climate adaptation in smallholder paddy farming by jointly analyzing adaptation strategies and farm revenue outcomes. By applying a multivariate regression framework, this study provides insights into how adaptation strategies relate to revenue under varying farmer and contextual conditions. The findings offer implications for policymakers in designing context-specific climate adaptation support.

Keywords: climate adaptation, farm revenue, paddy farming, smallholder, Indonesia

How to cite: Mandasari, P., Mayasari, D., & Nahar, N. (2026). Climate adaptation strategies and revenue implications in smallholder paddy farming: Evidence from Klaten Regency. Jurnal Manajemen & Agribisnis, 23(1), 126. https://doi.org/10.17358/jma.23.1.126

[1] Corresponding author:
Email: putriesti_mandasari@staff.uns.ac.id

INTRODUCTION

Increasing cases of extreme weather and climate change threaten rice livelihoods in developing countries (Khan et al. 2022). The paddy farmer with smallholders is the most exposed, as they depend more on seasonal rainfall patterns and irrigation performance, both of which are highly volatile. In some nations, e.g., Vietnam and Sri Lanka, droughts, unpredictable rainfall, and heat waves can significantly reduce farmers' yields and income (Khan et al. 2022; Scognamillo et al. 2022). These implications are particularly evident in Southeast Asian rice-based systems, where production is highly climate-sensitive, and smallholder farmers dominate the agricultural sector (Khan et al. 2022; Scognamillo et al. 2022). With yield losses, pest outbreaks, and disrupted harvests, climatic conditions in the areas may result in unstable revenues. Thus, it weakens the economic sustainability of smallholder farming systems.

In Indonesia, particularly in Central Java, crop production remains closely tied to climatic conditions. Evidence of the adverse impacts of climate change on crop production has been found in Kebumen (Sekaranom et al. 2021), Wonogiri (Ansari et al. 2021), Semarang (Suntoro et al. 2025), and Demak (Suntoro et al. 2025). For instance, rainfall variability disrupts planting schedules and increases input costs due to replanting and pest management (Ojo et al. 2022; Scognamillo et al. 2022). As climate risks intensify, farmers are compelled to adjust their management practices through adaptation strategies to mitigate potential losses, such as adjusting planting calendars, adopting more climate-tolerant crop varieties, and implementing crop diversification and input intensification strategies (Ojo et al. 2022; Sekaranom et al. 2021). Adaptation in this context is reflected in practical farm-level responses to reduce climate-related damages or exploit emerging opportunities. However, while adaptation is widely observed, the extent to which these strategies translate into improved farm revenue remains an open empirical question.

A growing body of literature suggests that climate adaptation strategies can enhance resilience and, in some cases, profitability. Climate-smart agricultural practices, improved water management, and the use of stress-tolerant varieties have been associated with higher productivity and income stability in several Southeast Asian contexts (Aung et al. 2017; Duyen et al. 2019; Tione et al. 2022). Collective action and governance support further strengthen adaptation outcomes by improving access to information and shared infrastructure (Jabbar et al. 2023; Wu et al. 2021). Nonetheless, the profitability of adaptation is not guaranteed. Evidence from cross-country studies highlights trade-offs between reducing vulnerability and maximizing revenue. Thus, emphasizing the need to assess economic outcomes with careful attention to contextual heterogeneity.

Nevertheless, there is limited empirical evidence regarding the revenue impacts of a particular adaptation strategy in paddy farming among the Indonesian smallholders. Adopters and non-adopters may be overstated and understated with respect to economic benefits, as there will be heterogeneity among farmers, tenure arrangements, and conditions within a district. Recent climate adaptation studies have mainly examined adoption, resilience, and productivity (Duyen et al. 2019; Khan et al. 2022; Scognamillo et al. 2022), while the association between specific strategies and revenue remains underexplored, especially for smallholder paddy farming in Indonesia. The paper bridges these gaps by discussing commonly used strategies, which include shifting planting dates, ridge building, and income diversification.

Among commonly used strategies in paddy systems, shifting planting dates and building ridges play a central role in managing rainfall variability. Adjusting planting dates allows farmers to better align crop growth stages with water availability (Duyen et al. 2019; Scognamillo et al. 2022). Thereby, decreasing exposure to drought or excessive rainfall, which eventually minimizes the risk of crop failure (Duyen et al. 2019; Scognamillo et al. 2022). By adjusting the planting dates, farmers stabilize their yields and increase profitability (Duyen et al. 2019; Kissi et al. 2023; Scognamillo et al. 2022; Yousafzai et al. 2022). Meanwhile, the use of technologies for water management at the farm level, such as ridge construction and bund maintenance, is also expected to improve drainage, reduce waterlogging, and enhance soil aeration (Choudhary et al. 2022; Nkuba et al. 2022). Previous findings show that proper water management may improve productivity and resistance to climatic extremes, though outcomes depend heavily on local agroecological conditions (Adaawen, 2021; Iqbal et al. 2020; Ngoma et al. 2020; Singh et al. 2018).

In addition, income diversification represents another critical adaptation pathway (Muliyadi et al. 2025).

Through off-farm employment, livestock activities, or a combination of income-earning activities, farmers' households may reduce income variation and mitigate the effects of agricultural shocks (Mamun et al. 2021). Portfolios in which income has been diversified have been associated with greater resilience, improved food security, and higher income levels, especially in climate-prone areas (Adam & Abdulai, 2024; Khan et al. 2022; Ojo et al. 2022; Usman et al. 2023).

Previous studies have examined climate adaptation using different analytical perspectives, including farm household decision models under risk (Keil et al. 2009), behavioral frameworks such as Protection Motivation Theory (Luu et al. 2019), and economic approaches that assess trade-offs (Scognamillo et al. 2022). To approach the problem, this study uses the framework of farm household decisions under a climate risk perspective, as in Keil et al. (2009). In this framework, farmers choose adaptation strategies as management responses to reduce production risks and stabilize farm income under uncertain climatic conditions (Keil et al. 2009; Scognamillo et al. 2022). Managerial choices to adapt to the environment (such as changing planting dates, ridge design, and diversifying income) are then seen as a solution to environmental exposure and resource limitations (Ho et al. 2021). In that view, heterogeneous decision-making with different degrees of risk exposure and resource endowments may explain differences in farm revenue between adopters and non-adopters. By studying these differences, the analysis can estimate whether adaptation strategies correlate with better revenue performance after accounting for structural and contextual factors.

This paper aimed to describe the adoption rates, compare differences in farm revenue, and estimate multivariate associations using various empirical models. We argue that climate adaptation actions have revenue-heterogeneous and contextual aspects. This research offers evidence supporting the use of extension services and climate-risk governance by integrating the agribusiness management view with a farm-household decision model in climate risk, and clarifies how structural heterogeneity influences the relationship between adaptation and revenue.

METHODS

This study was conducted in Klaten Regency, Central Java, Indonesia, during October 2025. Klaten is a rice-growing area with irrigated and semi-irrigated paddy systems that are prone to changes in rainfall patterns. Figure 1 shows the research location in the three purposively chosen districts, *i.e.,* Polanharjo, Delanggu, and Trucuk. These districts were selected because they represent important rice-producing areas with varying irrigation conditions and exposure to climate variability. The empirical study is based on a primary survey of 271 paddy farmers. This sample size was estimated using the Slovin approach, based on the population of the selected districts, with a 6% margin of error. To ensure relatively balanced representation and enable meaningful comparison across the three districts, the sample was distributed almost equally among them. Accordingly, samples from each district were randomly selected: Polanharjo (n=100), Delanggu (n=96), and Trucuk (n=75).

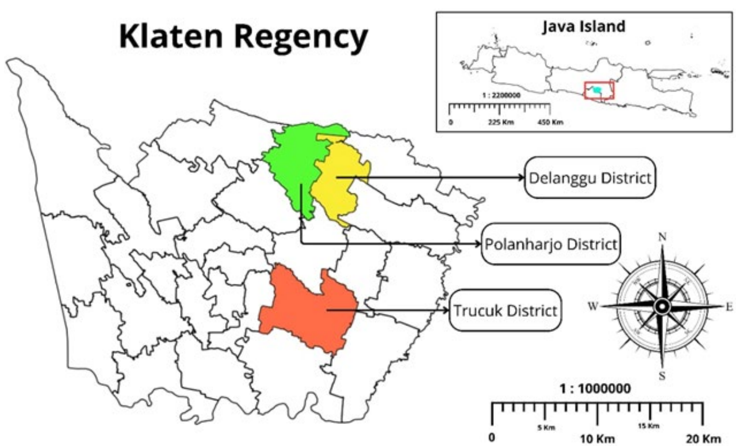

Figure 1. Research location of paddy farmer survey in three districts of Klaten Regency, Central Java, Indonesia

The survey collects detailed data on socioeconomic characteristics of farms and farmers, which are common in farm-level studies (Muliyadi et al. 2025). The key variables include farm revenue, age, education, gender, farming experience, household size, and farm size measured in hectares, as in Muliyadi et al. (2025), Ojo et al. (2022), and Choudhary et al. (2022). In addition, the survey records land tenure categories, including landowners (Ali et al. 2022; Tione et al. 2022), tenants (Ali et al. 2022; Tione et al. 2022), and sharecroppers, as well as district identifiers. The dataset also includes binary indicators for three adaptation strategies: shifting planting dates, ridge construction, and income diversification (engagement in off-farm work). These variables enable the analysis to examine both adaptation behavior and its potential association with farm revenue.

To ensure a systematic empirical analysis, the study was conducted through a series of research procedures. First, a structured survey was used to collect field data from paddy farmers through direct interviews in the selected districts. The interviews were conducted with farmers who actively manage paddy fields and make production decisions. This approach allowed the researchers to obtain detailed and reliable information directly from farm households. In addition, direct interviews helped clarify farmers' responses and ensure the accuracy of the collected information on farm practices and adaptation strategies. Second, the survey data were compiled and verified using a data preparation procedure. This phase involved checking incomplete responses, ensuring consistency in variable coding, and organizing the dataset for empirical analysis. Third, relevant variables were constructed for analytical purposes. In particular, farm revenue was transformed into logarithmic form to reduce skewness and enable proportional interpretation of regression coefficients. Fourth, the empirical analyses outlined in the research framework were applied to the dataset. Definition and measurement of variables in Table 1.

The empirical analysis proceeds through several steps. First, to address objective 1, adoption patterns of the three adaptation strategies are described using summary statistics and adoption rates (%). Additionally, these descriptive statistics present the prevalence of the adaptation patterns in tenure categories. Second, to address objective 2, this study compares the mean of log farm revenue between adopters and non-adopters of each strategy using Welch's t-test. Unlike the independent sample t-test, Welch's t-test is more appropriate when the two groups have unequal variances and unequal sample sizes (Ruxton, 2006), which is consistent with the structure of this dataset. This method will give a diagnostic evaluation of unconditional revenue disparities before structural controls can be implemented. To address objective 3, this research estimates the associations between the climate adaptation practices and farm revenue. These relationships are examined using OLS, which controls for observable farmer and farm characteristics.

Table 1. Definition and measurement of variables

Variable	Description	Measurement
Log farm revenue	Total farm revenue from paddy production	Natural logarithm of total revenue
Shifting planting dates	Adoption of planting time adjustment	Dummy (1 = yes; 0 = no)
Ridge construction	Use of ridges for water management	Dummy (1 = yes; 0 = no)
Income diversification	Engagement in off-farm income activities	Dummy (1 = yes; 0 = no)
Age	Age of the farmer	Years
Education	Years of formal education	Years
Farming experience	Years of farming experience	Years
Farm size	Size of cultivated land	Hectares
Gender	Gender of the farmer	Dummy (1 = male; 0 = female)
Household size	Number of household members	Number of persons
Tenant	Whether the farmer operates under a tenant arrangement	Dummy (1 = tenant; 0 = otherwise)
Sharecropper	Whether the farmer operates under a sharecropping arrangement	Dummy (1 = sharecropper; 0 = otherwise)
Delanggu	Whether the farm is located in the Delanggu district	Dummy (1 = Delanggu; 0 = Polanharjo)
Trucuk	Whether the farm is located in the Trucuk district	Dummy (1 = Trucuk; 0 = Polanharjo)

OLS is widely used for estimating average relationships between variables in empirical economic research (Aung et al. 2017; Khan et al. 2022). In this respect, this paper views regression coefficients as conditional associations rather than causal impacts. Despite the common recommendation of causal designs, including instrumental variable methods to address endogeneity (Dai et al. 2017; Khan et al. 2022; Luu et al. 2019; Scognamillo et al. 2022), OLS is purposefully employed in this study to clearly test how associations between adaptation and revenue change as additional controls are introduced. The application of OLS as a conditional association is also consistent with the fact that naive estimates are distorted by selection and contextual heterogeneity (Ndamani & Watanabe, 2017; Usman et al. 2023). This approach provides insights into the potential economic implications of adaptation strategies in smallholder farming systems.

The econometric specifications are presented in three Models that progressively incorporate additional explanatory variables. The first model (Model 1) is the baseline specification, comprising only three adaptation indicators. Model 2 extends the baseline by including farm and farmer-level controls, $X_i'\gamma$, consisting of age, education, farming experience, farm size, gender, and household size. Model 3 further includes land tenure categories and district fixed effects ($\mu_{d(i)}$) to explain the institutional arrangements and market heterogeneity that do not vary over time. Polanharjo serves as the reference district, and landowners serve as the reference tenure category.

Model 1: Baseline

$$\log(\text{Revenue}) = \alpha_0 + \alpha_1\text{Shift} + \alpha_2\text{Ridge} + \alpha_3\text{Diversification} + \varepsilon_i \quad (1)$$

Model 2: Baseline + controls

$$\log(\text{Revenue}) = \beta_0 + \beta_1\text{Shift} + \beta_2\text{Ridge} + \beta_3\text{Diversification} + X_i'\gamma + e_i \quad (2)$$

Model 3: Baseline + controls + tenure + district fixed effects

$$\log(\text{Revenue}) = \delta_0 + \delta_1\text{Shift} + \delta_2\text{Ridge} + \delta_3\text{Diversification} + X_i'\,\Phi + \delta_4\text{Tenant} + \delta_5\text{Shareholder} + \mu_{d(i)} + u_i \quad (3)$$

The inclusion of tenure controls and district fixed effects is intended to enhance identification by minimizing confounding from unobserved heterogeneity. District fixed effects capture local climate, infrastructure, and market factors that may jointly affect adaptation and revenue, thereby enhancing the isolation of within-district associations (Asiama et al. 2017; Saha et al. 2025). Land tenure controls capture differences in incentives and constraints for investing in adaptive practices (Attiogbé et al. 2024; Khan et al. 2022). More secure or favorable tenure arrangements can strengthen incentives to undertake soil and water management measures and shape economic outcomes (Attiogbé et al. 2024; Khan et al. 2022). All OLS models are estimated with heteroskedasticity-robust standard errors (HC3). Multicollinearity is assessed using variance inflation factors (VIF), with values below 2 indicating no serious collinearity concerns. Lastly, the analysis focuses on diagnostic evidence of coefficient attenuation across specifications as diagnostic evidence of heterogeneity. Such trends have been extensively observed in the literature on adaptation-income research after accounting for farmers' attributes and contextual influences (Duyen et al. 2019; Ndamani & Watanabe, 2017).

Although adaptation strategies have implications for economic outcomes (Scognamillo et al. 2022), these implications are not universal and can vary with agroecological factors and farmers' characteristics. Previous studies show that climate change adaptation can influence economic outcomes through changes in climate exposure, production efficiency, and livelihood resilience (Adam & Abdulai, 2024; Duyen et al. 2019; Khan et al. 2022; Muliyadi et al. 2025; Ojo et al. 2022; Scognamillo et al. 2022). In particular, shifting planting dates may reduce crop exposure to drought or excessive rainfall, while ridge construction may improve drainage and moisture management, with their effects on economic outcomes depending on local agroecological conditions (Adaawen, 2021; Choudhary et al. 2022; Duyen et al. 2019; Iqbal et al. 2020; Nkuba et al. 2022). In addition, income diversification has been associated with improved livelihood resilience, better food security, and more stable economic conditions in climate-prone areas (Adam & Abdulai, 2024; Khan et al. 2022; Ojo et al. 2022; Usman et al. 2023). Therefore, this study formulates several hypotheses to examine the relationship between climate adaptation strategies and log farm revenue. First, the study tests whether adopters and non-adopters of adaptation strategies differ in farm revenue using mean-comparison analysis. Accordingly, H1 states that the mean log farm revenue of adopters differs significantly from that of non-adopters. Furthermore, the study evaluates the role of specific adaptation strategies in shaping farm revenue outcomes. H2 proposes that shifting planting dates is associated with differences in log farm revenue. H3 proposes that ridge construction is associated with differences in log farm revenue, although the direction of the relationship may depend on agroecological risk. Finally, H4 proposes that income diversification is associated with differences in log farm revenue.

The analytical framework of this study is illustrated in Figure 2, which outlines the pathway from climate variability to farm revenue outcomes. Climate variability increases production risk, leading to revenue instability among smallholder farmers and prompting adaptive responses at the farm level. In the study area, the problem is reflected in the vulnerability of paddy systems to changing rainfall patterns and climate-related production risk. This setting motivates farmers' adaptation strategies, such as shifting planting dates, constructing ridges, and diversifying income sources, as practical responses in Klaten Regency to manage uncertainty and stabilize production. The framework further distinguishes three analytical components: assessing adoption patterns, comparing unconditional revenue differences, and estimating conditional revenue associations using regression models. These analytical steps collectively evaluate how adaptation strategies relate to farm revenue under different levels of control and model specifications. The framework ultimately links these empirical findings to policy implications that promote context-specific climate adaptation and improve revenue stability for smallholder farmers.

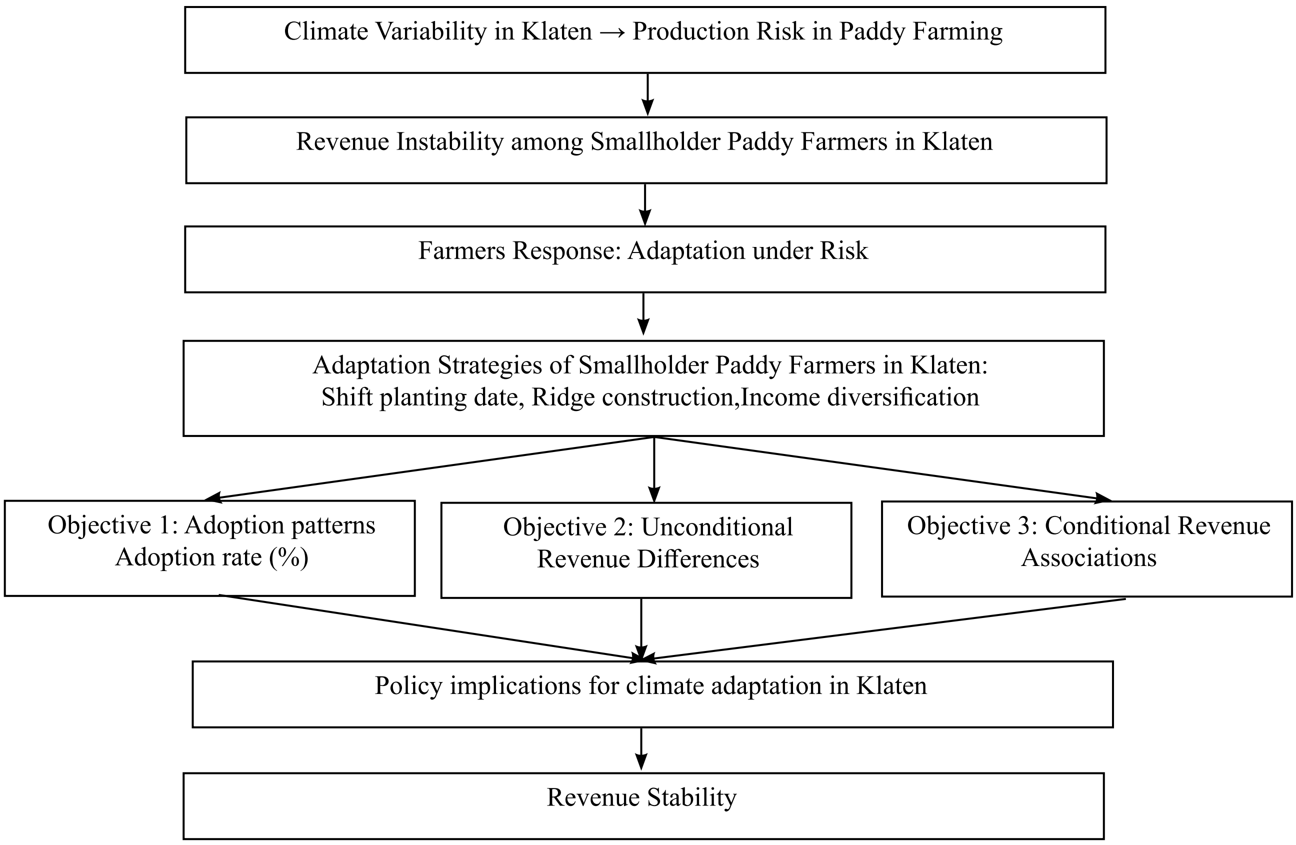

Figure 2. Research framework illustrating the relationship between climate adaptation strategies and farm revenue

RESULTS

Adoption of Climate Adaptation Strategies

The three study districts differ in their agricultural land profiles, which may also influence their adaptation strategies. Polanharjo appears to have a more diverse agricultural land base, including a larger area of non-wetland agricultural land, whereas Delanggu and Trucuk are more strongly oriented toward paddy-based agriculture (BPS, 2018). These differences in land-use profiles may shape farmers' production conditions, resource use, and risk exposure, which in turn can influence the choice of adaptation strategies across districts.

Figures 3 and 4 show the adoption rates of the three climate-adaptation strategies among the 271 paddy farmers, where each farmer may have one or more strategies. These strategies offer potential advantages in reducing climate-related production risk, improving water management, and strengthening household resilience. The most common strategy is shifting planting dates (53.90%), followed by ridge construction (36.50%) and income diversification through off-farm work (31.40%). These values demonstrate that more than half of farmers have already adjusted their planting schedules to the changing climate, but physical water management and livelihood diversification are less common. Similar patterns of multi-strategy adoption have also been reported in other rice-based systems under rainfall uncertainty (Duyen et al. 2019; Khan et al. 2022).

Meanwhile, adoption varies by land tenure type (Figure 4). The use of ridge building is also prevalent among sharecroppers (50.00%), compared with landowners (32.50%) and tenants (31.60%). Income diversification, on the other hand, is most common among tenants (47.40%), then among landowners (31.40) and sharecroppers (21.90). This implies that tenants, potentially more exposed to income uncertainty and asset buffers, react by shifting labor to off-farm work as a risk-reduction option, which is in line with the findings that tenure insecurity and income risk do affect the choice to diversify labor (Ojo et al. 2022; Usman et al. 2023).

Generally, the descriptive evidence reveals that the climate adaptation is multi-dimensional and tenure-sensitive. The differences across tenure groups show that the institutional setting may shape the incentives and constraints for adopting a particular strategy. For example, tenants may diversify income sources to reduce income instability, while sharecroppers may rely more on field-level management practices such as ridge construction. These variations indicate that adaptation decisions are influenced not only by climate exposure but also by differences in resource access and risk management capacity. The results are consistent with the literature emphasizing tenure security and exposure heterogeneity as key determinants of adaptation behavior (Attiogbé et al. 2024; Kehinde et al. 2021).

Revenue Comparisons: Adopters Vs Non-Adopters

Table 2 provides the results of the mean comparison of log farm revenue between adopters and non-adopters through the Welch t-test. Farmers who shift planting dates have a higher mean log revenue (2.900) than non-adopters (2.682), differing by 0.217 log points ($t = 2.866$; $p = 0.005$). This implies that the unconditional revenue gap is statistically significant for planting-date shifters. Conversely, ridge adopters have a lower mean log revenue (2.649) than non-adopters (2.886), with a difference of 0.238 log points ($t = -2.955$; $p = 0.004$). In the case of income diversification, the difference (−0.101 log points) is not statistically significant ($p = 0.216$).

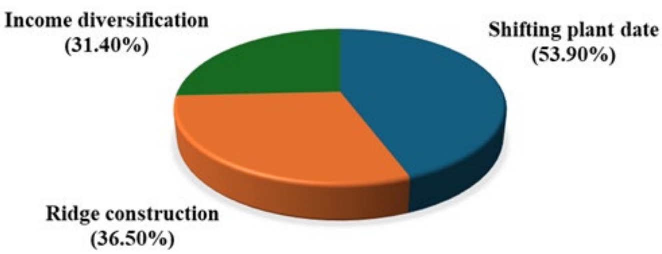

Figure 3. Adoption rates of climate adaptation strategies among smallholder paddy farmers

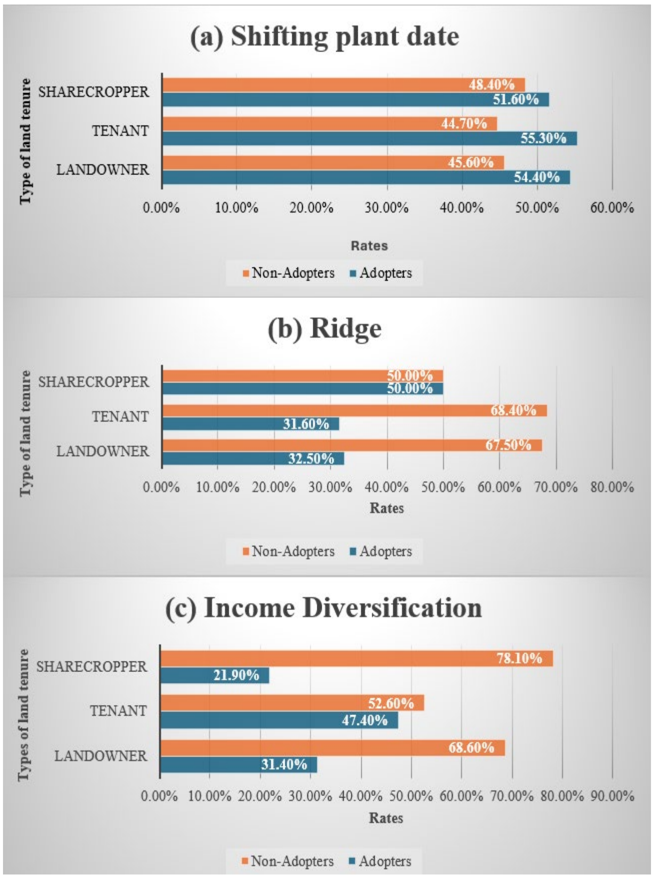

Figure 4. Adoption rates (%) of climate adaptation strategies (shifting planting date, ridge construction, and income diversification) by land tenure

To some extent, these unconditional results are consistent with previous empirical findings of increased income among adopters of climate-smart practices, though they do not apply to all adaptation strategies (Duyen et al. 2019; Ojo et al. 2022). The positive revenue difference observed for farmers who shift planting dates suggests that better alignment between crop calendars and rainfall patterns may improve production outcomes. Conversely, the negative gap in ridge adopters may indicate that this strategy is unfavorable for farmers at a higher agroecological risk. In such cases, ridge construction may function primarily as a protective measure rather than as a strategy to increase farm revenue. This finding is supported by previous cross-sectional studies (Ndamani & Watanabe, 2017; Scognamillo et al. 2022). These comparisons imply heterogeneous revenue implications across the adaptation strategies.

Multivariate Regression Results

Table 3 shows the OLS estimates of the association between log farm revenue and adaptation strategies in three specifications. In Model 1, which incorporates only the adaptation indicators, the shift in planting dates is positively associated with log farm revenue ($\beta = 0.184$; $p < 0.05$), whereas the ridge construction is negatively associated ($\beta = -0.223$; $p < 0.01$). Income diversification is not statistically significant. These results are also in line with Table 2 and with studies that found positive average income associations with some of the adaptation strategies (Khan et al. 2022).

When the farmers' and the farms' characteristics are introduced as controls in Model 2, the magnitude of the adaptation coefficients declines. The coefficient of shifting planting dates goes down to 0.144 and becomes marginally significant ($p < 0.10$), while the ridge coefficient decreases to −0.139 ($p < 0.10$). Farm size is significantly and positively related to revenue ($\beta = 0.438$; $p < 0.01$), suggesting that scale is a key factor in explaining revenue heterogeneity. There is also a weak positive association with education ($\beta = 0.021$; $p < 0.10$), whereas age, farming experience, gender, and household size are not significant. The prevalence of farm size and human capital in determining economic outcomes is in line with the broader smallholder literature (Duyen et al. 2019; Kehinde et al. 2021).

Table 2. Mean comparisons of log revenue between adopters and non-adopters of climate adaptation strategies (Welch's t-test)

Variable	Mean Non-adopter	Mean adopter	Diff.	t-statistics	p-value	n non-adopter	n adopter
Shifting planting dates	2.682	2.900	0.217	2.866	0.005	125	146
Ridge	2.886	2.649	-0.238	-2.955	0.004	172	99
Income diversification	2.831	2.730	-0.101	-1.242	0.216	186	85

Table 3. OLS regression results of the relationship between climate adaptation strategies and log farm revenue across three model specifications

Variable	Model 1	Model 2	Model 3
Shifting planting dates (dummy)	0.184**	0.144*	0.121
	-0.079	-0.082	-0.082
Ridge (dummy)	-0.223***	-0.139*	-0.126
	-0.08	-0.071	-0.087
Income diversification (dummy)	-0.078	-0.129	-0.154*
	-0.084	-0.088	-0.084
Age (years)	-	-0.006	-0.004
		-0.004	-0.004
Education (years)	-	0.021*	0.019*
		-0.012	-0.011
Farming experience	-	0.008	0.006
		-0.006	-0.006
Farm size (ha)	-	0.438***	0.412***
		-0.095	-0.093
Gender (dummy, 1=male)	-	0.073	0.065
		-0.152	-0.149
Household_size	-	0.017	0.012
		-0.028	-0.027
Tenant (dummy, ref = landowner)	-	-	-0.092
			-0.081
Sharecropper (dummy, ref = landowner)	-	-	-0.148*
			-0.087
Delanggu (dummy, ref = Polanharjo)	-	-	0.118
			-0.094
Trucuk (dummy, ref = Polanharjo)	-	-	-0.203**
			-0.101
Constant	13.842***	12.936***	12.517***
	-0.112	-0.428	-0.457
N	271	269	269
R-squared	0.061	0.31	0.346

Notes: *** p<0.01, ** p<0.05, * p<0.10. Model 1 includes only adaptation indicators. Model 2 adds farmer and farm controls. Model 3 further adds tenure categories and district fixed effects. Robust standard errors (HC3) in parentheses.

Model 3 further includes land tenure and district fixed effects. Once these institutional and spatial variables have been controlled, the coefficients on shifting planting dates ($\beta = 0.121$) and ridge construction ($\beta = -0.126$) are no longer statistically significant. Income diversification is weakly negative ($\beta = -0.154$; $p < 0.10$). The R-squared of Model 3 (0.346) is higher than that of Model 1 (0.061), indicating that tenure and district effects provide a significant portion of the change in revenue. The sharecropper status is negatively associated with revenue ($\beta = -0.148$; $p < 0.10$), and farmers in Trucuk district have much lower revenue as compared to Polanharjo ($\beta = -0.203$; $p < 0.05$). Such attenuation of adaptation coefficients in models with structural and contextual controls is common in the adaptation literature and is often attributed to sorting and unobserved heterogeneity (Ndamani & Watanabe, 2017; Saha et al. 2025; Usman et al. 2023).

Taken together, the regression results demonstrate systematic coefficient attenuation as structural and contextual controls are introduced into the model. In this model, the positive association between shifting planting dates and revenue weakens, while the negative ridge coefficient becomes smaller and statistically insignificant. These findings suggest that some of the revenue differences between adopters and non-adopters are due to structural factors, including farm size, tenure, and regional factors, rather than the direct revenue impacts of adaptation strategies alone. These findings align with conclusions from cross-sectional adaptation and income studies in other contexts (Scognamillo et al. 2022).

The analysis generates three insights applicable to agribusiness management under climate risk. First, adaptation among smallholder paddy farmers in Klaten Regency is common and multi-dimensional, yet it represents a combination of proactive management and constraint-based coping behavior. Shifting planting dates is the most robust strategy associated with log revenue. This pattern is consistent with the broader literature, which indicates that aligning crop calendars with rainfall onset can help decrease yield losses and replanting costs (Duyen et al. 2019; Khan et al. 2022). However, the coefficient for planting-date shifting weakens after introducing district and tenure controls, suggesting that contextual factors (such as irrigation coordination, access to climate information, and labor availability) jointly influence both adoption and revenue. In this regard, shifting planting dates may act as a proxy for stronger management capacity, as it is associated with higher revenue.

This trend may indicate planting-time adjustments to minimize production risks amid fluctuating rainfall. This process allows farmers to match the existing water conditions with the more advantageous periods of crop growth to avoid water stress in sensitive stages of the crop (flowering and grain filling) and will stabilize the yields as well as reduce the use of replanting and more input during the periods after an early crop failure at the beginning of the season. The same process has been observed in rice-based models, in which a practical response to rainfall variability and seasonal uncertainty is an adjustment to planting calendars (Duyen et al. 2019; Khan et al. 2022). In practice, however, the success of planting-date changes usually requires managerial capacity and access to institutional support. These contextual elements are known to influence the effectiveness of climate adaptation strategies and their economic outcomes (Ojo et al. 2022). These contextual variables may explain why the estimated revenue advantage flattens as district and tenure controls are added.

Second, ridge construction is negatively associated with revenue in the baseline specification, but this result should not be interpreted as evidence that ridges reduce income. A more plausible explanation is adverse selection: farmers facing higher flood risk, poorer drainage, or less reliable irrigation are more likely to adopt ridges. In such contexts, ridge construction serves as a defensive adaptation strategy to reduce potential production losses rather than increasing productivity (Ndamani & Watanabe, 2017; Scognamillo et al. 2022). Consequently, the negative coefficient may partly capture underlying agroecological risks rather than the intrinsic economic performance. Similar patterns have been reported in adaptation studies in which farmers adopt protective measures in response to unfavorable environmental conditions (Ndamani & Watanabe, 2017; Scognamillo et al. 2022).

This result suggests that ridge construction may be undertaken primarily to limit downside losses in risk-prone plots rather than to generate immediate revenue gains. It means that the practice is more in line with a defensive adaptation strategy in that regard than an income-enhancing investment. Scognamillo et al. (2022) demonstrate that adaptation in rice-based farming in a climate-stressed environment may imply obvious trade-offs between vulnerability reduction and profit maximization. This view seems to apply in the Indonesian context, since farmers who build ridges could be reacting to increased drainage pressures or exposure to floods, and thus the negative coefficient in the baseline model may reflect the harsher production environment in which the practice is adopted. Meanwhile, Ndamani & Watanabe (2017) underscore that the perception of climatic risks influences adaptation choices of farmers, meaning that the more exposed a farmer is, the greater the likelihood of taking protective measures, even when the short-term economic benefit is not clear. Therefore, ridge construction in this paper should be regarded more as a response to adverse agroecological conditions than as revealing a reduced inherent profitability of the practice itself.

Third, income diversification becomes weakly negative in the most controlled model ($p < 0.10$). One potential mechanism is labor reallocation: households engaged in off-farm activities may devote less time to timely farm operations, reducing management intensity. The sensitivity of coefficients across models (with R^2 increasing from 0.061 to 0.346) indicates that tenure and district fixed effects capture substantial heterogeneity correlated with both adaptation and revenue. This pattern is consistent with evidence that adaptation effects often attenuate after controlling for farmer characteristics and contextual variability (Saha et al. 2025; Usman et al. 2023).

This result implies that income diversification in this respect can be mainly a household risk-management measure and not necessarily a direct tool for increasing farm revenues. Previous studies show that income diversification can strengthen household resilience, reduce risk exposure, and support more stable livelihoods (Adam & Abdulai, 2024; Ho et al. 2021; Ojo et al. 2022). However, this does not necessarily mean that diversification will increase farm revenue in every context. This is consistent with studies showing that adaptation may involve trade-offs between reducing vulnerability and economic outcomes, and that its effects often depend on local conditions (Adam & Abdulai, 2024; Ho et al. 2021; Scognamillo et al. 2022). When climate variability increases uncertainty in agricultural production, households often allocate labor to off-farm activities to stabilize their overall income. Although such a strategy can positively improve livelihood resilience, it can also reduce the time and attention devoted to farm management. As a result, the intensity and timeliness of farm management may decline, which is potentially associated with farm-level revenue. Empirical data also indicate that in many situations, the diversification of livelihoods is the reaction of households in response to climatic and economic risks and not the strategy to optimize the profit of farms alone (Adam & Abdulai, 2024; Ho et al. 2021). This suggests that the weakly negative relationship in the most controlled specification might be a trade-off between farm revenue and household income stability under climate risk.

Overall, the results support the importance of structural factors in the revenue model: farm size is closely and positively associated with revenue across all specifications, and education has a weak positive impact. These results point out the contributions of scale and human capital to smallholder performance. In addition to adaptation variables, the negative association for sharecroppers and for farmers in Trucuk district indicates institutional and spatial differences in revenue performance. Attiogbé et al. (2024) and Etana et al. (2020) explain that land tenure security shapes incentives to invest in adaptive practices. Meanwhile, regional differences in infrastructure, irrigation quality, and market access mediate the economic returns to adaptation (Kissi et al. 2023; Scognamillo et al. 2022). These findings confirm that climate adaptation strategies are associated positively with revenue only under supportive conditions, such as secure tenure, effective extension, and market connectivity, rather than as stand-alone technical fixes.

Managerial Implications

One practical way to put these findings into a managerial perspective is to view the adaptation strategies as part of a broader risk-management package. First, shifting planting dates is a simple and low-cost procedure that would mainly entail proper planning. It works best when farmers are well informed about climate conditions, can coordinate planting with the rest of the community and extension workers, and can find labor when required. Stronger extension services that give local seasonal forecasts and practical planting calendars would make it easier for farmers to apply this strategy effectively. Meanwhile, the negative association between ridge construction and revenue underscores the risk that some adaptation practices may primarily function as coping responses in high-risk plots rather than as revenue-enhancing mechanisms. Farmers and local governments should treat ridges as a complement to broader water management interventions, such as maintaining tertiary canals and improving drainage at the scheme level. In addition, income diversification should be framed primarily as an income-smoothing and resilience strategy rather than as a direct enhancer of farm revenue. Lastly, because adaptation–revenue associations vary by district and tenure status, interventions should be geographically targeted and tenure-aware.

From a managerial perspective, climate adaptation requires coordinated support from farmers, government, private actors, and state-owned enterprises. Farmers need timely climate information and practical guidance to implement strategies, such as shifting planting dates. Government agencies, including state-owned enterprises where relevant, should strengthen extension services, irrigation maintenance, drainage management, and local water governance to create enabling conditions for adaptation. Meanwhile, private-sector actors can contribute by improving access to inputs, climate information, and market linkages.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Using a primary survey of 271 paddy farmers in Klaten Regency, this study documents high adoption rates of three adaptation strategies and explores their associations with log farm revenue. Shifting planting dates is positively associated with revenue in simpler models and in mean comparisons, while ridge use is negatively associated in raw comparisons. This is likely indicative of the increased underlying risk of the ridge adopters. After controlling for farmer characteristics, land tenure, and district context, the estimated adaptation coefficients weakened, which means that contextual and selection factors play important roles. Overall, the study concludes that climate adaptation strategies are associated with revenue outcomes, particularly within supportive structural, institutional, and spatial conditions. Thus, the economic implications of climate adaptation strategies are dependent on scale, tenure security, local infrastructure, and access to information and extension systems. To facilitate the adoption of the practice, complementary services and infrastructure should be provided to ensure that farmers' work translates into stable revenue benefits. The study has several limitations. First, the analysis is based on a cross-sectional survey of paddy farmers. Therefore, the findings may not apply to other areas or with farmers who cultivate other crops. Second, unobserved factors, such as farmers' skills, risk attitudes, or access to informal support networks, may influence their decisions on adaptation strategies and their farm revenue.

Recommendations

The climate adaptation policy for smallholder paddy systems should prioritize strengthening enabling conditions rather than pursuing only technical interventions. Policymakers should enhance coordination among extension services, irrigation management institutions, and local governments to ensure timely and location-specific climate information. In addition, policies should promote equitable access to resources, particularly for farmers with less secure land tenure, and support region-specific interventions that account for differences in agroecological conditions. Strengthening these enabling environments is essential to ensure that adaptation strategies translate into improved and stable farm revenue.

ACKNOWLEDGEMENT

The authors acknowledge their gratitude to Universitas Sebelas Maret (UNS) for providing both financial and administrative support through its institutional research grant program.

FUNDING STATEMENT: This work was funded by Universitas Sebelas Maret [PKGR-UNS 2026; Natural Resource and Environmental Economics Research Group (RG ESDAL)].

CONFLICTS OF INTEREST: The authors state that there is no conflict of interest.

DECLARATION OF GENERATIVE AI STATEMENT: During the preparation of this manuscript, the authors used ChatGPT to improve language clarity and readability only in selected sections of the text. All outputs were carefully reviewed, revised, and verified by the authors. The authors take full responsibility for the content of this publication.

REFERENCES

Adaawen, S. (2021). Understanding Climate Change and Drought Perceptions, Impact and Responses in the Rural Savannah, West Africa. Atmosphere, 12(5), 594. https://doi.org/10.3390/atmos12050594

Adam, B., & Abdulai, A. (2024). Heterogeneous Impact of Crop Diversification on Farm Net Returns and Risk Exposure: Empirical Evidence from Ghana. Canadian Journal of Agricultural Economics/ Revue Canadienne D Agroeconomie, 72(4), 469–487. https://doi.org/10.1111/cjag.12360

Ali, S., Khatak, N. U. R., Saqib, S. E., & Rehman, S. U. (2022). Impact of Tenancy Status on Wheat Productivity in Central Khyber Pakhtunkhwa, Pakistan. Sarhad Journal of Agriculture, 38(2). https://doi.org/10.17582/journal.sja/2022/38.2.693.700

Ansari, A., Lin, Y.-P., & Lur, H.-S. (2021). Evaluating and Adapting Climate Change Impacts on Rice Production in Indonesia: A Case Study of the Keduang Subwatershed, Central Java. Environments, 8(11), 117. https://doi.org/10.3390/environments8110117

Asiama, K. O., Bennett, R., & Zevenbergen, J. A. (2017). Land Consolidation on Ghana's Rural Customary Lands: Drawing from the Dutch, Lithuanian and Rwandan Experiences. Journal of Rural Studies, 56, 87–99. https://doi.org/10.1016/j.jrurstud.2017.09.007

Attiogbé, A. A. C., Nehren, U., Quansah, E., Bessah, E., Salack, S., Sogbedji, J. M., & Agodzo, S. K. (2024). Cocoa Farmers' Perceptions of Drought and Adaptive Strategies in the Ghana–Togo Transboundary Cocoa Belt. Land, 13(11), 1737. https://doi.org/10.3390/land13111737

Aung, T., Huylenbroeck, G. V., & Speelman, S. (2017). Determining Factors for the Application of Climate Change Adaptation Strategies Among Farmers in Magwe District, Dry Zone Region of Myanmar. International Journal of Climate Change Strategies and Management, 9(1), 36–55. https://doi.org/10.1108/ijccsm-09-2015-0134

BPS. (2018). Luas panen, rata-rata produksi, produksi padi sawah dan padi gogo menurut kecamatan di Kabupaten Klaten tahun 2014. https://klatenkab.bps.go.id/id/statistics-table/1/MTQ5IzE%3D/luas-panen-rata-rata-produksi-produksi-padi-sawah-dan-padi-gogo-menurut-kecamatan-di-kabupaten-klaten-tahun-2014.html

Choudhary, B. B., Dev, I., Singh, P., Singh, R., Sharma, P., Chand, K., Garg, K. K., Anantha, K. H., Akuraju, V., Dixit, S., Kumar, S., Ram, A., & Kumar, N. (2022). Impact of Soil and Water Conservation Measures on Farm Productivity and Income in the Semi-Arid Tropics of Bundelkhand, Central India. Environmental Conservation, 49(4), 263–271. https://doi.org/10.1017/s0376892922000352

Dai, X., Pu, L., & Rao, F. (2017). Assessing the Effect of a Crop-Tree Intercropping Program on Smallholders' Incomes in Rural Xinjiang, China. Sustainability, 9(9), 1542. https://doi.org/10.3390/su9091542

Duyen, T. N. L., Rañola, R. F., Sander, B. O., Waßmann, R., Tiến, N. Đ., & Nong, N. K. N. (2019). Determinants of Adoption of Climate-Smart Agriculture Technologies in Rice Production in Vietnam. International Journal of Climate Change Strategies and Management, 12(2), 238–256. https://doi.org/10.1108/ijccsm-01-2019-0003

Etana, D., Snelder, D. J., Wesenbeeck, C. F. A. v., & Buning, T. d. C. (2020). Dynamics of Smallholder Farmers' Livelihood Adaptation Decision-Making in Central Ethiopia. Sustainability, 12(11), 4526. https://doi.org/10.3390/su12114526

Ho, T. D. N., Tsusaka, T. W., Kuwornu, J. K., Datta, A., & Nguyen, L. T. (2021). Do Rice Varieties Matter? Climate Change Adaptation and Livelihood Diversification Among Rural Smallholder Households in the Mekong Delta Region of Vietnam. Mitigation and Adaptation Strategies for Global Change, 27(1). https://doi.org/10.1007/s11027-021-09978-x

Iqbal, M. A., Abbas, A., Naqvi, S. A. A., Rizwan, M., Samie, A., & Ahmed, U. I. (2020). Drivers of Farm Households' Perceived Risk Sources and Factors Affecting Uptake of Mitigation Strategies in Punjab, Pakistan: Implications for Sustainable Agriculture. Sustainability, 12(23), 9895. https://doi.org/10.3390/su12239895

Jabbar, A., Liu, W., Zhang, J., Wang, Y., Wu, Q., Peng, J., & Liu, J. (2023). Enhancing Adaptation to Climate Change by Fostering Collective Action Groups Among Smallholders in Punjab, Pakistan. Frontiers in Sustainable Food Systems, 7. https://doi.org/10.3389/fsufs.2023.1235726

Kehinde, M. O., Shittu, A. M., Adewuyi, S. A., Osunsina, I. O. O., & Adeyonu, A. G. (2021). Land Tenure and Property Rights, and Household

Food Security Among Rice Farmers in Northern Nigeria. Heliyon, 7(2), e06110. https://doi.org/10.1016/j.heliyon.2021.e06110

Keil, A., Teufel, N., Gunawan, D., & Leemhuis, C. (2009). Vulnerability of Smallholder Farmers to ENSO-related Drought in Indonesia. Climate Research, 38, 155–169. https://doi.org/10.3354/cr00778

Khan, N. A., Khanal, U., Wilson, C., Shah, A. A., & Muhammad Atiq Ur Rehman Tariq. (2022). The Impact of Farmers' Adaptation to Climate Change on Rice Yields: Implications for Sustainable Food Systems. Sustainability, 14(23), 16035. https://doi.org/10.3390/su142316035

Kissi, A. E., Abbey, G. A., & Villamor, G. B. (2023). Perceptions of Climate Change Risk on Agriculture Livelihood in Savanna Region, Northern Togo. Climate, 11(4), 86. https://doi.org/10.3390/cli11040086

Luu, T. A., Nguyen, A. T., Trinh, Q. A., Pham, V. T., Le, B. B., Nguyen, D. T., Hoang, Q. N., Pham, H. T. T., Nguyen, T. K., Luu, V. N., & Hens, L. (2019). Farmers' Intention to Climate Change Adaptation in Agriculture in the Red River Delta Biosphere Reserve (Vietnam): A Combination of Structural Equation Modeling (SEM) and Protection Motivation Theory (PMT). Sustainability, 11(10), 2993. https://doi.org/10.3390/su11102993

Mamun, A., Roy, S., Abu Reza Md. Towfiqul Islam, Alam, G. M. M., Alam, E., Pal, S. C., Sattar, A., & Mallick, J. (2021). Smallholder Farmers' Perceived Climate-Related Risk, Impact, and Their Choices of Sustainable Adaptation Strategies. Sustainability, 13(21), 11922. https://doi.org/10.3390/su132111922

Muliyadi, K. A., Wahyuningtyas, A. S. H., & Sujarwo. (2025). Adaptation Strategies and Constraints to Climate Change Among Clove Farmers in East Kolaka. Jurnal Manajemen Dan Agribisnis, 22(3), 317. https://doi.org/10.17358/jma.22.3.317

Ndamani, F., & Watanabe, T. (2017). Determinants of Farmers' Climate Risk Perceptions in Agriculture—A Rural Ghana Perspective. Water, 9(3), 210. https://doi.org/10.3390/w9030210

Ngoma, H., Machina, H., & Kuteya, A. (2020). Can Agricultural Subsidies Reduce Gendered Productivity Gaps? Panel Data Evidence from Zambia. Development Policy Review, 39(2), 303–323. https://doi.org/10.1111/dpr.12483

Nkuba, M. R., Chanda, R., Mmopelwa, G., Kato, E., Mangheni, M. N., Lesolle, D., John, J. G., & Mujuni, G. (2022). Factors Associated with Farmers' Use of Indigenous and Scientific Climate Forecasts in Rwenzori Region, Western Uganda. Regional Environmental Change, 23(1). https://doi.org/10.1007/s10113-022-01994-0

Ojo, T. O., Ogundeji, A. A., & Emenike, C. U. (2022). Does Adoption of Climate Change Adaptation Strategy Improve Food Security? A Case of Rice Farmers in Ogun State, Nigeria. Land, 11(11), 1875. https://doi.org/10.3390/land11111875

Ruxton, G. D. (2006). The Unequal Variance t-test is An Underused Alternative to Student's t-test and The Mann–Whitney U test. Behavioral Ecology, 17(4), 688–690. https://doi.org/10.1093/beheco/ark016

Saha, S., Alam, M. J., Abbasi, A. A. A., Begum, I. A., Parikh, P., & Rola-Rubzen, M. F. (2025). The Effect of Rural Land Mortgaging on Rural Transformation at the Regional Level in Bangladesh. Land Degradation and Development, 36(6), 1977–1992. https://doi.org/10.1002/ldr.5476

Scognamillo, A., Sitko, N. J., Bandara, S., Hewage, S., Munaweera, T., & Kwon, J. (2022). The Challenge of Making Climate Adaptation Profitable for Farmers: Evidence from Sri Lanka's Rice Sector. Environment and Development Economics, 27(5), 451–469. https://doi.org/10.1017/s1355770x21000371

Sekaranom, A. B., Nurjani, E., & Nucifera, F. (2021). Agricultural Climate Change Adaptation in Kebumen, Central Java, Indonesia. Sustainability, 13(13), 7069. https://doi.org/10.3390/su13137069

Singh, C., Osbahr, H., & Dorward, P. (2018). The Implications of Rural Perceptions of Water Scarcity on Differential Adaptation Behaviour in Rajasthan, India. Regional Environmental Change, 18(8), 2417–2432. https://doi.org/10.1007/s10113-018-1358-y

Suntoro, A., Marbun, A. A. Y., & Sayekti, C. W. (2025). Climate Change Challenge: Coastal Community Adaptation Towards Achieving Sustainable Community Resilience in Central Java, Indonesia. In S. C. Pal, U. Chatterjee, A. Saha, & D. Ruidas (Eds.), Climate Change: Conflict and Resilience in the Age of Anthropocene (Vol. 80, pp. 235–255). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-85359-3_10

Tione, S. E., Nampanzira, D. K., Nalule, G., Kashongwe, O. B., & Katengeza, S. P. (2022). Anthropogenic Land Use Change and Adoption of Climate Smart Agriculture in Sub-Saharan Africa. Sustainability, 14(22), 14729. https://doi.org/10.3390/su142214729

Usman, M., Ali, A., Bashir, M. K., Rădulescu, M., Mushtaq, K., Wudil, A. H., Baig, S. A., & Akram, R. (2023). Do Farmers' Risk Perception, Adaptation Strategies, and Their Determinants Benefit Towards Climate Change? Implications for Agriculture Sector of Punjab, Pakistan. Environmental Science and Pollution Research, 30(33), 79861–79882. https://doi.org/10.1007/s11356-023-27759-8

Wu, Z., Mohammed, A., & Harris, I. (2021). Food Waste Management in the Catering Industry: Enablers and Interrelationships. Industrial Marketing Management, 94, 1–18. https://doi.org/10.1016/j.indmarman.2021.01.019

Yousafzai, M. T., Shah, T., Khan, S., Ullah, S., Nawaz, M., Han, H., Ariza-Montes, A., Molina-Sánchez, H., & Vega-Muñoz, A. (2022). Assessing Socioeconomic Risks of Climate Change on Tenant Farmers in Pakistan. Frontiers in Psychology, 13. https://doi.org/10.3389/fpsyg.2022.870555