Investing in Resilience: What Drives Smallholder Adoption and Profitability of Climate-Smart Agriculture?

Amareswar Barik[1] and Nilkantha Mondal[1]*

[1]*M.Sc. Scholar, Department of Agricultural Economics, College of Agriculture, Odisha University of Agriculture and Technology (OUAT), Bhubaneswar-751003, Odisha, India*

Corresponding Author
Nilkantha Mondal
Email: agriconilu24@gmail.com

OPEN ACCESS

Keywords

Climate-Smart Agriculture, Smallholders, Technology Adoption, Cost-Benefit Analysis, Extension, Real Options

How to cite this article:

Barik, A. and Mondal, N. 2026. Investing in Resilience: What Drives Smallholder Adoption and Profitability of Climate-Smart Agriculture? *Vigyan Varta* 7 (11): 16-20.

ABSTRACT

Climate-smart agriculture (CSA) seeks to improve agricultural productivity and incomes, strengthen resilience to climate change and reduce greenhouse-gas emissions where possible. Yet, technically suitable practices are not automatically adopted by smallholders. Adoption depends on labour, land, liquidity, information, credit, extension and the farmers' ability to absorb risk. The household resources shape the capacity to adopt, whereas the expected profitability, discount rates, crop choices and uncertainty shape the incentive to adopt. Low-cost and flexible practices often fit resource-constrained households better, while capital-intensive technologies may require suitable finance and markets. CSA should therefore be viewed as an investment decision under uncertainty rather than simply a behavioural choice.

INTRODUCTION:

Climate variability has increased the importance of farm-level adoption, especially where production depends on rainfall and households have limited savings or insurance. CSA is not a single technology; it is an approach that combines productivity, resilience, and mitigation objectives according to local conditions (FAO,

2010; FAO, 2015). Practices may include improved varieties, soil and water conservation, crop rotation, intercropping, composting, agroforestry, precision nutrient management and efficient irrigation.

From an economic perspective, adoption has two linked dimensions. First is feasibility: can a household supply the labour, cash, land, knowledge and complementary inputs required? Second is profitability: after accounting for costs, risk, opportunity costs and the timing of returns, does the investment justify adoption? Reviews show that CSA adoption is strongly context dependent and influenced by socioeconomic, institutional, environmental and human capital factors (Mizik, 2021; Abebe *et al*., 2023; Bekele *et al*., 2025). Thus, a practice can be profitable on average but remain inaccessible to a cash-constrained household.

HOUSEHOLD DETERMINANTS OF ADOPTION

➢ Labour and household size

Family labour can be an important productive asset where CSA practices require work during short and demanding periods. Seman and Maru (2026) analysed CSA adoption among 141 households in Ethiopia; and reported an odds ratio of 1.94 for an additional household member, while Karwani *et al*. (2025) examined maize-common bean intercropping among 240 smallholders in semi-arid Tanzania; and identified household size as a strong positive factor. Composting, bund construction, rotation and intercropping may therefore easier for labour-rich households. However, household size is not automatically beneficial: larger families also have greater consumption requirements,so available farm labour rather than population alone is of certain relevance.

➢ Land, livestock and assets

Farm size can facilitate experimentation and spread fixed costs over a larger area. Both core household studies reported a positive relationship between farm size and adoption (Karwani *et al*.,2025; Seman & Maru, 2026). Livestock and other assets can provide productive inputs and financial buffers. Livestock ownership was strongly associated with adoption (Seman & Maru, 2026). Assets can reduce the downside of experimentation because they can be mobilized after a poor season. Nevertheless, land size alone does not guarantee successful adoption; tenure, soil quality, management ability and access to complementary inputs also matter (Mizik, 2021; Manda *et al*., 2022).

➢ Off-farm income and credit

Off-farm income can relax the seasonal liquidity constraint faced by farm households. Households with off-farm income had substantially higher adoption odds (Seman & Maru, 2026). The economic mechanism is straightforward: a profitable technology may still be infeasible if its initial cost must be paid before harvest revenue arrives. Expensive credit, collateral requirements and repayment risk can therefore suppress adoption even when long run returns are positive (World Bank, 2019; World Bank, 2025).

➢ Education, extension and information

Information reduces uncertainty about how a technology works and whether it is suitable. Greater extension contact was found among adopters (Seman & Maru, 2026) and a positive role of extension was reported among peoples (Karwani *et al*.,2025). Training, demonstrations and local climate information can lower information costs and perceived failure risk (Thomas *et al*., 2023).

➢ **Gender and resource access**

Gender differences in adoption should largely be interpreted through access to land, finance, labour, information and decision making. It is generally found that greater adoption for CSA is seen in some male-headed households but the true root cause for the differences in adoption lies with unequal resource access (Manda *et al*., 2022; Bekele *et al*., 2025). Policies should therefore address resource constraints rather than assuming that gender itself determines technological ability.

Does climate-smart agriculture pay?

Knowing who can adopt does not establish whether adoption is economically worthwhile. Evaluating the economic viability of CSA requires integration of conventional capital budgeting, social valuation and real-option frameworks. Empirical assessment across a 15-year horizon reveal that several practices produced positive NPVs, financial returns exhibit high sensitivity to crop-technology pairs and site-specific lending rates. An analysis showed that, vegetable-integrated crop rotation generated an NPV of approximately US$ 1,464/ha with a Benefit-Cost ratio (BCR) of 1.14, whereas bean rotations achieved an IRR of around 44% and a positive NPV for drip irrigation in capsicum (Poudel & Vergalli, 2026).

However, because many BCR estimates closely approach unity, these financial margins remain vulnerable to minor exogenous shocks in crop yields, market prices or input expenditures. Furthermore, technologies such as drip irrigation demonstrate that capital performance is intrinsically tied to commodity specific revenue capacities (Akinyi *et al*.,2022; Poudel *et al*., 2024).

- **Discount rates and payback**

Discounting is particularly important for investments whose benefits arrive slowly. The higher the discount rate, the lower the present value of future benefits. Rotational NPVs declined as discount rates increased. This has a direct policy implication: reducing the cost of finance can improve the attractiveness of a technology without changing its physical productivity (Poudel & Vergalli, 2026). Seasonal credit, longer repayment period, guarantee and targeted investment support can be relevant where liquidity is the binding constraint (World Bank, 2019; World Bank, 2025).

- **Private and Social returns**

Farmers do not receive every benefit generated by CSA. Reduced erosion, soil health improvement, biodiversity, lower emissions and cleaner air can create social benefits that are not fully reflected in farm-gate prices. A practice may be socially desirable even when private profitability is insufficient to induce adoption. Public intervention is strongest when it corrects a genuine externality or a clearly identified market or credit failure (FAO, 2010; World Bank, 2019).

- **Flexibility and real options**

Conventional NPV does not fully capture the value of waiting, scaling or changing direction under uncertainty. Real option theory recognizes that an irreversible investment can be less attractive than a similarly profitable investment that preserves flexibility (Dixit & Pindyck, 1994). Capital-intensive investments may lose flexibility because money is sunk, once equipment or structures are installed. Thus, farmers may rationally prefer a slightly lower return practice if it carries less downside risk and can be reversed.

An integrated economic interpretation

A household first asks whether it can undertake the investment with its available labour, liquidity, assets and information. It then considers whether expected discounted

benefits exceeds costs and compensate for risk. This explains why the same CSA practice can be attractive to one farmer but burdensome to another. Low-capital practices may be favoured because they require less cash and preserve flexibility, whereas capital-intensive technologies depend more heavily on credit, scale, crop value and reliable markets (Mizik, 2021; Akinyi *et al*., 2022; Poudel & Vergalli, 2026). Farmers with more resources may adopt more readily and seek extension or credit, producing selection effects.

Policy implications

First, policy should target the binding constraints rather than promoting technologies uniformly. Second, extension should be practical, locally relevant, combining demonstrations with climate and market information. Third, low cost and flexible practices can be prioritized for resource constrained households, while capital-intensive technologies should be linked to crop value, scale and financing conditions. Fourth, programme appraisal should include social costs and benefits and conduct sensitivity analysis for discount rates, prices and yields (FAO,2010; World Bank, 2019).

CONCLUSION

CSA adoption is better understood as an economic investment decision under resource constraints and uncertainty than as a simple question of farmer willingness. Land, labour, credit, education, extension etc. affect the ability to adopt, while profitability depends on crop choice, prices, payback period, discount rates and risk. Positive private returns may be too small or too delayed for households facing high financing costs, whereas social returns can be larger because environmental benefits are not fully captured privately. Thus, the most suitable policy is constraint-specific approach combining finance, extension, market support and targeted incentives. Future research should track the same households over time using panel data to assess adoption, costs, returns and financing. This would clarify whether CSA practices are both climate smart and economically viable for farmers.

REFERENCES

Abebe, G.K., *et al*. (2023). Impact of adoption of climate smart agricultural practices to minimize production risk in Ethiopia: A systematic review. Journal of Agriculture and Food Research, 13, 100655.

Akinyi, D.P., Ng'ang'a, S.K., Ngigi, M., Mathenge, M., & Girvetz, E. (2022). Cost-benefit analysis of prioritized climate smart agricultural practices among smallholder farmers. Heliyon, 8(4), e09228.

Bekele, T.A., *et al*. (2025). Climate-smart agricultural practices and it's application in Ethiopia: A systematic review. International Journal of Climate Change Strategies and Management, 17(1), 3-22.

Dixit, A. K., & Pindyck, R. S. (1994). Investment under uncertainty. Princeton University Press.

FAO. (2010). Climate-smart agriculture: Policies, practices and financing for food security, adaptation and mitigation. Food and Agriculture Organization of the United Nations.

FAO. (2013). Climate-smart agriculture sourcebook. Food and Agriculture Organization of the United Nations.

Karwani, G. M., Phillipo, M., Meya, A.I., & Teshale, M. A. (2025). Socioeconomic factors influencing adoption of climate-smart agriculture technologies by smallholder farmers in semi-arid areas,

Tanzania. International Journal of Agronomy and Agricultural Research, 26 (5), 14-25.

Manda, J., Alene, A.D., Garderbroek, C., Kassie, M., & Tembo, G. (2022). Adoption of climate-smart agricultural practices among smallholder farmers in Western Kenya. Heliyon, 8(1), e08677.

Mizik, T. (2021). Climate-smart agriculture on small-scale farms: A systematic literature review. Agronomy, 11, 1096.

Poudel, S., Thapa, R., & Mishra, B. (2024). A farmer centric cost-benefit analysis of climate-smart agriculture in the Gandaki River Basin of Nepal. Climate, 12(9), 145.

World Bank. (2019). Economics of climate-smart agriculture: Considerations for economic and financial analyses of climate-smart agriculture projects. World Bank.

World Bank. (2025). Agricultural technology adoption and financial constraints among smallholder farmers. World Bank.