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Determinants of agricultural innovation adoption in eastern Madagascar

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Abstract

This study examines the adoption of agricultural innovations on the east coast of Madagascar in a context marked by high exposure to climate shocks and agroecological constraints. The study addresses the gap between a widely recognized need for adaptation and still limited levels of adoption. Its overall objective is to identify the determinants of adoption levels and the factors that structure influence and dominance within the adoption system. Two questions guide the analysis: which socioeconomic factors determine levels of adoption of agricultural innovations, and which factors structure the relative influence and dominance of agricultural innovation adoption? The study adopts a methodological individualism approach by focusing the analysis on innovation adoption at the farm household level. The survey covers 395 households. An innovation index ranks adoption into four levels based on nine practices. Ordinal regression was used to identify predictors, followed by discriminant analysis and benchmarking to synthesize observed contrasts. A significant correlation matrix was then used to position variables within a strategic rectangle. The results show a concentration in the lower adoption levels: 68% of households fall into the "non-adopter" and "low" categories. Higher adoption levels are associated with access to water, agricultural and livestock income, savings, and durable housing. The strategic rectangle identifies two variables that are both influential and dominant: non-use of chemical pesticides and financing through agricultural income. These findings point to the need for longitudinal monitoring, for distinguishing input-based intensification from agroecological innovations, and for testing differentiated support according to household profiles.

Keywords: Agricultural Financing; Productive Diversification; Farm Income; Adoption; Rural Strategies

1. Introduction

On the east coast of Madagascar, farming households must balance food crops and cash crops in an environment exposed to cyclones, flooding, and intra-seasonal variability. The regions of Analanjirofo and Atsinanana combine cash-crop systems and rice-growing areas, with unequal access to water. Previous studies describe a lean season during which diets fluctuate sharply and wild plants contribute to food consumption [1, 2]. Agroforestry may provide benefits, but outcomes vary across households [3].

At the global level, agricultural transformation can be understood through innovation systems and adoption trajectories. Studies on innovation systems highlight coordination difficulties among research, extension, and markets, as well as financial instruments that remain poorly suited to smallholders [4, 5]. Reviews of climate-smart agriculture report potential gains, but they also emphasize transition costs, risk, and land tenure, with effects that differ across farms [6, 7]. Multivariate typologies have also linked household profiles to bundles of innovations [8, 9].

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In the Indian Ocean region, food dependence and narrow markets combine with high exposure to shocks [10]. In Madagascar, project assessments have documented difficulties in appropriation and continuity [11]. Land insecurity limits investment and constrains the scaling up of restoration and agroecological interventions [12, 13]. These constraints were compounded by value-chain disruptions during the COVID-19 period [14, 15].

In the Malagasy context, the gap between potential and observed practices is particularly clear. In the north-east, a strong perception of climate change coexists with a limited proportion of farmers reporting changes in their practices, with differences by gender [16]. Targeted innovations have shown labor savings and high acceptability under trial conditions, but price and access to credit continue to hinder their diffusion [17]. In other areas, food insecurity remains high and seasonal [2].

These realities coexist with positive indicators and strong expectations. Labor-saving sowing devices under rainfed conditions have shown time gains of up to 82%, lower total costs per hectare, and a high producer preference rate [17]. Analyses of innovation systems in smallholder farming also show potential for social impact when projects align organizational support with local demand [5]. Recent international literature further highlights the rise of bundled innovations and multi-constraint support approaches, with significant adoption effects when technical and institutional alignment is achieved [18].

However, this potential continues to face persistent constraints. Introduced innovations often remain accessible to only a minority of farmers because of high initial costs, mismatches between market prices and farmers' purchasing capacity, or insufficient extension services [19]. Scaling effects therefore remain limited, creating inequalities in access and a gap between expectations of rapid diffusion and the reality of fragmented implementation. The central issue is thus the discrepancy between a widely documented innovation potential and adoption practices that remain largely concentrated at lower levels on the east coast of Madagascar. This issue is addressed through two research questions: What socioeconomic factors determine levels of adoption of agricultural innovations? Which factors structure the relative influence and dominance of agricultural innovation adoption?

Two hypotheses are proposed. First, the availability of economic and productive resources increases the probability of progressing toward higher levels of adoption of agricultural innovations. Second, technical and organizational levers structure the configuration of agricultural innovation adoption.

2. Material and methods

2.1. Study area and sample

The study was conducted on the east coast of Madagascar, in two contiguous regions, Analanjirofo and Atsinanana (16°30′00″ S to 19°30′00″ S; 48°50′00″ E to 49°40′00″ E). The climate is tropical humid under the influence of southeast trade winds, with recurrent exposure to cyclones and flooding. The study area covers a coastal continuum extending from the district of Soanierana Ivongo in the north to Brickaville in the south, over approximately 44,000 km². It is bordered by the Indian Ocean to the east and the central highlands to the west, creating sharply contrasting agroecological constraints over short distances.

The data were drawn from a household survey conducted using a standardized questionnaire administered face-to-face to producers. Sample size was determined using Cochran's formula:

$$n = (z^2\hat{P}(1-\hat{P}))/e^2$$

With a 95% confidence level (z = 1.96), an a priori proportion of P = 0.5, and a margin of error of e = 5%, the theoretical sample size was 384 households. Oversampling was used to account for non-response and unusable questionnaires. A total of 395 questionnaires were retained for analysis. Households were selected using a quota sampling procedure. Data were collected between March 2024 and April 2024. The questionnaire was administered in Malagasy. Responses were recorded in Malagasy and translated into French for analysis.

2.2. Construction of the innovation adoption index

The adoption of agricultural innovations was assessed through a set of practices identified at farm level. Each practice corresponds to an agronomic or organizational innovation intended to increase productivity, improve the sustainability of cropping systems, and strengthen resilience to climatic shocks.

First, each respondent was characterized by a response vector corresponding to the nine selected practices. Second, a global innovation score was constructed by summing the adopted practices, producing values from 0 to 9. This score was then transformed into an ordered categorical variable to identify adoption levels: non-adopter for 0 innovation, low for a score of 1 to 2, medium for a score of 3 to 5, and high for a score above 5.

The study retained nine indicators of innovation adoption, each coded as a binary variable (0 = no, 1 = yes). The indicators were: use of mechanized equipment or improved irrigation (INNOV1); crop rotation (INNOV2); soil conservation practices, including under-cover planting and slope management (INNOV3); integrated pest management (INNOV4); use of biological alternatives such as organic fertilizers or biological control (INNOV5); biodiversity conservation through hedgerows, buffer zones, or natural reserves (INNOV6); maintenance of habitats favorable to natural pollinators (INNOV7); implementation of good water management practices (INNOV8); and use of varieties resistant to climatic conditions (INNOV9).

2.3. Determinants of agricultural innovation adoption

Discriminant analysis was performed to characterize the four adoption categories according to their determinants. An ordinal logistic regression was first carried out to select the variables. Only predictors found to be significant at 5% in the ordinal logistic regression were retained in order to reduce redundant noise and maximize analytical coherence (Table 1). The expected outputs of the discriminant analysis included Wilks' lambda, the overall p-value, and the group classification functions. Based on these classification functions, variable-by-group scores were extracted and then standardized into a stochastic matrix, making it possible to define the maximum reference value for each variable. The variables were then presented as radar charts for benchmarking.

Table 1 Variables retained for discriminant analysis and coding

Variable	Code
Adequate water source	adequate_water_source
Main source of financing: agricultural income	agricultural_income
Main source of financing: livestock income	livestock_income
Use of chemical pesticides	chemical_pesticides
Change in practices in response to climate	climate_practice_change
Permanent house	permanent_house
Ownership of savings	savings
Geographical setting: high altitude (>1500 m)	high_altitude
Agricultural land area	agricultural_land_area

2.4. Strategic rectangle: Analysis of influential and dominant variables in agricultural innovation adoption

Influential and dominant variables in agricultural innovation adoption were analyzed using the matrix of significant correlations between variables as the analytical basis. The significance of a correlation was determined using the critical threshold $|\rho|$:

$$|\rho| = \frac{t_{\propto}}{\sqrt{n - 2 + t_{\propto}^2}}$$

where n represents the number of observations and $t\alpha$ the quantile of the Student distribution with $n - 2$ degrees of freedom and α = 0.05. Values below the critical threshold were neutralized, and only the upper part of the matrix was retained in order to avoid redundancy due to symmetry. Two indicators were calculated for each variable: the ratio between emitted and received correlations (X) and the product of these correlations (Y). For each variable, X represents the influence ratio and Y the combined strength. These two indicators were used to position variables within the strategic rectangle by distinguishing:

- influential factors, with X values above the mean;
- dominant factors, with Y values above the mean; and

- variables combining both statuses.

All processing was carried out in Excel for data organization and indicator calculation, and in XLSTAT for construction of the correlation matrix. Only variables that were significant among the determining factors were included in the correlation matrix. This selection ensures that the strategic rectangle analysis focuses on factors that are genuinely associated with the adoption of agricultural innovations.

3. Results

3.1. Innovation adoption categories

Households were classified into four ordered categories based on the innovation index: 0 = non-adopter, 1 = low, 2 = medium, and 3 = high. The total sample comprised 395 households. This categorization summarizes the cumulative adoption of innovation practices at farm level and provides a synthetic view of the adoption levels observed in the sample (Table 2).

Table 2 Distribution of innovation adoption categories

Innovation category	Adoption category code	Observations	Share (%)
Non-adopter	0	141	36
Low	1	127	32
Medium	2	94	24
High	3	33	8
Total	-	395	100

The non-adopter profile includes 141 households, representing 36% of the sample. This category accounts for the largest share and reflects the absence of adoption within the index used. The low-adoption profile includes 127 households (32%). Together, these two categories account for 268 households, or 68% of the total sample, placing the majority of observations in levels 0 and 1 of the index.

The medium-adoption profile includes 94 households (24%) and occupies an intermediate position in the distribution. Finally, the high-adoption profile comprises 33 households (8%), making it the least frequent category.

Overall, the distribution shows a decreasing pattern in the number of households from level 0 to level 3. The intermediate levels, 1 and 2, include 221 households (56%), whereas the extreme categories, 0 and 3, account for 174 households (44%). The combined “medium + high” category includes 127 households (32%), which is the same number as that observed for the “low” category alone.

3.2. Determinants of agricultural innovation adoption

The global test indicates a clear separation between classes: Wilks’ lambda = 0.3967; observed F = 13.8459; critical F = 1.4693; df1 = 30; df2 = 1122; p-value < 0.0001; α = 0.05.

For the non-adopter profile (Figure 1), benchmarking highlights strong shares on the axes coded “0,” such as adequate_water_source-0, livestock_income-0, high_altitude-0, chemical_pesticides-0, and climate_practice_change-0, as well as agricultural_land_area-2, with no contribution from permanent_house-1 or agricultural_income-1.

For the low profile (Figure 2), benchmarking shows intermediate weights across the axes, close to the non-adopter profile for variables coded “0,” with moderate contributions from agricultural_land_area-2 and near-zero contribution from permanent_house-1.

For the medium profile (Figure 3), benchmarking shows visible shares for permanent_house-1, agricultural_income-1, and agricultural_land_area-2, lower shares on the “0” axes, and zero shares for high_altitude-0 and savings-0.

For the high profile (Figure 4), benchmarking concentrates the shares on permanent_house-1 and agricultural_income-1, with zero contributions on most axes coded “0” and no contribution from agricultural_land_area-2; a residual presence appears for high_altitude-0 and savings-0.

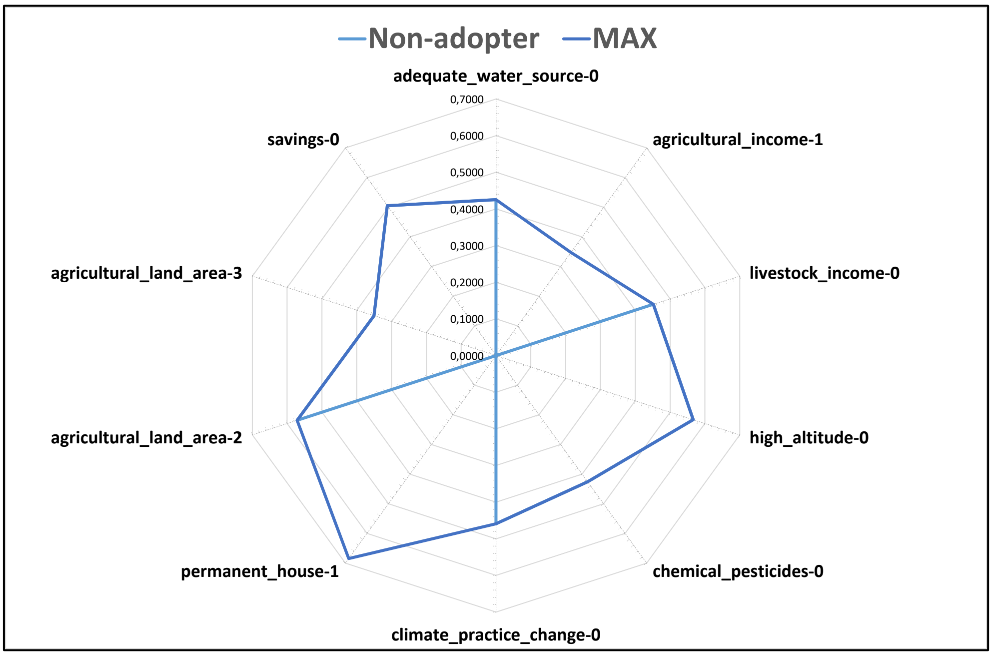

Figure 1 Benchmarking of discriminant factors in agricultural innovation adoption for non-adopter profile

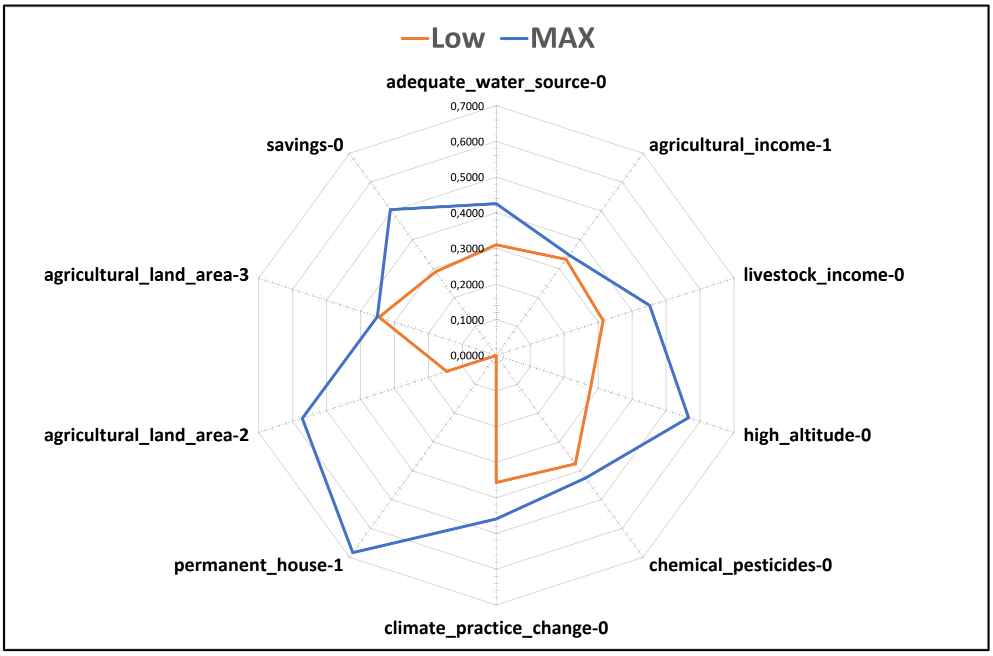

Figure 2 Benchmarking of discriminant factors in agricultural innovation adoption for low profile

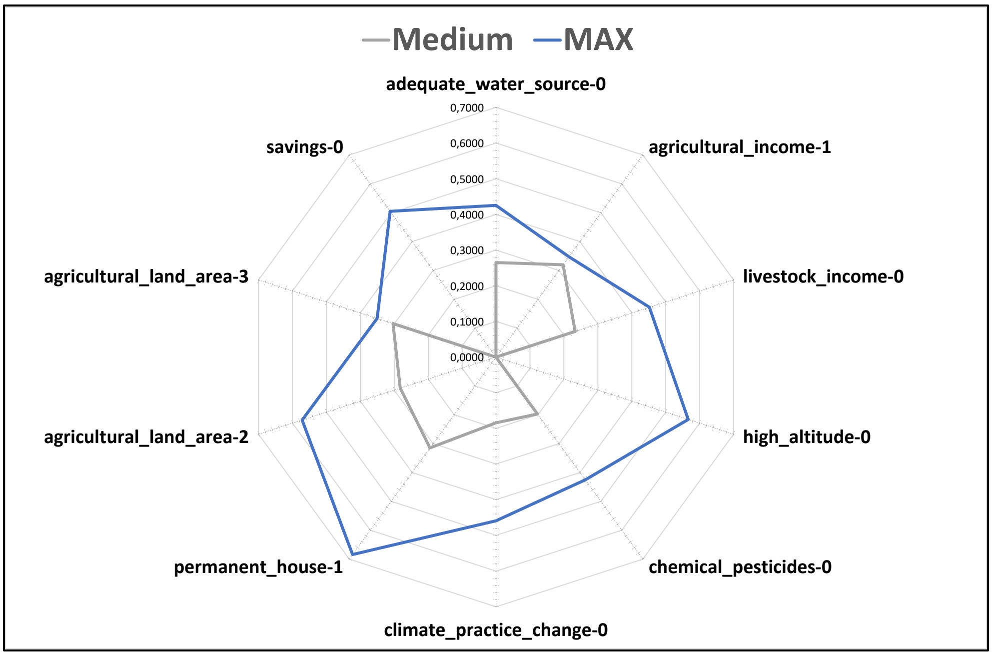

Figure 3 Benchmarking of discriminant factors in agricultural innovation adoption for medium profile

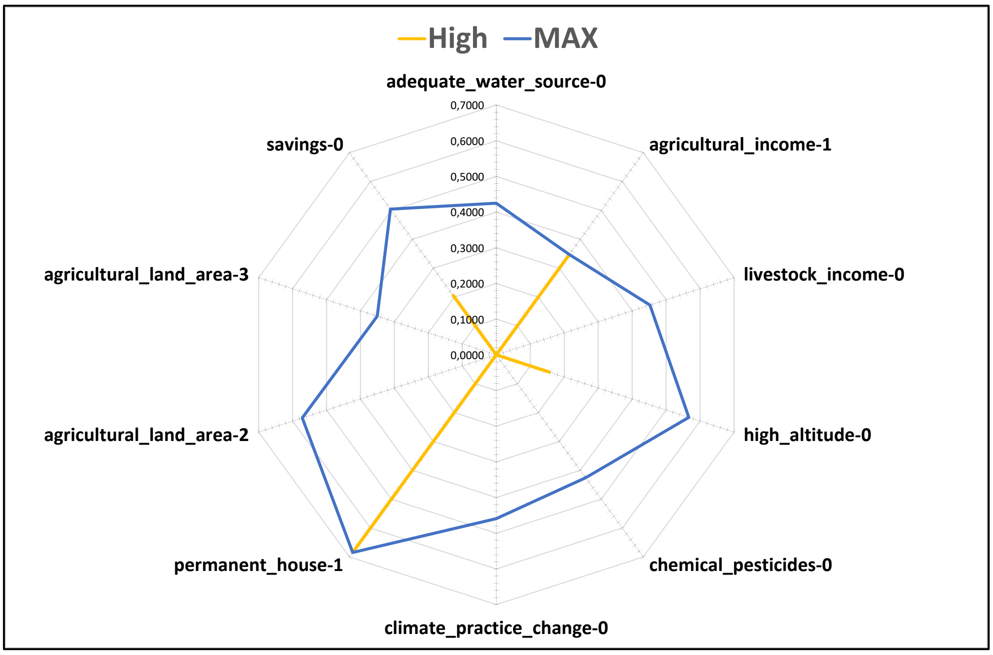

Figure 4 Benchmarking of discriminant factors in agricultural innovation adoption for high profile

Legend: chemical_pesticides-0 = non-use of chemical pesticides; agricultural_income-1 = main source of financing: agricultural income; livestock_income-0 = livestock income is not the main source of financing; agricultural_land_area-2 = agricultural land area between 0.5 and 2 ha; agricultural_land_area-3 = agricultural land area greater than 2 ha; adequate_water_source-0 = absence of an adequate water source for irrigation; high_altitude-0 = geographical setting: medium or low altitude; climate_practice_change-0 = no change in practices in response to climate; permanent_house-1 = lives in a permanent house; savings-0 = no savings

3.3. Influential and dominant factors in innovation adoption

Analysis of the influence and dominance matrix made it possible to position the selected variables according to their relative values of X (influence ratio) and Y (combined strength). The mean values of the indicators (X = 1.05; Y = 1.40) were used as thresholds to distinguish the different variable profiles (Table 3).

Table 3 Strategic rectangle: Influence and dominance of variables in innovation adoption

Variables	X (influence ratio)	Y (combined strength)	Status
chemical_pesticides-0	1.18	1.51	Influential and dominant
agricultural_income-1	1.07	1.48	Influential and dominant
livestock_income-0	1.39	1.39	Influential
agricultural_land_area-2	1.37	1.37	Influential
adequate_water_source-0	1.32	1.32	Influential
high_altitude-0	1.16	1.16	Influential

Legend: chemical_pesticides-0 = non-use of chemical pesticides; agricultural_income-1 = main source of financing: agricultural income; livestock_income-0 = livestock income is not the main source of financing; agricultural_land_area-2 = agricultural land area between 0.5 and 2 ha; adequate_water_source-0 = absence of an adequate water source for irrigation; high_altitude-0 = geographical setting: medium or low altitude.

Two variables have values above the mean for both X and Y indicating a position that is both influential and dominant: non-use of chemical pesticides and financing through agricultural income. Some variables exceed the mean for X but remain below the mean for Y. This is the case for livestock income not being the main source of financing, agricultural land area between 0.5 and 2 ha, absence of an adequate water source for irrigation, and medium or low altitude.

4. Discussion

4.1. Low level of agricultural innovation adoption

The distribution of households across four innovation levels first reveals a simple result, but one with major analytical implications: adoption is concentrated at the lower levels, and access to the high level remains rare (Table 2). This pattern does not suggest homogeneous diffusion of a technical “package.” It instead points to a discontinuous progression, marked by trials, partial adjustments, and then consolidation among only a small fraction of farms. The contrast between non-adopters and high adopters, with a clear numerical imbalance to the disadvantage of level 3, suggests that the accumulation of practices takes place within a social and productive space that is already differentiated, even before any causal interpretation is proposed.

The “non-adopter” profile is structured around modalities coded as “no” for several dimensions: lack of adequate access to water, livestock income not being the main source of financing, non-use of chemical pesticides, and no reported change in practices in response to climatic shocks, together with a marked presence of intermediate agricultural land area. This pattern does not indicate only a technical deficit; it also reflects a specific relationship to risk and production security, in which visible markers of investment remain limited.

The “low” profile remains close to these same axes, although without such a marked concentration. It appears as an intermediate zone, combining incomplete sets of resources and practices. The “medium” profile differs in nature: the radar chart shows visible contributions from permanent housing and agricultural income. The “high” profile is distinguished by a strong contribution from permanent housing and agricultural income, while the axes coded as “no” largely fade, even though residual effects remain on certain dimensions. The higher levels therefore correspond to a combination of signals: observable material capacity, a more structured agricultural economic base, and involvement in practices of protection, management, or reported adjustment.

4.2. Gradual adoption and profiles of conditions

A first reading fits within the literature on partial and gradual adoption in sub-Saharan Africa. Reviews frequently describe stepwise diffusion, with initial adoption of simpler components followed by progressive combinations according to assets, information, and access to services [7, 19, 20]. The observed distribution, with nearly two thirds of households at levels 0-1, is consistent with this pattern. The interest here, however, lies in the alignment between this hierarchy and the discriminant profiles: the categories differ not only by “more” or “less” innovation, but by distinct combinations of conditions.

4.2.1. Lower profiles: water access and risk security

For non-adopters and low adopters, benchmarking (Figure 1; Figure 2) suggests a combination of access constraints and risk security issues rather than a simple lack of knowledge. The presence of “no” modalities for water points to a classic mechanism: without an adequate water resource, several practices become less profitable or riskier, and expected gains remain uncertain. Studies on the adoption of portfolios of sustainable practices in eastern and southern Africa often show that water and resource management condition entry into more complex combinations [21, 22], and reviews of smart water management technologies emphasize this structuring role in family farming systems [23]. In this context, the non-adopter profile may correspond to a risk-minimization strategy, in which priority is given to continuity of harvests rather than technical experimentation, especially in settings where shocks and intra-seasonal variability make yields unstable [24].

4.2.2. Medium profile: visible capital and absorptive capacity

The "medium" profile appears as a more capitalized transition. Permanent housing and agricultural income become visible, pointing to asset-related proxies often associated with investment capacity, creditworthiness, and the ability to absorb potential losses (Figure 3). Findings on risk-sharing networks and liquidity constraints in the Philippines help clarify this point: when access to formal credit remains limited, the ability to mobilize resources depends on savings, assets, and social arrangements [25], while subsidies or targeted support mechanisms may alter investment trade-offs, sometimes in a non-linear way, as shown in a study conducted in Malawi [26]. In the sample, savings emerges in the regression as a marker associated with movement to a higher category, but it contributes little in the discriminant analysis. This may indicate internal heterogeneity: some households move upward without showing savings as measured here, because of investment choices, expenditure cycles, or limits of the indicator itself.

4.2.3. High profile: inputs and ambiguity of the trajectory

The "high" profile raises a clearer point of debate. The results show a very strong association between innovation level and non-use of chemical pesticides. In syntheses on adoption, access to inputs and the ability to finance entry costs often accompany transitions toward higher adoption levels, especially when innovations are combined in "packages" [6, 7, 20]. Interpretation depends on what the innovation index aggregates. Because the index combines agroecological practices with more technical or intensification-oriented components, it may capture a modernizing trajectory rather than a strictly agroecological transition. Studies conducted in Switzerland on pesticide reduction and pathways toward low-pesticide systems show that moving away from inputs does not follow a monotonic path: it requires changes in organization, knowledge, and risk management that are often built only after a phase of intensification [27]. From this perspective, pesticide use may function as a marker of a farm already integrated into input markets rather than as a normative objective.

4.3. Influential and dominant factors in innovation adoption

The strategic rectangle provides a cross-cutting reading of the discriminant analysis. The variables related to non-use of chemical pesticides and agricultural sources of income are located in the "influential and dominant" quadrant. The combined influential and dominant status of non-use of chemical pesticides is consistent with the dynamics of input-based innovations described in the literature on integrated protection: reducing chemical pesticide use often lies at the core of technical packages adopted jointly, with an entry role in agroecological trajectories [28]. The high status of the variable "agricultural sources of income" reinforces the idea that an income base derived from agricultural activity supports both adoption and adoption intensity, a dimension widely documented in syntheses on the adoption of sustainable practices in Africa [19, 29].

The group of variables classified as influential only, such as livestock-based income, agricultural land area, irrigation, and geographical setting, points to factors that diffuse strongly through the correlation network without reaching high combined strength. The irrigation variable is consistent with the fact that access to water explains productivity gaps, with irrigation in eastern zones providing higher yields than rainfed systems [30]. Environmental and accessibility contrasts also appear repeatedly in recent longitudinal monitoring, in which the Rural Observatories Network documents variability in hydrological and climatic constraints across territories [31]. For agricultural land area, the literature shows that farm size influences investment capacity and the selection of practices, with non-linear effects depending on context, resource endowment, and access to information [19, 29].

5. Conclusion

This study shows that adoption is concentrated mainly at the lower levels: 68% of households fall into the "non-adopter" and "low" categories, whereas the "high" category remains marginal. The results of the discriminant analysis support this finding through a clear statistical separation among the four profiles. The observed contrasts associate the medium and high levels with more favorable endowments and investment capacities, linked to access to water, the structuring of agricultural income, permanent housing, and other economic markers. These results support Hypothesis 1, as the upper adoption profiles are associated with stronger resource endowments and productive assets.

The analysis of influence and dominance complements this explanation by identifying variables that are both influential and dominant, particularly non-use of chemical pesticides and financing through agricultural income. This empirical evidence supports Hypothesis 2, as technical and organizational factors structure the configuration of innovation adoption. Nevertheless, the inferences remain limited to associations, since the adoption index is based on self-reported data and the study design is cross-sectional. Future research could track adoption trajectories over time, distinguish more clearly between input-based intensification and agroecological innovations, and test differentiated support according to household profiles.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

Statement of ethical approval

The study was conducted in accordance with standard ethical principles governing social research involving human participants.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study prior to questionnaire administration.

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