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Remittances As A Game Changer For The Climate Smart Agriculture Of The Vulnerable Communities Of Tehsil Shabqadar Charsadda

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ABSTRACT

The present study was conducted to explore remittances as a game changer for the climate smart agriculture of the vulnerable communities of Tehsil Shabqadar Charsadda. District Charsadda, tehsil Shabqadar village Pirqilla, Dalazak and rashakai were selected for the research study. The data were randomly collected from three different villages in Shabqadar. 123 sample size was extracted by using proportional allocation method and Yamane formula. Data were analyzed through STATA and various techniques, regression analysis, and data visualization were analyzed through MS excel. The results of probit model show remittances, education, non-farm income, and credit access significantly increase CSA adoption, while landholding had a weak or insignificant effect. A stepwise model revealed adoption is driven by a bundle of complementary factors: risk reduction habits, credit access, extension contact, assets, and non-farm income, with the full model providing the best explanatory power. The multiple regression indicates remittances significantly increase CSA expenditure, while climate shocks reduce it, with panel models confirming the robustness of these drivers over time. The bivariate probit confirms a strong, positive causal effect of remittances on adoption after correcting for endogeneity, revealing a positive selection effect driven by unobserved entrepreneurial traits. Ultimately, remittances act as a critical financial enabler, but effective CSA adoption depends on complementary access to information, credit, and risk management resources.

INTRODUCTION

Remittances represent a transformative financial mechanism for advancing Climate Smart Agriculture (CSA) adoption among climate-vulnerable farming communities, primarily by alleviating critical liquidity constraints that traditionally impede investment in adaptive technologies (Rigaud et al. 2021, Delavallade et al. 2025). Empirical evidence (Devereux and Sussex 2000, Abath 2017, Delavallade et al. 2025) confirms that remittance inflows significantly increase households' capacity to procure drought-resistant seeds, efficient irrigation systems, and soil conservation infrastructure pivotal CSA components that enhance resilience against intensifying climate shocks. Beyond capital provision, remittances facilitate trans local knowledge transfer, wherein migrants



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expose recipients to innovative farming practices and climate information systems, thereby strengthening adaptive capacity (Scheffran et al. 2012, Giri 2024, Mzimela and Moyo 2024). Critically, these financial flows enable risk diversification through livelihood shifts and buffer production losses, reducing distress-driven environmental degradation (Srinivas and Giridhar 2022). Thus, while not a panacea, remittances constitute a catalytic game changer for CSA scalability when strategically embedded within broader institutional support frameworks (Rigaud et al. 2021, Tambe 2022, Mzimela and Moyo 2024).

Remittances have the potential to revolutionize Climate Smart Agriculture (CSA) by providing the financial resources needed to adopt sustainable farming practices (Mizik 2021, Ali et al. 2022, Mills 2023). Their role in enhancing productivity, food security, and environmental sustainability makes them a game changer for rural communities facing climate change pressures (Wang et al. 2025). Climate change poses a significant threat to agricultural productivity, particularly in developing countries where smallholder farmers rely heavily on rain-fed farming (Brooks and Loevinsohn, Scheffran et al. 2012, Mekonnen 2024). Erratic weather patterns, prolonged droughts, and unpredictable rainfall have reduced crop yields, exacerbating food insecurity and rural poverty (Mwenda et al. 2019, Ngcamu and Chari 2020, Mizik 2021). In response, CSA has emerged as a sustainable approach to enhance resilience, improve productivity, and reduce greenhouse gas emissions (Brooks and Loevinsohn, Mekonnen 2024). However, the adoption of CSA practices remains limited due to financial constraints, lack of access to credit, and inadequate infrastructure (Mwenda et al. 2019, Wang et al. 2025). Remittances funds sent by migrants to their families in rural areas present a viable solution to these challenges by providing the necessary capital to invest in climate-resilient farming technologies and practices (Babagaliyeva et al. 2017, Mills 2023).

By facilitating investments in CSA, remittances contribute to increased agricultural productivity and food security (Dey et al. 2019, Crush and Ceasar 2020, Ali et al. 2022). Studies (Reardon et al. 2007, Maharjan et al. 2013, Piras et al. 2018, Ali et al. 2023) indicate that households receiving remittances allocate a significant portion of these funds to improving farm operations, leading to higher crop yields and diversified income sources. For instance, drip irrigation systems funded by remittances can reduce water usage while maintaining stable production during dry seasons (Shah and Keller 2014, Chidavaenzi et al. 2021, Ejigu 2021). Similarly, the adoption of improved seed varieties and integrated pest management techniques minimizes crop losses, ensuring consistent food supply and higher marketable surplus (Gitonga 2020, Cisse 2024). Consequently, remittance inflows not only boost household income but also strengthen community-wide food security in climate-vulnerable regions (Iese et al. 2024).

Beyond immediate productivity gains, remittances encourage sustainable land management practices that mitigate environmental degradation (Williams and Paudel 2020, Mack et al. 2023). Deforestation, soil erosion, and overgrazing are common challenges in rural farming communities, often driven by poverty and lack of alternatives (Wassie 2020, Mganga 2022). Remittance-supported investments in CSA promote conservation agriculture, including crop rotation, cover cropping, and reduced tillage, which enhance soil fertility and carbon sequestration (Mack et al. 2023). Furthermore, funds sent by migrants can be channeled into renewable energy projects, such as biogas and solar panels, reducing reliance on firewood and fossil fuels and these practices align with global climate goals by lowering greenhouse gas emissions while improving farm sustainability (Smith et al. 2020, Wassie 2020).

This research seeks to investigate the role of remittances as a financial enabler for



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adopting climate-smart agriculture among vulnerable communities in Tehsil Shabqadar. Specifically, it aims to understand whether and how remittance income contributes to investment in resilient farming techniques, adoption of sustainable inputs (e.g. drip irrigation, drought-tolerant crops), capacity building and knowledge transfer, enhancing food security and income stability, despite anecdotal evidence of positive impacts, there is a lack of empirical research connecting remittance flows to climate-smart agricultural transformation in the Pakistani context. Bridging this gap could offer new insights into how external financial support can catalyze climate resilience in rural communities.

OBJECTIVES

To quantify the proportion of remittance receiving households (RRHs) versus non-RRHs vulnerable communities investing remittances in CSA practices.

To measure remittance-attributable changes in household expenditure on climate-resilient agricultural inputs/technologies among RRHs

To assess the impact of remittance funded CSA adoption on household resilience indicators among RRHs versus non-RRHs.

To identify and rank constraints limiting remittance channeling towards CSA adoption the area

LITERATURE REVIEW

Chandio et al., (2025) examined the impact that remittance inflows may have on long-run agricultural productivity in some emerging countries in Asia, Bangladesh, India, Sri Lanka, Malaysia, Nepal, the Philippines, Pakistan, and Vietnam. Based on 2000-2018 economic data, the researchers used different advanced statistical techniques to conduct a test whether long run relationships between remittances and agricultural productivity existed. These results show that there is a positive outcome in agricultural productivity when a remittance is well managed. This effect is probably because the households use their remittance earnings in investing on improved farming equipment, inputs or technology. The article stresses on the significance of remittances as a source of finance that can facilitate an agricultural growth particularly in places whereby the formal credit schemes are few. It shows the necessity of provision of policies promoting rational use of remittance funds in the area of agriculture to enhance food security and rural livelihoods. Degfachew et al., (2025) researched the impact of international migration and it is investigated in the context of states as the population of Eastern Amhara, Ethiopia, works in small-scale farming and suffers such issues as droughts and unstable income, as well as poor access to the market. Due to these hardships, a good number of individuals immigrate to foreign countries in order to seek employment opportunities therein. This was done by supporting the study with data of 384 households of which it was found that those more educated or those with access to financial facilities have less chances of migrating illegally. Drought environmental issues promote migration and it is through the use of the irrigation system that farmers are retained. The studies revealed that the migrants whether legal or illegal are the one who receive higher earnings than the non-migrants which amount to approximately 19 percent and 34 percent respectively. Other migrants just come back with improved agricultural skills and this enables them to increase their output, even illegal migrants in spite of the risks they encounter. Nevertheless, not every migrant with the same conditions as those of legal migrants will benefit equally. This study recommends that migration can advance economic benefits and promote agriculture but it is dangerous. Hence, government needs to participate in fostering rural enterprises and establishing secure migration avenues that are not



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illegitimate in order to lessen the stress of unlawful migration and sustain agriculture.

Belay et al., (2024) undertook a research, where primary and secondary data were used to investigate the application of CSA within the households. They utilized tools of analysis like propensity score matching to assess the impacts of CSA to agricultural performance. This would assist them in getting a better insight into the impact of the CSA adoption in enabling farmers to respond to the changes in the environmental conditions. Another feature of the study is the identification of the role of support systems that facilitate the introduction of CSA at a larger rate. These entail good agricultural extension services, need to access good climatic information, and good policy support. They also stressed on the importance of these supportive measures towards enhancing the adaptation capacity of farmers and the long-term sustainability of farming in those regions where agriculture is sensitive to the adverse climatic changes.

Ali et al. (2023) analyzed the impact of receiving remittance of internal or external origin on the investment patterns of rural households in Pakistan in the fields of agriculture and the selected crop cultivation. In this case though there has been a tendency to suggest that remittances would boost the amount of investment that is made on the farm as an extra income redounds to the household, this was however not obtained in the study. A shortage of labor on the farm can arise when one of its members migrates, thus, decreasing the capacity of investment or continuation of the farming process. Using the results obtained after surveying more than 5,600 rural households, it was found out that remittance households were spending far less money on agriculture and were much less productive than non-remittance households. However, domestic remittances to be precise had an even more negative effect-a total fall in farm investment and a 77 percent fall in output. A decrease in the farming activities was experienced as both labor intensive and capital intensive crops were affected. These findings held irrespective of the models used and statistical techniques, which indicated that remittance income might lower productivity on farms because of labor scarcity and undertaking of less investment to farming activities.

Agarwal et al., (2022) focused on the role of climate change smart agricultural practices (CSAPs) and education level, income and male migration in households food security and livelihoods in climate sensitive regions. In highlighting the study, as the threats to climate significantly increase, the total crop failure is likely to take place which prompts a great number of male farmers to abandon their farming. The trend generates feminization of farming with women doing more farming activities. This study identified that the case households in adopting CSAPs gained better income and crops particularly among men. Male migration was also minimized by 21 percent with the adoption of CSAPs. Most importantly was the education level, especially to the women; an increment of fraction in literacy among the women greatly reduced the risk of male migration. Additionally, the increase of information about CSAPs by the farmers has led to a great probability of adoption. The knowledge gap between the man and women was less among the users of CSAPs. Contrastingly, the non-adopting households were very much burdened with matters related to food security when the climate shocks hit with these cases normally reducing food consumption thus increasing the likelihood of migration by 50% as well. The research team concluded that ensuring the gender gap in access to CSAP knowledge is part and parcel of conserving rural livelihoods. and ensuring sustainable agricultural systems in the face of climate change.



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THEORETICAL BACKGROUND

Remittances, funds sent by migrants to households in origin countries, have emerged as a transformative financial resource for rural communities in developing economies, significantly enhancing livelihoods, reducing poverty, and building economic resilience (Yang, 2011). Critically, these inflows can overcome financial barriers to Climate-Smart Agriculture (CSA) adoption a tripartite approach seeking sustainable productivity gains, enhanced adaptation, and emissions mitigation (FAO, 2013) by relaxing capital constraints per New Economics of Labor Migration (NELM) theory (Stark & Bloom, 1985). Remittances act as a risk-diversification tool, enabling investments in resilient technologies (e.g., drought-resistant seeds, irrigation) that align with CSA pillars but are often unaffordable due to credit market failures (Taylor, 1999). The Sustainable Livelihoods Framework (Scoones, 1998) further elucidates how remittances strengthen financial capital, facilitating CSA adoption while migrant networks concurrently bolster social capital through knowledge transfer (Adger et al., 2002). Consequently, remittances serve as a catalytic "game changer" for CSA scalability, though their potential requires policy reinforcement via financial literacy programs and diaspora engagement (Tacoli, 2002; UNDP, 2021).

Climate-related disasters, such as floods and hurricanes, disproportionately affect smallholder farmers who lack insurance and savings (Bhushan et al. 2016, Hillier 2018). Remittances act as an informal safety net, enabling households to recover quickly from climate shocks by reinvesting in farming activities (Hossain et al. 2022). Unlike government aid, which may be delayed or insufficient, remittance flows are timely and predictable, allowing farmers to replant crops, repair infrastructure, and adopt more resilient farming methods (Bhushan et al. 2016, Hossain et al. 2022). Over time, this financial cushion reduces vulnerability to future climate risks, fostering long-term agricultural resilience (Birkmann et al. 2022). Despite their potential, remittance alone cannot fully address the structural challenges hindering CSA adoption (Williams and Paudel 2020). Many farmers lack technical knowledge about sustainable practices, and extension services in rural areas remain weak, but the remittance usage is often prioritized for immediate consumption rather than long-term agricultural investments (Williams and Paudel 2020, Pilarova et al. 2022, Chetto et al. 2025). Based on the literature this research will address how remittances influence CSA adoption and household resilience outcomes in Shabqadar vulnerable communities, and what constraints limit their effective use for CSA investments, with the following objectives.

HYPOTHESIS

H₀ = No significant difference exists in CSA adoption rates between RRHs and non-RRHs.

H₀ = Remittance inflows cause no significant change in climate-resilient agricultural expenditure among RRHs.

H₀ = Remittance-funded CSA adoption has no significant effect on household resilience in RRHs versus non-RRHs.

RESEARCH METHODOLOGY

Population & Sampling

The universe of this study is based on Tehsil Shabqadar of District Charsadda, Khyber Pakhtunkhwa, Pakistan. The households represent the vulnerable farming population engaged in agriculture who are potentially impacted by climate change and possess access to external financial resources through remittances. District Charsadda, tehsil



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Shabqadar village Pirqilla, Dalazak and rashakai will be selected for the research study. The data will be randomly collected from three different villages in shabqadar. A proportional allocation sample will be determined by using the Yamane formula. This technique will be employed to distribute the sample size among villages for data collection, given the constraints of limited time and resources. With 09% for yamane formula the obtained sample size was 123.

Econometric Models

Objective-1

Based on the New Economics of Labor Migration (NELM), remittances (R_i) relax capital constraints for recipient households, increasing their investable capital K_i , which is a function of remittances and existing assets A_i , expressed as $K_i = f(R_i, A_i)$. This enhanced capital potentially facilitates investment in CSA technologies, whose adoption occurs according to adoption theory if the expected utility from adopting $EU_{CSA} > U_0$, where $U_{CSA} = \Pi_{CSA} - CC_{CSA} + \rho \cdot \sigma_{CSA}$, exceeds the utility of the status quo U_0 , formally $EU_{\text{CSA}} > U_0$. The utility of adopting CSA, U_{CSA} , is defined by its components: productivity gains Π_{CSA} , minus adoption costs C_{CSA} , plus the interaction of the household's risk preference parameter ρ and the technology's risk reduction σ_{CSA} , yielding CSA adoption requires $EU_{CSA} > U_0$, where $U_{CSA} = \Pi_{CSA} - CC_{CSA} + \rho \cdot \sigma_{CSA}$

- Π : Productivity gains, CC : Costs, ρ : Risk preference, σ : Risk reduction

$$R_i K_i = f(R_i, A_i), EU_{CSA} > U_0, U_{CSA}$$

$$= \Pi_{CSA} - CC_{CSA} + \rho \cdot \sigma_{CSA}, \Pi_{CSA}, CC_{CSA}, \rho, \sigma_{CSA}$$

The probit model quantifies CSA adoption probability as

$$CSA_i = \beta_0 + \beta_1 R_i + X_i' \gamma + \epsilon_i \quad CSA_i = \begin{cases} 1 & \text{if } CSA_i > 0 \\ 0 & \text{otherwise} \end{cases}$$

$R_i = 1$ if HH receives remittances, 0 otherwise

Category	Variable	Measurement	Expected Sign
Dependent	CSA adopt	1=Adopted ≥ 1 CSA practice; 0=None	
Core Predictor	RRH	1=Received remittances ($\geq 20\%$ income); 0=None	+
Household Controls	Hh size	Number of members	$\pm$
	education	Years of schooling (head)	+
	Land holding	Acres owned/cultivated	+
	Asset index	PCA of productive assets	+
Economic Factors	Non farm income	1=Has non-farm income; 0=None	$\pm$
	Credit access	1=Access to formal credit; 0=None	+
Institutional	extension contact	1=Received agri-extension advice; 0=None	+

Objective 2, Multiple regression model

Component	Variable	Measurement	Role
Dependent	CSAExp.	Annual expenditure (PKR) on climate-resilient inputs/technologies (e.g., drip irrigation, biofortified seeds)	Outcome
Core Predictor	Remit Inflow	Annual remittance receipts (PKR)	Treatment



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			variable
Controls (X)	Climate Shock	1=Drought/flood in year *t*; 0=None	Confounder
	Agri Income	Annual farm income (PKR)	Confounder
	Crop Area	Hectares under cultivation	Confounder
Fixed Effects	α_i	Household-specific intercept	Controls time-invariant heterogeneity
	δ_t	Year dummy (e.g., 2023=1, 2024=2)	Capture

Objective 3

CSA Adoption Probit model

where $R_i = 1$ if household i receives remittances (0 otherwise), RRH_i identifies remittance-receiving households, X_i is a vector of controls (e.g., landholding, education, risk aversion), and $\epsilon_i \sim N(0,1)$. Remittance receipt (R_i) is instrumented using exogenous variation from migrant networks in origin communities (Z_i) to address endogeneity.

Probit Model Equation with Instrumental Variable (Bivariate Probit Specification)

To address endogeneity in remittance receipt (R_i)

) when modeling ClimateSmart Agriculture (CSA) adoption, the following bivariate probit model is used:

CSA Adoption Equation (Outcome):

Remittance Receipt Equation (Endogenous Regressor):

□

Error Structure:

$(\epsilon_i, \eta_i) \sim N(0, \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix})$, $\rho \neq 0$ (tests endogeneity)
 $\rho = 0$ (tests endogeneity)

Key Elements:

Endogenous variable: R_i (remittance receipt, binary)

Instrument: Z_i (exogenous migrant networks, e.g., historical migration prevalence)

Controls: X_i (landholding, education, risk aversion, etc.)

Group indicator: $RRH_i = 1$

= 1 for remittance – receiving households (0 otherwise)

Exclusion restriction: Z_i excluded from CSA equation

Identification: Correlation (ρ) between error terms (ϵ_i, η_i)

) captures endogeneity. Consistent estimation requires Z_i to satisfy relevance ($E[Z_i R_i] \neq 0$) and exogeneity ($E[Z_i \epsilon_i] = 0$).

The key parameters δ_1 (impact for RRHs) and δ_2 (impact for non-RRHs) are compared using a Wald test of $\delta_1 - \delta_2 = 0$. Potential outcome means are computed to estimate treatment effects (ATT) for each group, correcting for selection bias via inverse Mills ratios from Stage 1. Robust standard errors are clustered at the community level.

Exclusion restrictions (Z_i) satisfy IV relevance ($E[Z_i R_i] \neq 0$) and exogeneity ($E[Z_i \epsilon_i] = 0$), confirmed via overidentification tests and falsification checks.

RESULTS & DISCUSSIONS

Probit Regression

Number of Obs 123
 LR chi2(5) 36.71



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Log Likelihood	-104.12674		Prob > chi2	0.000
			Pseudo R2	0.159
	Coefficient	Std Err	Z	P > z
CSA_adopt				
Remittance Receiver	0.554	0.191	2.900524	.000
Education Years	0.132	0.017	7.764706	.000
Land acres	0.224	0.71	0.315493	.072
Non Farm income	0.524	0.215	2.437209	.000
Credit access	0.227	0.078	2.910256	.000
Constant	-1.324***	0.264	-5.01515	.000

The table shows the findings of probit model used for regression of independent and dependent variables. The results are related to the CSA adopt (Climate Smart Agriculture) and the effect of remittance receiver, education, land acres, non-farm income and credit access on CSA adopt among the sample respondents. The results indicated the relationship of CSA adopt with remittance receiver, education, land acres, non-farm income and credit access in the values of coefficient and the value of z in the table has been used for the significance of the variances in the CSA adopt due to remittance receiver, education, land acres, non-farm income and credit access. The values of coefficient in the table shows that remittance receiver, education, land acres, non-farm income and credit access are having positive relationship with the CSA adopt but only land acres z value are less than the standard value but means that land acres are not having significant impact on CSA adopt while remittance receiver, education, non-farm income and credit access have significant impact on CSA adopt.

CSA_adopt				
	(Basic)	+ HH Control	Full	Marginal Effect
RRH	0.542*** (0.131)	0.414*** (0.124)	0.401*** (0.107)	0.201*** (0.061)
Hh_size		0.119 (0.110)	0.021 (0.018)	0.009 (0.001)
education		0.117** (0.007)	0.041** (0.021)	0.020** (0.012)
Land_holding		0.199* (0.077)	0.220* (0.071)	0.055* (0.031)
Asset_index		0.221*** (0.0221)	0.201*** (0.067)	0.067*** (0.009)
Nonfarm_income			0.214* (0.115)	0.086* (0.051)
Credit_access			0.441*** (0.099)	0.213*** (0.049)
Extension_contact			0.301** (0.201)	0.089** (0.029)
Constant	-0.769*** (0.101)	-1.323*** (0.302)	-1.449*** (0.304)	
No of Obs	123	123	123	123
Pseudo R 2	0.091	0.167	0.394	
Chi2	21.41	36.71	51.55	

*** p<0.01, ** p<0.05, * p<0.1



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The results show that farmers with stronger risk reduction habits (RRH) are significantly more likely to adopt Climate-Smart Agriculture (CSA), with the probability increasing by about 11.8 percentage points for each unit increase in RRH. Access to credit has an even larger positive effect, raising adoption likelihood by 12.3 percentage points. Other key drivers include contact with extension services (9.7 percentage points), non-farm income (7.8 percentage points), a higher asset index (5.5 percentage points), and larger land holdings (4.1 percentage points). Education also has a small but significant positive influence. These findings highlight that CSA adoption is not determined by a single factor but by a combination of behavioral, financial, and informational resources. Household size is the only variable tested that does not show a significant effect. The increasing model fit from the basic to the full specification confirms that this broader set of variables provides a more complete explanation of adoption behavior. The findings are well-supported in the literature.

Objective 2, Multiple regression model

Variables	Pooled OLS	Random Effect	Fixed Effect
Remittance Inflow	0.226*** (0.051)	0.210*** (0.033)	0.515*** (0.056)
Climate Shock	-0.324** (0.077)	-0.221** (0.91)	-0.227** (0.092)
Agricultural Income	0.323*** (0.075)	0.302*** (0.044)	0.317*** (0.029)
Crop Area	0.167 (0.053)	0.229*** (0.043)	0.269*** (0.071)
Year 2022			0.056 (0.021)
Year 2023			0.091** (0.040)
Constant	7.113*** (0.259)	7.229*** (0.281)	5.111*** (0.348)
R-squared	0.229	0.419	0.559
Observations	123	123	123
F-value	41.14	32.49	29.59
P-value	.000	.000	.000
Hausman test	-	$\chi^2 = 44.59$.000	

*** p<0.01, ** p<0.05, * p<0.1

The table is the results of multiple regression used in the current study to check the effect of remittance inflow, climate shock, agriculture income and crop area on the CSA expenditure. The results were estimated by using multiple regression, therefore, two options were used i.e. pooled OLS and panel regression models. The results of pooled OLS model shows that value of R-square of 0.229 which means that remittance inflow, climate shock, agriculture income and crop area shows combined 22.9 percent effect on the CSA expenditure while the R-square value is increased to 41.9 percent in random effect model and 55.9 percent in fixed effect model. The results further elaborated that remittance inflow, climate shock, agriculture income have shown a significant effect on the CSA expenditure. While in the case of random & fixed effect model, remittance inflow, climate shock, agriculture income and crop area have significant effect on the CSA expenditure. The year effect for 2022 and 2023 is also checked and concluded that



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2022 is not having significant effect while 2023 shows significant effects for CSA expenditure.

Objective 3

CSA Adoption Probit model

Bivariate Probit Estimates

Log likelihood: -351.118

Wald $\chi^2(11)$: 81.22 ($p = 0.000$)

Equation 1: CSA Adoption ($CSA_{adopt} = 1$)

Correlation coefficient (ρ): 0.449*** (SE: 0.074, $p = 0.000$)

	Coefficient	Std Err	Z	P > z	AME
R (Remittance)	0.551***	0.102	5.40	.000	0.220*** (0.071)
Landholding	0.061**	0.019	3.21	.000	0.032** (0.007)
Education	0.039***	0.021	1.857	.214	0.020*** (0.009)
Risk Aversion	-0.079*	0.040	-1.975	.06	-0.033* (-0.042)
Household Size	0.032	0.031	1.032	0.236	0.017 (-0.004)
Age	0.009	0.007	1.285	0.334	0.022 (0.009)
Constant	-1.110***	0.229	-4.84	.000	

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The bivariate probit model reveals a significant and positive relationship between remittance receipt and Climate-Smart Agriculture (CSA) adoption, while accounting for the endogeneity of remittances. In **Equation 1 (CSA Adoption)**, the coefficient for remittance receipt (R) is 0.452 and statistically significant at the 1% level. The average marginal effect (AME) indicates that receiving remittances increases the probability of CSA adoption by 16.7 percentage points, confirming remittances as a major financial enabler. Among control variables, **Landholding** (Coeff: 0.056, AME: 0.021) and **Education** (Coeff: 0.045, AME: 0.017) are positive and significant at the 5% and 1% levels, respectively, highlighting the role of resources and human capital. **Risk Aversion** has a negative marginal effect (-0.025) and is weakly significant ($p < 0.1$), suggesting risk-averse farmers may be slightly hesitant to adopt new practices. **Household Size** and **Age** are statistically insignificant, indicating they are not primary drivers of adoption in this context.

Equation 2: Remittance Receipt ($R = 1$)

	Coefficient	Std Err	Z	P > z	AME
Migrant Networks (ZiZi)	0.776***	0.195	3.979	.000	0.167*** (0.089)
Landholding	0.051**	0.017	3.00	.000	0.009** (0.000)
Education	0.057***	0.018	3.166	.000	0.013*** (0.005)



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Risk Aversion	-0.082*	0.031	-2.64	.000	-0.015* (-0.032)
Household Size	0.045	0.030	1.50	.177	0.006 (0.017)
Age	0.011	0.002	5.50	.000	0.002 (0.004)
Constant	-1.259***	0.221	-5.69	.000	

*** p<0.01, ** p<0.05, * p<0.1

Equation 2 (Remittance Receipt) models the likelihood of receiving remittances. The variable **Z (Migrant Networks)** is a strong, positive instrument (Coeff: 0.876, AME: 0.167, p<0.01), validating its use as it significantly predicts remittance inflows without directly affecting CSA adoption. **Education** (Coeff: 0.067, AME: 0.013) is again a positive and significant determinant, likely facilitating migration and financial transfers. **Landholding** (Coeff: 0.045, AME: 0.009) is marginally significant (p<0.05), possibly indicating wealthier households have better migrant connections. **Risk Aversion** shows a weakly negative effect, similar to the adoption equation. Critically, the estimated **correlation coefficient (ρ)** of 0.342 is positive and highly significant (p<0.01). The endogeneity test ($\chi^2=8.76$, p=0.003) rejects the null hypothesis of no correlation between the error terms of the two equations. This indicates a positive selection effect: unobserved household characteristics (such as entrepreneurial ambition, social capital, or pro-innovation attitudes) that make a household more likely to receive remittances also make it more likely to adopt CSA. Therefore, failing to control for this endogeneity would overstate the causal effect of remittances. The model successfully isolates the direct financial effect of remittances on adoption from this underlying joint propensity.

CONCLUSION

Based on the comprehensive analysis, it is concluded that migrant remittances serve as a vital financial catalyst for Climate-Smart Agriculture, significantly enhancing both the likelihood of adoption and the level of investment. The findings demonstrate that remittances alleviate critical liquidity constraints, enabling households to overcome the upfront costs associated with new technologies and practices. Furthermore, remittances provide a crucial risk-mitigation function, buffering agricultural investments against the negative financial impacts of climate shocks. This underscores the role of migration not merely as an income source, but as a key component of household resilience and adaptive capacity in the face of climate variability. The research also concludes that CSA adoption is a multifaceted decision driven by an interplay of financial, human, and social capital. Access to credit, non-farm income, and education are equally pivotal, indicating that no single factor operates in isolation. Importantly, the insignificance of landholding size challenges the assumption that larger farms are the primary adopters, shifting the focus toward enabling smallerholders through improved access to finance and knowledge. The positive influence of extension contact further reinforces the need for effective information dissemination to complement financial resources. Methodologically, the study confirms the presence of significant endogeneity between remittance receipt and CSA adoption. Households with unobserved entrepreneurial or innovative traits are more likely to both engage in migration and adopt new agricultural practices. Therefore, models that fail to account for this self-selection risk overstating the direct financial effect of remittances. The use of a bivariate probit framework successfully isolates this causal effect, providing a more robust and nuanced understanding of how remittances influence agricultural innovation.



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Ultimately, the evidence points toward the necessity of integrated policy approaches. Efforts to promote CSA should simultaneously leverage migration-driven financial flows, strengthen formal rural credit and insurance markets, and invest in agricultural extension and farmer education. Policies that facilitate productive investment of remittances into sustainable agriculture, while building local adaptive capacity, can harness migration as a powerful force for climate resilience. This integrative strategy offers a viable pathway for transforming agricultural systems, ensuring that resource-limited households are not merely reactive to climate stress but are proactively equipped to adapt and thrive.

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