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Determinants of smallholder farmers' responsiveness to agroecological practices and principles in Ethiopia, Kenya and Madagascar

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Abstract

Smallholder farmers across East Africa face significant challenges in fully adopting agroecological practices, despite their demonstrated benefits for soil health, biodiversity, water conservation, and farm resilience. This study examined the determinants of smallholder farmers' responsiveness to agroecological principles and practices in Ethiopia, Kenya, and Madagascar using a sample of 993 farmers. A multi-stakeholder cross-sectional survey was conducted using a detailed, structured, and expert-validated questionnaire administered to smallholder farmers, considering multidimensional variation at both the farm and system levels. Multiple regression analysis and Principal Component Analysis (PCA) were employed to explore the underlying dimensions of adoption and predictors of responsiveness. The results revealed substantial variation across countries. In Kenya, farmers implemented 12 or more principles, whereas in Madagascar and Ethiopia, adoption was moderate, with lower uptake of agroecological principles. Farmer Field Schools (FFS) influenced adoption primarily through social learning, whereby farmers collaboratively experiment, observe outcomes, and share experiences, rather than through top-down technology transfer. Regression analysis showed that knowledge co-creation, education level, agroecology-specific land use, and incentives for participation in and sharing of agroecological practices were significant predictors of responsiveness, while structural constraints played a moderating role. These findings highlight the need to prioritize extension models that are inclusive, participatory, and adaptive, linking farmer education, locally appropriate land-use strategies, and targeted incentives to overcome structural barriers and ensure agroecology delivers both ecological resilience and improved livelihoods. PCA extracted seven components—ecological practices, extension methods, social learning, institutional enhancements, experiential knowledge, adoption behaviors, and gender/culture—which explained 63.38% of the total variance. The study concludes that farmers' responsiveness to agroecological principles is shaped by a dynamic interplay of structural, behavioral, and institutional factors. Strengthening participatory extension systems, co-creation platforms, and incentive frameworks can enhance uptake. These findings provide evidence-based insights for designing context-specific interventions to accelerate agroecological transitions towards sustainable agriculture.

Introduction

In Eastern Africa, agriculture remains the primary source of livelihood for over 80% of the population (Kotir et al., 2017; Thornton et al., 2017). Increasingly erratic rainfall, rising temperatures, and frequent extreme weather events are undermining agricultural productivity and pushing vulnerable communities deeper into poverty (Intergovernmental Panel on Climate Change [IPCC], 2023; Food and Agriculture Organization of the United Nations [FAO], 2021).

Agroecology has emerged as a transformative response to these intersecting crises. It provides a holistic framework that integrates ecological science, traditional knowledge, and social equity into the design and management of sustainable food systems (High Level Panel of Experts on Food Security and Nutrition [HLPE], 2019; Anderson et al., 2021). As both a science and a practice, agroecology promotes principles such as nutrient recycling, biodiversity conservation, soil health, and reduced reliance on synthetic inputs (Wezel et al., 2020). These principles are operationalized through a wide range of practices, including intercropping, agroforestry, reduced tillage, the use of organic fertilizers, rainwater harvesting, and biological pest control (Gliessman, 2020). While agroecological practices are context-specific applications of agroecological principles adapted to local ecological and socio-economic conditions (Kerr et al., 2021; Wezel et al., 2014), agroecological principles refer to the broader ecological and socio-economic guidelines, such as diversity, synergies, recycling, resilience, and the co-creation of knowledge, that underpin the design and management of sustainable food systems (HLPE, 2019; Wezel et al., 2020).

Sustainable land management and ecosystem-based approaches form the foundation of agroecology (Wezel et al., 2020). Ecosystem-based approaches offer several advantages by addressing the critical interconnections among biodiversity, climate change, and sustainable resource management. Their implementation can reduce greenhouse gas emissions, enhance carbon sinks, and improve biodiversity conservation, livelihood opportunities, health outcomes, and recreational benefits (Neumann et al., 2025). Similarly, large-scale programmes designed to support smallholder farmers must take local priorities into account and incorporate lessons from successful autonomous adaptation strategies, as climate impacts are often highly location-specific (Wright et al., 2024). Through improved farming practices, sustainable land management (SLM) strategies can reduce carbon emissions associated with soil erosion and land disturbance while enhancing long-term carbon sequestration in soils. SLM therefore has significant potential to mitigate greenhouse gas emissions on agricultural land (Liniger et al., 2011). The benefits of agroecology are multidimensional. It not only improves environmental outcomes, such as carbon sequestration, soil regeneration, and biodiversity enhancement, but also contributes to greater resilience, income diversification, and food sovereignty among smallholder farmers (Altieri et al., 2015; Kerr et al., 2021). Despite these proven advantages, the uptake of key agroecological practices remains uneven. Farmers' responsiveness is shaped by a range of factors, including agroecological conditions, access to resources, institutional support, and behavioural drivers (Manyanga et al., 2023; Mockshell et al., 2023). This underscores the need for extension approaches that are responsive to emerging issues such as climate change, agroecology, and gender.

According to FAO (2022), agricultural extension encompasses the wide range of activities that provide farmers and other actors in agrifood systems and rural development with the information and advisory services they need. Agricultural extension services play a critical role in facilitating the adoption of agroecological practices. In contrast to conventional top-down models, participatory approaches such as Farmer Field Schools (FFS), innovation platforms, and farmer-to-farmer extension have shown considerable promise in promoting knowledge co-creation and enabling farmers to experiment with context-specific innovations (Bakker et al., 2021; FAO, 2022). These approaches foster social learning, build trust, and bridge the gap between scientific research and local realities (Andres et al., 2022). Furthermore, Farmer Field Schools (FFS) empower smallholder farmers through experiential and participatory learning processes, thereby enhancing knowledge co-creation, practical skills, and adaptive capacity (FAO, 2016; Davis et al., 2012).

The nexus between agroecology and agricultural extension is particularly evident in the Farmer Field School approach, in which innovation and practice are grounded in transforming farmers' attitudes, knowledge, and skills through experiential and participatory learning. Within the socio-cultural contexts in which farmers operate, the interaction between agroecological principles and extension methodologies provides a strong basis for shaping policy directions and guiding development interventions that promote the adoption of sustainable practices. As Le Coq et al. (2019) emphasize, scaling agroecology requires context-specific pathways, strong local organizations, collective learning, linkages with social movements, and the mobilisation of financial and human resources, alongside farmer-led experimentation, participatory extension, and policy-oriented research embedded within broader analytical and engagement strategies. Similarly, Kohl and Cooley's (2005) framework for scaling, which focuses on the "what, how, who, and where," reinforces the importance of coordinating local and external actors through iterative cycles of learning, monitoring, and institutionalisation. Viewed through the FFS lens, these frameworks converge in positioning farmers as co-creators of knowledge and central actors in scaling agroecological transitions. According to Charry et al. (2023), agroecological transitions can be advanced by generating evidence on the effectiveness of co-designed innovations, identifying market opportunities and funding sources for local enterprises that support agroecological innovation, developing action plans and behaviour change strategies based on agroecological principles, and formulating policies that support agroecological transitions.

However, the complexity of transitioning to agroecology requires multidimensional changes at both the farm and system levels. These shifts involve farming objectives, resource management strategies, knowledge systems, and social networks (Borrello et al., 2016; Duru et al., 2015). Factors such as farm size, education level, market access, gender, and experience with agroecology have been identified as key determinants influencing adoption behaviour (Milheiras et al., 2022; Rizzo et al., 2024). There is also growing recognition that supportive policies, financial mechanisms, and institutional incentives, such as subsidies, technical assistance, and access to credit, are essential for enabling agroecological transitions (Iyabano et al., 2023; Mockshell et al., 2023). In addition, behavioural attributes such as perceived benefits, risk attitudes, and environmental values shape farmers' adaptation and adoption decisions (Slijper et al., 2023).

Agroecology is increasingly recognized as a viable pathway for enhancing climate resilience and promoting sustainable food systems in sub-Saharan Africa (Adoyo et al., 2025; Madsen et al., 2025). In countries such as Ethiopia, Kenya, and Madagascar, where smallholder agriculture is highly vulnerable to climate variability, land degradation, and recurrent extreme weather events, agroecology offers a context-specific socio-ecological approach to adaptation and transformation (HLPE, 2019; IPCC, 2023). However, despite growing policy attention and the implementation of initiatives such as ProSoil and ProSilience, supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the uptake and effectiveness of agroecological principles and practices remain uneven and are largely confined to pilot interventions. Existing research has predominantly focused on the biophysical and outcome-based benefits of agroecology, with limited attention to the underlying factors that shape farmers' responsiveness across diverse socio-economic and institutional contexts.

This study addresses this critical gap by examining the determinants of smallholder farmers' responsiveness to agroecological principles and practices in Ethiopia, Kenya, and Madagascar. Specifically, it seeks to understand how context-specific factors, including knowledge systems, extension approaches, institutional support, and socio-economic conditions, shape adoption behaviour and the intensity of agroecological transitions. By providing a comparative and multidimensional analysis, the study aims to generate evidence to inform the design of context-sensitive policies, inclusive extension systems, and scalable agroecological interventions, thereby supporting the broader goal of moving from localized, pilot-level practices to systemic and sustainable food system transformation (Adoyo et al., 2025; Wezel et al., 2020).

Method

Research location

This study was conducted in three Eastern African countries—Ethiopia, Kenya, and Madagascar—selected for their agroecological diversity and the presence of agroecology-related interventions (Figure 1). Ethiopia has a four-tier administrative structure comprising regions, zones, districts (woredas), and wards (kebeles). The country consists of 12 regions and two city administrations, Addis Ababa and Dire Dawa, with multiple zones, woredas, and kebeles under these administrative units. Kenya has a two-tier system of government consisting of the national government and 47 county governments, together with 290 constituencies, 1,450 wards, and several sub-counties, divisions, locations, and sub-locations. Madagascar has an administrative structure composed of provinces, regions, and communes, including six provinces, 24 regions functioning as the main subnational level, 114 districts, and numerous communes.

Ethiopia, Kenya, and Madagascar align their agricultural policies broadly with the African Union's Comprehensive Africa Agriculture Development Programme (CAADP), with a focus on food security, reduction of post-harvest losses, and climate-resilient and sustainable agricultural practices. Although each country has distinct national policy frameworks—such as Ethiopia's Growth and Transformation Plan, Kenya's devolved county-level agricultural policies, and Madagascar's food security efforts supported by the World Food Programme (WFP)—they share common goals of increasing productivity, promoting the adoption of improved technologies, and enhancing farmers' incomes.

In Ethiopia, data were collected from four regions: Oromia, Sidama, Southern Region, and Central Region. In Kenya, the survey was conducted in Bungoma, Kakamega, and Siaya counties. In Madagascar, respondents were drawn from seven municipalities: five in the Boeny region (Ambato-Boeny, Mahajanga I, Mahajanga II, Marovoay, and Mitsinjo) and two in the Androy region (Ambovombe and Bekily).

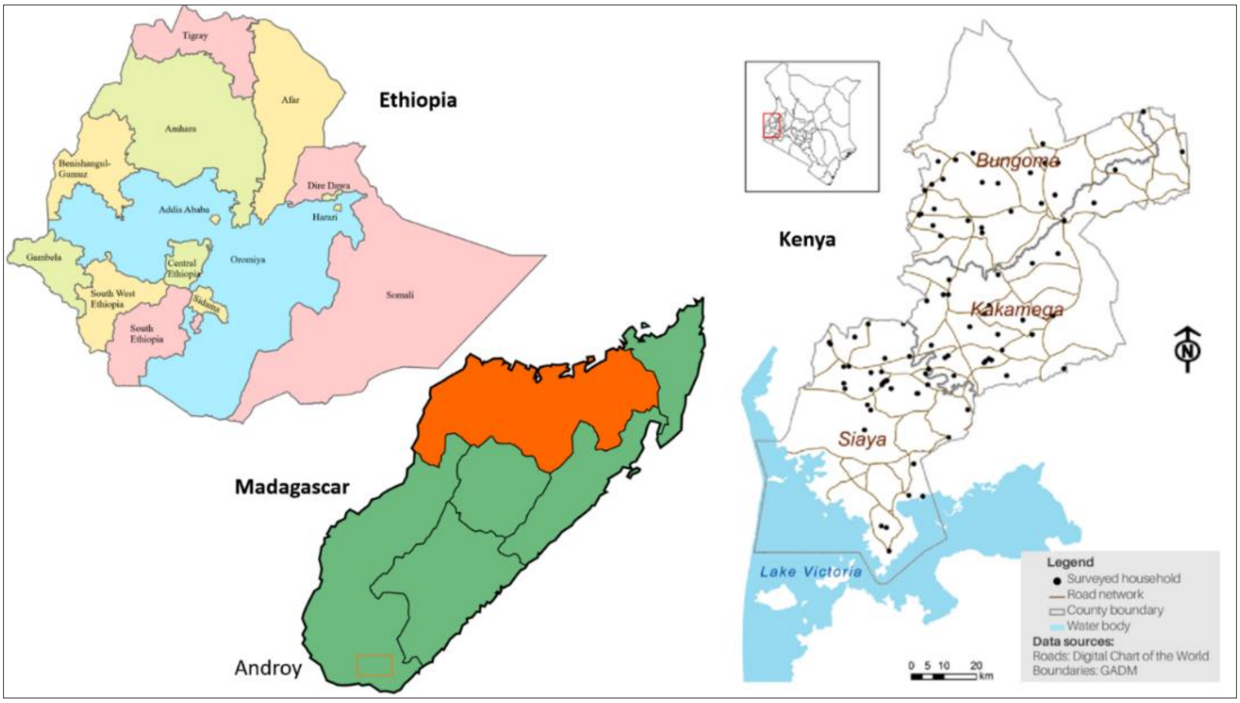

Figure 1. Schematic location of the study areas in Ethiopia, Kenya, and Madagascar

Research design and sampling

A cross-sectional research design was adopted to examine the characteristics of farming populations and their engagement with agroecological practices. This design enabled a systematic analysis of patterns and variations in adoption across diverse locations. The target population consisted of smallholder farmers drawn from the intervention areas of the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) ProSoil and ProSilience projects. These areas were described in relation to their environmental, social, and demographic characteristics to provide contextual understanding and reduce potential selection bias.

A list of farmers practising agroecology was obtained from the agricultural extension offices and disaggregated according to the predominant agroecological technologies practised. A multistage sampling approach was employed. First, regions and counties were purposively selected based on their agroecological relevance and their involvement in ProSilience and agroecological transition extension approaches. Second, villages within these areas were purposively selected. Finally, individual respondents were randomly sampled to enhance representativeness.

The number of farmers sampled in each country was determined in proportion to the number of farmers listed as agroecology practitioners. The final sample comprised 993 respondents: 301 from Kenya (121 from Bungoma, 120 from Kakamega, and 60 from Siaya), 326 from Ethiopia (distributed across Oromia, Sidama, Southern, and Central regions), and 366 from Madagascar (274 from Boeny and 92 from Androy). This sampling framework enabled comparability across countries and regions with different agroecological and institutional contexts.

Data collection

A structured questionnaire was developed and validated by subject-matter experts in agroecology, extension, and rural development. It comprised multiple sections covering demographic characteristics, farm attributes, and the use and intensity of adoption of 13 agroecological principles. According to FAO (2016), these principles include recycling, input reduction, soil health, animal health, biodiversity, synergy, economic diversification, co-creation of knowledge, social values and diets, fairness, connectivity, land and natural resource governance, and participation.

The questionnaire was piloted in Illu District, Ethiopia, and Murang'a County, Kenya, revised based on field feedback, and administered by trained enumerators. Data were collected using the KOBO Collect mobile application, a Computer-Assisted Personal Interviewing (CAPI) tool that enabled real-time data capture and improved consistency across countries. To ensure ethical compliance, enumerators explained the objectives of the study to each respondent and obtained informed consent. Participation was voluntary, and confidentiality and anonymity were assured. These procedures followed established ethical standards for research involving human participants (Babbie, 2016). The main outcome variable was responsiveness to agroecology, defined as the number and combination of the 13 agroecological principles applied by each respondent.

Data analysis

The collected data were analyzed with SPSS IBM Version 30, using Multiple regression, (the dependent variable transformed into a specific score index) while Principal Component Analysis (PCA), was applied to identify behavioral dimensions and explore the underlying adoption proportions and predictors of responsiveness. Graphs were used to summarize the results. The Multiple linear regression was expressed as:

$$\gamma_i = \beta_0 + \beta_{1xi1} + \beta_{2xi2} + \beta_{3xi3} + \beta_{4xi4} + \beta_{5xi5} \dots\dots\dots\dots\dots\dots + \beta_{nxin} + \varepsilon \dots\dots\dots\dots\dots\dots 1$$

Where

γ_i *is the* responsiveness to agroecology principles (The outcome variable being predicted).

β_0 *is the* Intercept, the predicted value of γ_i when all independent variables are zero

$\beta_1 - \beta_{1xi1}$ are the predictor, explanatory, or covariate variables used to explain changes in the dependent variable

ε *is the error term*

To reduce dimensionality and identify latent constructs underlying adoption patterns, Principal Component Analysis (PCA) was conducted. PCA transforms correlated variables into uncorrelated principal components that explain the maximum possible variance. Each component is a linear combination of the original variables:

Given variables (X_s…original variables of the composite responsiveness to agroecology)

$X_1 \dots X_p$ measured in 'n' farmers

$P_1 \dots P_p$: the principal components which are uncorrelated linear combinations of the original variable, $X_1 \dots X_p$, given as:

$$P_1 = \alpha_{11}X_1 + \alpha_{12}X_2 + \cdots + \alpha_{1p}X_p$$

$$P_2 = \alpha_{21}X_1 + \alpha_{22}X_2 + \cdots + \quad .$$

$$P_p = \alpha_{p1}X_1 + \alpha_{p2}X_2 + \cdots + \alpha_{1pp}X_{pz} \dots\dots\dots\dots (2)$$

The components with eigen values >1 were retained based on the Kaiser criterion (Kaiser, 1960). Only variables with factor loadings ≥ |0.30| were considered significant contributors. The PCA enabled the classification of influencing factors into thematic components such as practices, extension methods, social learning, and institutional enhancements.

Limitations

A key limitation of this study is that the respondents were drawn exclusively from areas where agroecological interventions or Farmer Field School programmes were already active. Consequently, the findings may reflect localized effects of programme exposure, such as higher levels of awareness, knowledge co-creation, or access to inputs, and may therefore not accurately represent smallholder farmers in non-intervention or more remote areas. This limits the generalizability of the results at the national level, as adoption patterns in non-intervention areas may differ because of variations in institutional support, resource endowment, or socio-cultural factors (Wossen et al., 2019). Future research should incorporate representative samples from both intervention and non-intervention areas to enable broader inference and validation of the contextual determinants of agroecology adoption.

Results and discussion

Figure 2 presents the proportion of farmers adopting key agroecological principles by country, based on the list of ten agroecological principles proposed by FAO (2016). Across Ethiopia, Kenya, and Madagascar, the adoption of these key agroecological principles varied considerably in both intensity, defined as the number of principles adopted per farmer, and breadth, referring to the specific principles adopted. These differences reflect underlying disparities in institutional support, farmer knowledge, and the local adaptation of agroecological interventions.

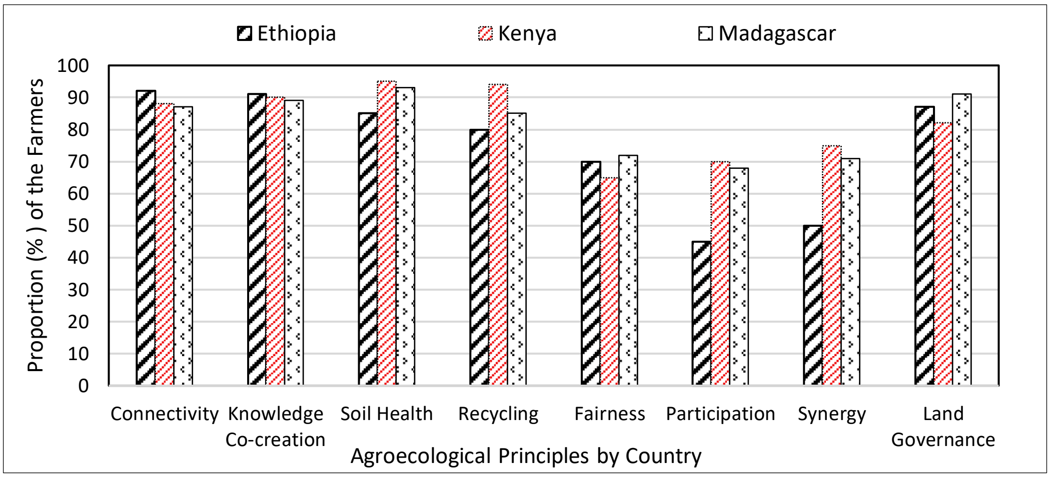

Figure 2. The proportion of farmers adopting the key agroecological principles *by Country*

In Ethiopia, Figure 2 shows that more than 90% of respondents reported applying the principles of connectivity and knowledge co-creation, whereas participation recorded the lowest uptake (45%). Only 20% of farmers had adopted all thirteen principles, while 15% had adopted none. According to Cicek et al. (2023), the adoption of agroecological principles is often partial and heterogeneous, with farmers tending to adopt specific practices incrementally rather than as a complete "package." Adoption rates vary widely depending on the specific practice, local context, and socio-economic conditions. These findings suggest that practices aligned with informal learning networks and local ecological knowledge are more prevalent, whereas those requiring structured group collaboration or collective advocacy remain less widely adopted. Similar patterns have been reported in other East African studies (Dosso et al., 2024; Ifeanyi-Obi et al., 2024). From an extension perspective, this implies the need to strengthen participatory and group-based advisory approaches, moving beyond individual knowledge dissemination towards the facilitation of collective action, farmer organisation, and multi-stakeholder engagement. Recent studies further indicate that weak participation in formal extension structures constrains the scaling of agroecology, thereby necessitating greater investment in facilitation skills and social learning approaches within extension systems (Davis et al., 2012; Madsen et al., 2025).

Figure 3 shows that, in Kenya, adoption was both broader and more intense. More than 90% of farmers adopted the principles of soil health, recycling, and knowledge co-creation, while over 60% applied at least 12 principles. The least adopted principle was fairness (65%). According to Kirui et al. (2025), the intensity of agroecological adoption generally remains selective, with most farmers tending to adopt a limited number of individual agroecological practices rather than the full set of principles and practices. The specific practices adopted depend heavily on local agroecological conditions, available resources, and the immediate challenges faced by farmers. The principle of fairness emphasizes equitable relationships and social justice within food systems, with the aim of ensuring that all participants, particularly small-scale producers, receive fair compensation, recognition, and opportunities. This relatively widespread uptake may reflect the concerted efforts of non-governmental organizations (NGOs), research institutions, and government actors to mainstream agroecology through Farmer Field Schools and innovation platforms (Davis et al., 2012).

Figure 5 reveals that, in Madagascar, adoption was moderate but consistent. More than 85% of respondents implemented the principles of soil health, connectivity, and land governance, whereas synergy recorded the lowest adoption rate (71%). Most farmers applied between 8 and 12 principles, indicating a relatively high level of engagement. This pattern reflects a context in which government policies increasingly support agroecological zoning and community-based land-use management (Razanakoto et al., 2021). These findings are consistent with recent evidence showing that contextualized approaches, particularly those that take ecological, social, and institutional realities into account, are more likely to promote meaningful agroecological transitions (Kerr et al., 2023; Wezel et al., 2025). From an extension perspective, this suggests that systems in Madagascar should move beyond promoting adoption alone to addressing equity and inclusiveness within agroecological value chains. Emerging evidence indicates that although agroecological practices can improve productivity and resilience, these benefits are not always equitably distributed in the absence of targeted extension support related to markets, pricing, and institutional inclusion (Barrett et al., 2022; Madsen et al., 2025). Extension services therefore need to integrate market-oriented and socio-economic advisory support, linking farmers to fair markets and strengthening inclusive innovation platforms.

Figures 3 to 5 present the findings on the intensity of agroecological principles adoption among farmers in Ethiopia, Kenya, and Madagascar. They show both the number of farmers adopting each agroecological principle and the number of principles adopted by each farmer. In this study, responsiveness to agroecological principles was operationalized as the number of farmers in each country adopting each principle and the number of principles adopted by each farmer. The results are therefore presented in terms of the intensity of agroecological principles adoption and the uptake of agroecological practices among farmers. In the graphs, the secondary axis represents the number of principles adopted per farmer, while the primary axis depicts the number of farmers adopting each agroecological principle. Higher adoption intensity is often positively associated with better outcomes, including increased crop yields, improved food security, enhanced soil health, and higher household incomes, particularly in the long term. These findings suggest that agricultural extension strategies in Ethiopia, Kenya, and Madagascar need to be adaptive and differentiated, targeting both the number of principles adopted and the intensity of adoption per farmer through tailored interventions that support incremental learning, the integration of multiple principles, and context-specific advisory services.

In Ethiopia, more than 90% of the farmers indicated the adoption of connectivity, and knowledge co-creation, while the lowest adopted principle is participation (Figure 3). This may be due to the differential levels of farmers involvement in the field and post field activities of agroecology practices and products, such that involvement is high in knowledge co-creation of agroecology practice to enhance adoption, but low in participation of agroecology products during off-field activities. In addition, less than 20% of the respondents incoporate all principles while 15% had not incoporated any of the agroecology principles. Extension systems should focus on strengthening farmer participation and collective engagement in agroecology, complementing knowledge co-creation with structured group-based activities to enhance full adoption of principles.

The findings from Kenya presented in Figure 4 show that more than 90% of respondents reported adopting the agroecological principles of recycling, soil health, and knowledge co-creation, whereas fairness was the least adopted principle, reported by 65% of farmers. The relatively high proportion of farmers adopting each agroecological principle, as well as the high intensity of use per farmer, may be attributed to the presence of multiple international, national, and local development actors promoting agroecological practices in different forms across the study area. Similarly, more than 60% of farmers had incorporated at least 12 principles, with none adopting fewer than six. Overall, the intensity of agroecological principles use indicates that most farmers applied between 8 and 12 principles. Although farmers widely adopted multiple agroecological principles, extension services should place greater emphasis on promoting fairness, equity, and inclusive practices, while also supporting the integration of these principles into coherent, system-level approaches.

In Madagascar, as shown in Figure 5, more than 85% of respondents reported adopting the agroecological principles of soil health, connectivity, and land and natural resource governance, whereas synergy was the least adopted principle, reported by 71% of farmers. These principles are central to the policy directions and extension messages promoted by the government, non-governmental organisations, and other actors in the agroecology landscape. The intensity of agroecological principle use shows that most farmers applied between 8 and 12 principles. However, the application of these principles must be accompanied by accurate and context-appropriate implementation to support successful agroecological transitions. The adoption of fully integrated agroecological systems, including complete transitions to organic farming or comprehensive conservation agriculture packages, remains relatively limited, often due to constraints such as labour shortages, lack of equipment, or high initial investment costs. The implication for extension is the need to strengthen systems-based advisory services that enhance synergies among practices, rather than promoting isolated technologies. Extension systems should therefore adopt landscape and farming systems approaches that support farmers in integrating crop, livestock, and natural resource management practices, which have been shown to enhance agroecological outcomes significantly (Altieri et al., 2015; Madsen et al., 2025).

Farmers' responsiveness to agroecological principles and practices is generally partial and incremental, with adoption shaped by local agroecological conditions, resource endowments, and socio-economic constraints (Cicek et al., 2023; Dumbrell et al., 2016; Kirui et al., 2025; Pedzisa et al., 2015). Higher adoption intensity correlates with improved productivity, soil health, and food security, yet full transitions remain constrained by labor, capital, and knowledge gaps. These patterns imply that agricultural extension must shift toward adaptive, modular, and continuous counselling, supporting progressive learning cycles and participatory experimentation rather than one-off trainings. Scaling agroecology further requires pluralistic extension systems, strengthened research–extension–farmer linkages, and integration of indigenous knowledge with scientific innovation to facilitate context-specific and sustainable transitions (African Climate Foundation, 2025; Kerr et al., 2021; Madsen et al., 2025).

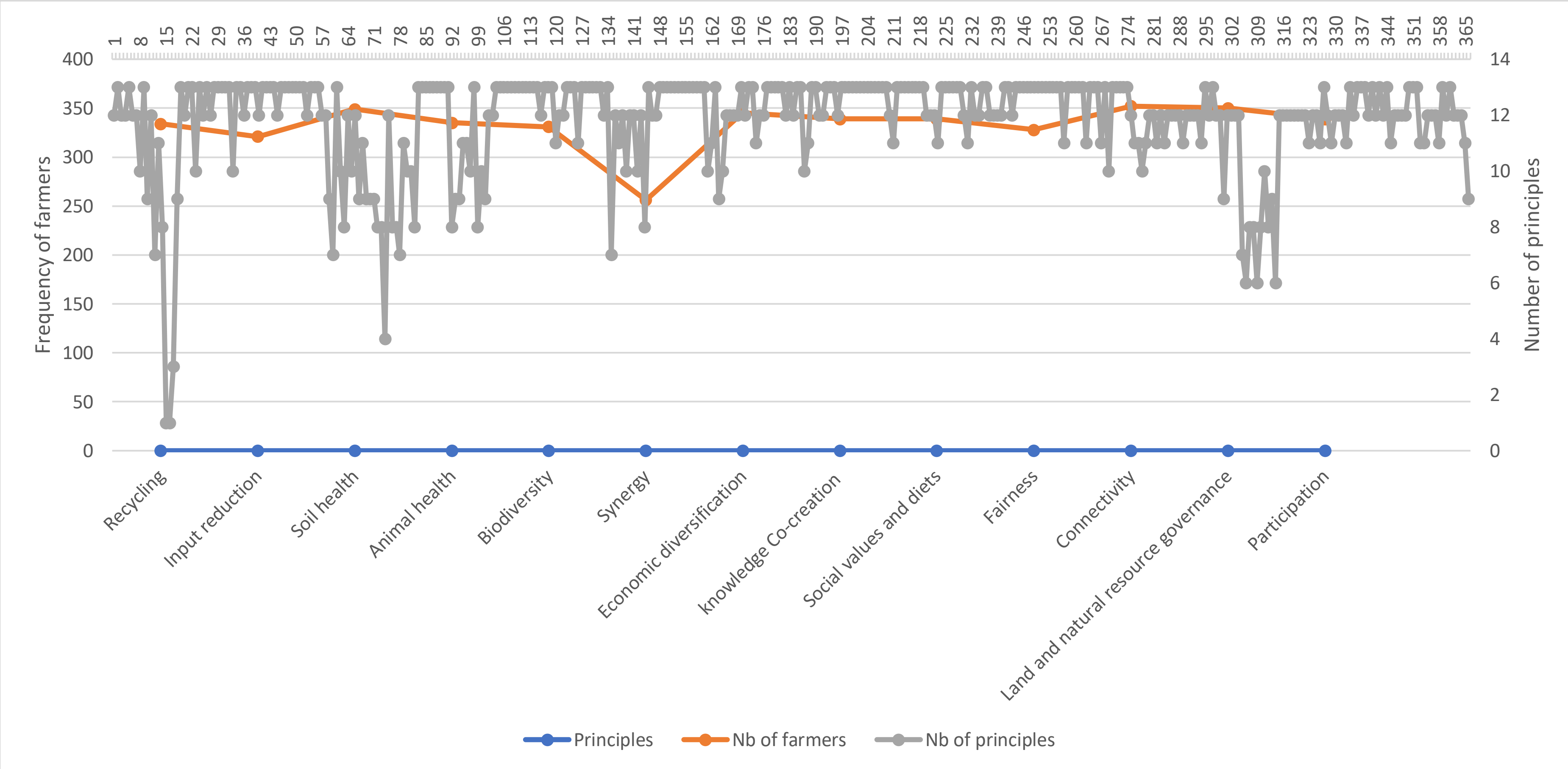

Figure 3. Intensity of agroecology principles adoption among Ethiopia farmers

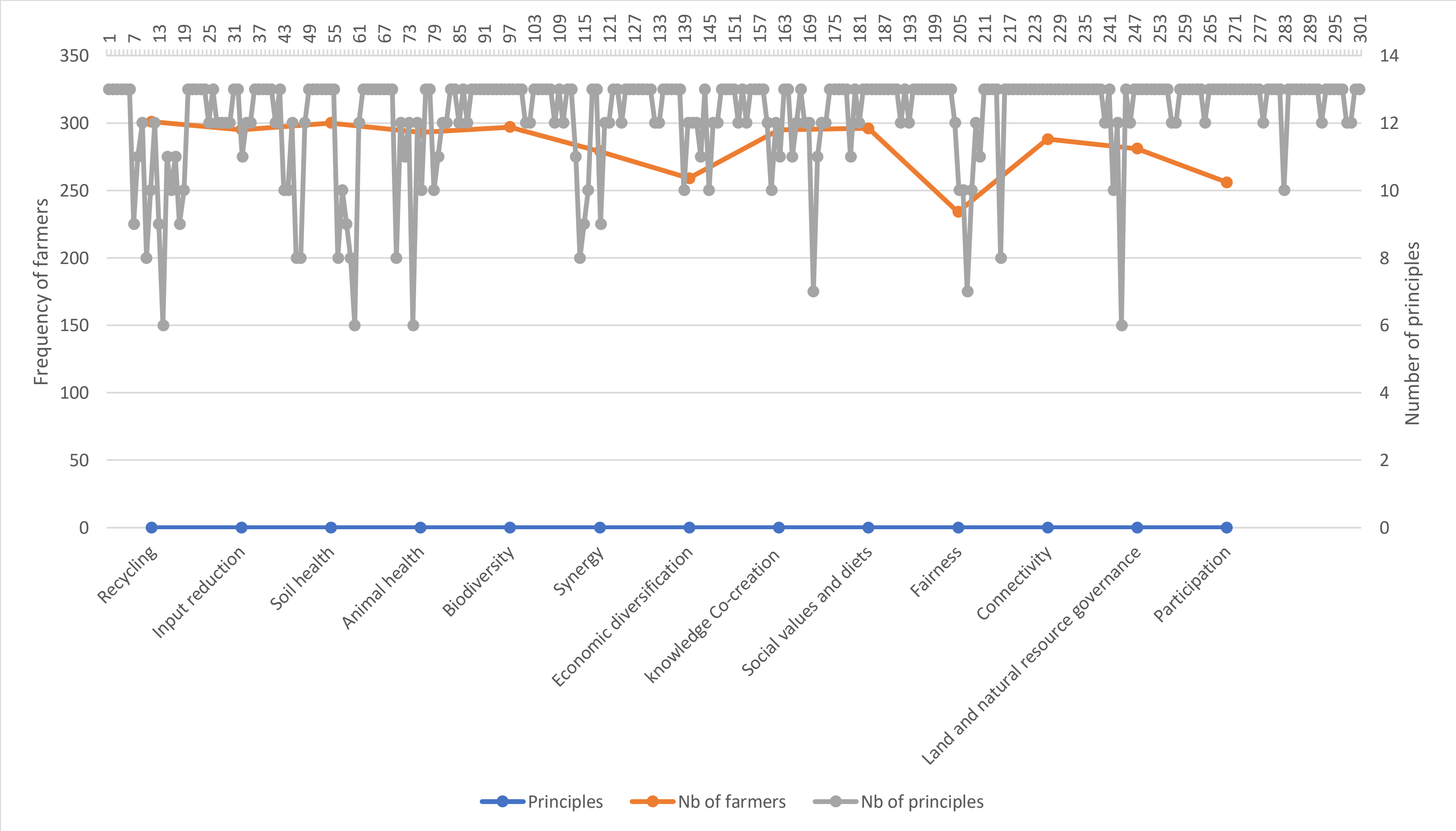

Figure 4. Intensity of agroecology principles adoption among Kenya farmers

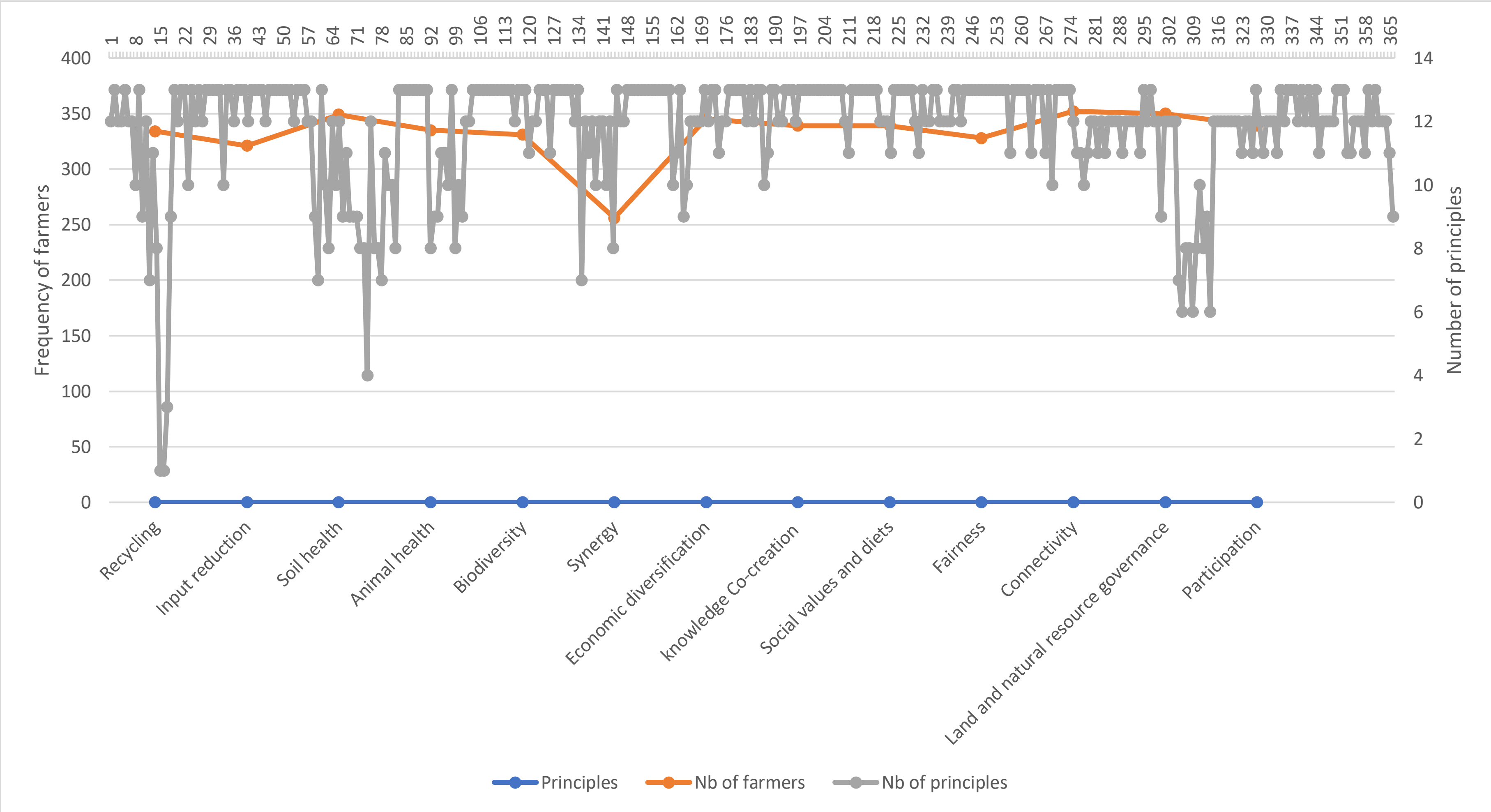

Figure 5. Intensity of agroecology principles adoption among Madagascar farmers

The results of the Principal Component Analysis show that the extracted components for responsiveness to agroecology practices and principles are described as factor 1 (practices), factor 2 (extension methods), factor 3 (social learning), factor 4 (enhancements) and factor 5 (experiential/knowledge), factor 6 (adoption) factor 7 (gender/culture) which accounted for 24.818%, 11.92%, 9.05%, 4.99%, 4.741%, 4.183% and 3.679% of the variances respectively; with a cumulative 63.38% variance (Figure 6).

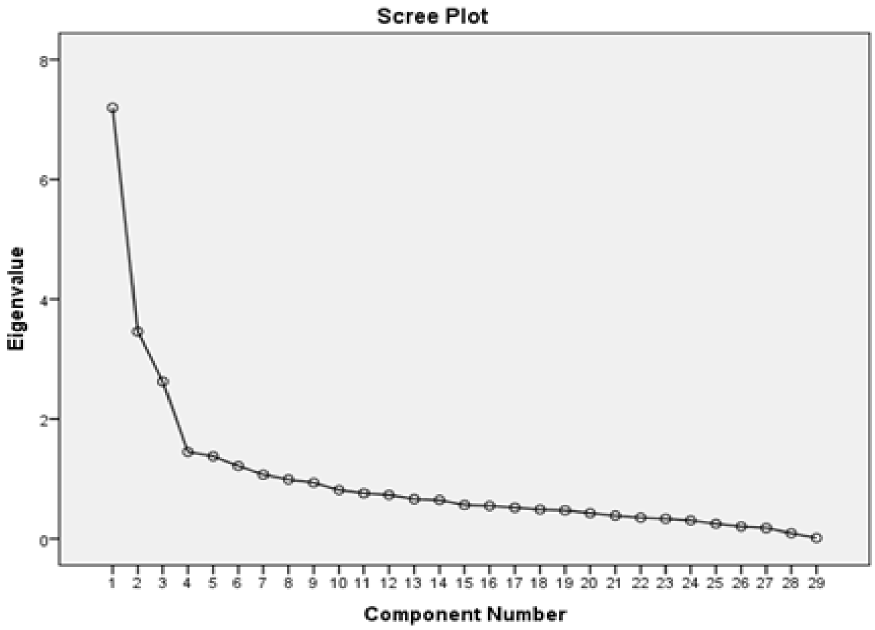

Figure 6. Scree plot of principal component analysis of responsiveness to agroecology practices and principles

The Kaiser criterion (1960), which was used to choose the underlying types and the number of components explaining the data, allowed for the extraction of seven elements from Figure 6. Variables with factor loadings larger than or equal to ±0.300 were taken into consideration when depicting the components, while all variables in each extracted component that had Eigen values, a measure of explained variance, of less than one were taken into account. Similarly, if a factor loading is greater than 0.30, it adds considerably to the study's derived component; as a result, every item on the scale that explains each derived component was appropriately expressed on the PCA. Only variables with factor loadings of ±0.346 and above at 10% overlapping variance were used to name the factors and significant at the 1% level of probability, according to Otitoju and Enete, (2016). As a result, variables with factor loadings of less than ±0.30 were not used, and variables loading in multiple constraints were also eliminated. The relationship between each variable and all other variables as well as the association between variables are demonstrated by the squared multiple correlations between each item and all other items that are commonalities. The research in this study explains limitations to the agroecology transition the least (0.339). The Factor Analysis of Mixed Data (FAMD) was applied due to different levels of measurement of data.

With regard to Figure 6, these findings support the Bartlett's Test of Sphericity, which has a value of □2 = 179.31, p = 0.00, and a Kaiser-Meyer-Olkin Measure of Sampling Adequacy of 0.73. The weights of their factor loadings were used to determine the impact of the variables that make up the extracted components explaining responsiveness to agroecology principles (Table 1). The prominent items under the practice factor are Number of agroecology principles (.978), Use of soil health (.892), Use of Nutrition sensitive agriculture (.829), Use of conservation agriculture (.817), Use of climate smart agriculture (.778), Use of crop rotation & intercropping (.758), Use of soil and water conservation (.756), Use of integrated pest management (.754), Use of agroforestry (.730), Use crop livestock integration (.582), Farm size (-.498), knowledge co-creation score (-.457). The explanation provided for each of the components are not cause and effect rather underlying factors for components.

Cover crops, no-till management, and management-intensive grazing are examples of conservation practices that have been adopted as components of agroecology practices (Lee and McCann, 2019; Winsten et al., 2020), intercropping, compost use, reduced tillage, cover cropping, crop rotation, and border planting are examples of underlying factors influencing conservation and agroecology practices (Gong et al., 2024; Liebert et al., 2022). Farm size is positively connected with land fallow, negatively correlated with crop rotation and intercropping, and non-significantly correlated with soil and water conservation and the use of organic fertilisers, according to Pham et al. (2022). Ward et al. (2016) found large farm size is correlated with no-tillage and intercropping in Malawi, while, Cavanagh et al. (2017) reported that total income influence agroecology practices. For the extension method factor, the items are use of plant clinics (.685), use of training and visit (.620), use of organic agriculture (.570), use of innovation platform (.556), education level (-.520); while the social learning factor is composed of items such as use of farmer training center (.667), use of farmer to farmer (.663), use of farmer field schools (.601), use of smallholder horticulture empowerment project (shep) (.531), use of e-extension (-.497).

The enhancement factor included incentives participation agroecology (.704), incentives share agroecology (.624), constraints to agroecology (.340). Mockshell et al. (2023) revealed that farmer organizations, input subsidies, price premiums, credit, technical assistance, and extension services emerged as important incentives for promoting agroecological practices and outcomes. Polonio-Punzano et al. (2021) found that the loss of producer income and the lack of social awareness, lack of access to planting materials, land tenure and property rights intrinsic motivation for agroecological transition, lack of knowledge, behaviour change, lack of time and labour intensity are among the important barriers to agroecological practices. The experiential/knowledge factor is composed of farming experience in agroecology (.624). Sufosec Alliance (2023) reported that factors underlying agroecology transition include mind-set of farmers; the natural, physical and financial assets on their farms; social cohesion aspects; community farmer groups, policies, availability of extension services, cultural and social norms, disasters, climate change, market shocks, and volatile prices.

The adoption factor is made up of farming experience (.520), agroecology farm size (.412), while the gender/culture factor is indicated by gender of the respondent (.623). Kanjanja et al. (2022) discovered that the adoption of agroecological practices on farm yard manure, composite and green manure, intercropping, and crop rotation by farming households was correlated with income, education level of the household head, distance from homestead to the farm, training in agroecology, and land ownership. Hurley et al. (2023) identified the following as major obstacles to agroecology practices: a lack of perceived financial viability; restrictions on land tenure; a lack of networks for knowledge sharing and advice; a lack of support for agroecological/regenerative production; and the exclusion of young and female farmers.

Table 1 shows the results of extracted components by the factor analysis of responsiveness to agroecology principles.

Table 1. Principal component analysis of responsiveness to agroecology principles

	Components							
	Practices	Extension methods	Social Learning	Enhancements	Experiential/ Knowledge	Adoption	Gender/ culture	Communalities
Number of agroecology principles	.978							0.976
Use of soil health	.892							0.846
Use of Nutrition sensitive agriculture	.829							0.829
Use of conservation agriculture	.817							0.70
Use of climate smart agriculture	.778							0.721
Use of crop rotation & intercropping	.758							0.647
Use of soil and water conservation	.756							0.596
Use of integrated pest management	.754							0.598

Use of agroforestry	.730							0.612
Use crop livestock integration	.582							0.554
Farm size	-.498							0.549
knowledge co-creation score	-.457							0.497
Use of plant clinics		.685						0.585
Use of training and visit		.620						0.687
Use of organic agriculture		.570						0.613
Use of innovation platform		.556						0.565
Education Level		-.520						0.468
Use of Farmer training center			.667					0.579
Use of Farmer to Farmer			.663					0.547
Use of Farmer Field Schools			.601					0.605
Use of Smallholder Horticulture Empowerment Project (SHEP)			.531					0.607
Use of e-extension			-.497					0.607
Incentives participation agroecology				.704				0.857
Incentives share agroecology				.624				0.843
Constraints to agroecology				.340				0.399
Farming experience in Agroecology					.624			0.557
Farming experience						.520		0.57
Agroecology farm size						.412		0.428
Gender of the respondent							.623	0.736

The analysis highlights distinct agroecological and socio-economic patterns, providing evidence to guide targeted extension. Extension policies should prioritize differentiated approaches based on farm typologies, promote synergistic agroecological practices, strengthen farmer capacity and access, integrate climate-smart interventions, and foster participatory knowledge co-creation to enhance adoption, resilience, and sustainable food systems.

Table 2 presents the results of the multiple regression analysis of the determinants of responsiveness to agroecology practices and principles among farmers in Ethiopia, Kenya and Madagascar. All the models are well-fitted with F values of 11.595, 3.574, 7.097 at $p = 0.00$ for Kenya, Madagascar, and Ethiopia respectively. The differences in results across the countries can be attributed to the underlying structural, cultural, and economic differences among farmers practicing agroecology technologies. Similarly, the underlying unique institutional contexts across the countries could be responsible for the differences. The trend of the results may be attributed to the impacts of farm size on the ability and willingness to adopt agroecological practices, the length of farming experience which influence farmer’s willingness to innovate and their ability to manage ecological complexity, as well as the prevailing policies and market incentives that drive the adoption of sustainable technologies. Furthermore, the observed heterogeneity in significant predictors and model explanatory power across countries likely reflects context-specific socio-economic, institutional, and agroecological conditions that shape smallholder responsiveness to agroecological practices. Across the countries, the variation explained are not large because the focus of the model is on identifying significant relationships rather than high prediction accuracy.

In Kenya the significant variables are agroecology farm size ($t = 1.71$, $p < 0.10$), Farming experience in agroecology ($t = 1.76$, $p < 0.10$), constraints to agroecology ($t = 5.97$, $p < 0.01$), incentives share agroecology ($t = 3.59$, $p < 0.01$), and incentives agroecology participation ($t = 2.21$, $p < 0.05$). These variables have R value of 0.59, R Square of 0.35, predicting 35 percent of the variance in responsiveness to agroecology practices and principles. In Kenya, the relatively higher model R^2 suggests that farm-level incentives and practical experience with agroecology exert a stronger influence on responsiveness, potentially attributable to the presence of well-established Farmer Field Schools (FFS) and functional extension networks that facilitate experiential learning and iterative problem-solving (Davis et al., 2012; Mugisha et al., 2025). FFS function as participatory platforms, enabling farmers to evaluate and adapt practices in situ, thereby reinforcing adoption through localized knowledge co-creation (Méndez et al., 2025).

In Madagascar the significant variables are Education Level ($t = 2.68$, $p < 0.05$), knowledge co-creation score ($t = 4.44$, $p < 0.01$), Constraints to agroecology ($t = 2.00$, $p < 0.05$), Incentives share agroecology ($t = 2.84$, $p < 0.05$), Incentives agroecology participation ($t = 2.74$, $p < 0.05$). These variables have R value of 0.33, R Square of 0.11, predicting 11 percent of the variance in responsiveness to agroecology practices and principles. In contrast, in Madagascar, where structured field-based support is comparatively limited, formal education and knowledge co-creation processes emerge as more salient determinants of agroecology adoption. This pattern indicates that cognitive engagement and participatory learning mechanisms are critical in contexts where direct technical support is constrained, enabling farmers to interpret, experiment with, and internalize agroecological concepts (Bhandari et al., 2024; Dumont et al., 2025).

In Ethiopia the significant variables are Farm size ($t = 2.40$, $p < 0.05$), Agroecology farm size ($t = 3.61$, $p < 0.01$), knowledge co-creation score ($t = 1.80$, $p < 0.10$), Constraints to agroecology ($t = 2.33$, $p < 0.05$), and Incentives share agroecology ($t = 1.71$, $p < 0.10$). These variables have R value of 0.22, R Square of 0.19, predicting 19 percent of the variance in responsiveness to agroecology practices and principles. In Ethiopia, both farm size and agroecology-specific farm characteristics; including crop diversity, tree cover, and access to inputs, significantly predict responsiveness, consistent with prior evidence linking resource endowment and institutional connectivity to adoption intensity (Kassie et al., 2017; Teklewold et al., 2013). These findings suggest that both the capacity to experiment with multiple practices and the availability of farm-level assets are critical determinants of smallholder engagement with agroecological innovations.

The results of the regression analysis align with findings with other authors. According to Silva et al. (2025), farmers adopt agroecological conservation practices on cover crops and vegetation strips, local crop varieties, intercropping, managed grazing, crop rotations, and no-till. Many farmers use multiple practices and expressed a willingness to implement additional conservation practices on cover crops, tree plantings, and no-till. According to Slijper et al. (2023) and Foguesatto et al. (2022), farmers' decisions to adopt agrocological practices are influenced by a variety of factors, including the farm, farmers, economic and environmental characteristics, off-farm influences, and behavioural factors. However, Liebert et al. (2022) discovered that while reduced tillage was prevalent on large farms, intercropping and border plantings were common on small farms. Improved soil quality and profitability encouraged farmers to adopt agroecological conservation measures, despite financial constraints, risk, ignorance, and resource accessibility being obstacles. According to Iyabano et al. (2023), at least one of the three drivers of individual motivation or innovative behavior—instrumentality, valence, and expectancy—as well as the activities of their Farmers Organisations have an impact on the adoption of agroecological innovations. According to Rizzo et al. (2024), environmental values encourage the adoption of agroecology principles (organic farming), but the primary obstacles to adoption are the complexity of innovation, a high level of innovation aversion, and a low perceived control over innovation. Oliveira da Silva et al. (2024) discovered that more agroecological innovations were chosen, co-designed, and implemented by farmers who worked with researchers and industry representatives through an iterative process of discussions and workshops. Dagunga et al. (2023) discovered that the knowledge and ability of the farmer/farm manager to implement various methods had an impact on the adoption of crop rotations, organic fertilisation, green manuring, early planting, and other agroecological activities. According to TIGR2ESS (2022), using organic or natural farm inputs, home-grown seeds, biofertilizers, pesticides, and a thorough understanding of the local ecological region all had an impact on the use of sustainable and agroecology farming practices.

Collectively, these country-specific differences underscore that the drivers of agroecology adoption are not universally generalizable but are highly contingent on local biophysical, socio-economic, and institutional contexts. This reinforces the imperative for context-tailored extension policies and intervention strategies that align with local incentives, resource endowments, and learning environments, rather than relying on standardized, one-size-fits-all approaches to promote sustainable agricultural transitions.

Table 2. Multiple regression analysis of the determinants of responsiveness to agroecology principles among farmers in Ethiopia, Kenya and Madagascar

	Kenya		Madagascar		Ethiopia	
	B(SE)	Tolerance (VIF)	B(SE)	Tolerance (VIF)	B(SE)	Tolerance (VIF)
(Constant)	5.119 (1.477) ***		.598(.564)		9.573(.261) ***	
Gender of the respondent	-.109(.273)	.878 (1.139)	.044(.134)	.985(1.015)	.035(.056)	.913(1.096)
Education Level	-.129(.170)	.714(1.401)	.126(.047) **	.848(1.180)	.010(.026)	.795(1.258)
Farm size	.134(.140)	.456(2.194)	-.001(.020)	.850(1.176)	.084(.035) **	.806(1.241)
Agroecology farm size	.317(.185) *	.436(2.293)	.013(.029)	.837(1.195)	-.253(.070) ***	.694(1.441)
Farming experience	.001(.010)	.893(1.119)	-.001(.005)	.852(1.173)	-.004(.003)	.729(1.371)
Farming experience in Agroecology	.067(.038) *	.804(1.244)	-.009(.022)	.917(1.090)	-.008(.005)	.791(1.264)
knowledge co-creation score	.029(.036)	.744(1.344)	.071(.016) ***	.882(1.134)	-.009(.005) *	.793(1.261)
Constraints to agroecology	-.179(.030) ***	.847(1.181)	-.044(.022) **	.923(1.083)	-.028(.012) **	.630(1.588)
Incentives share agroecology	.359(.100) ***	.687(1.456)	-.250(.088) **	.217(4.614)	-1.341(.782) *	.004(224.124)
Incentives agroecology participation	.234(.106) **	.746(1.340)	.236(.086) **	.210(4.761)	1.119(.748)	.004(223.481)
R	.596		.333		.464	
R Square	.355		.111		.215	
Adjusted R Square	.324		.080		.185	
Durbin- Watson	1.474		1.016		1.323	
F	11.595		3.574		7.097	
P	.000		.000		.000	

The regression analysis highlights that smallholder farmers' responsiveness to agroecology principles and practices in Kenya, Madagascar, and Ethiopia is influenced by farm size, farming experience, knowledge co-creation, and the presence of incentives, while structural and resource constraints reduce responsiveness (Barrera-Siabato et al., 2025; Kirui et al., 2025). Participation in Farmer Field Schools (FFS) and other participatory approaches strengthens farmer interaction and peer learning, which in turn enhances the practical application of agroecological principles, thereby increasing responsiveness to sustainable practices (FAO, 2023; Méndez & Nordstrom, 2025). Peer-to-peer knowledge exchange and collaborative learning have been shown to improve responsiveness by enabling farmers to contextualize and adapt innovations to local conditions (Maughan & Anderson, 2023). Furthermore, well-designed incentive mechanisms and targeted extension support reinforce farmer responsiveness, particularly when aligned with local agroecological and socio-economic realities (Van Asseldonk et al., 2023). Collectively, these findings indicate that effective extension policies in Eastern Africa must combine hands-on training, participatory knowledge co-creation, peer learning platforms, and context-specific incentives to enhance farmers' responsiveness and promote sustainable agroecological transitions.

Conclusion

The findings of this study highlight substantial variation in the intensity and breadth of agroecological adoption across the three countries. Kenya exhibited the highest overall responsiveness, with approximately two-thirds of farmers adopting nearly all the principles, likely reflecting stronger institutional support, more vibrant pluralistic extension ecosystems, and clear policy direction. Ethiopia and Madagascar showed moderate to high adoption, particularly of principles aligned with local knowledge systems and soil health management, although adoption was more selective and uneven. Key determinants of responsiveness included agroecology-specific land use, farming experience, education level, knowledge co-creation, and access to institutional incentives. Constraints to farmers' responsiveness were significant across all countries, underscoring the need for supportive policy environments that lower barriers while enhancing motivation and resource access. Notably, knowledge co-creation emerged as a consistent and cross-cutting driver, reinforcing the importance of participatory and experiential learning in agroecological transitions. The latent factors underlying adoption behaviour included ecological practices, extension methods, social learning, institutional enhancements, experiential knowledge, adoption behaviour, and socio-cultural influences.

The policy and extension implications are as follows: First, context-specific interventions tailored to ecological, socio-economic, and cultural realities are paramount. Second, investing in pluralistic and participatory extension systems, such as Farmer Field Schools and innovation platforms, is essential for scaling agroecology. Third, targeted incentives and enabling environments must address structural constraints, especially for underrepresented groups such as women and smallholders. In conclusion, agroecology represents a viable pathway toward more sustainable, resilient, and inclusive agricultural systems in East and Southern Africa. However, realizing its full potential requires a systemic approach that integrates farmer knowledge, institutional innovations, and supportive policies. Future research should explore longitudinal impacts and test context-specific intervention models to deepen understanding and inform scale-up strategies.

Furthermore, the implications for policy and extension include promoting agroecology, which requires more than technical diffusion; there is also a need for investment in co-creation mechanisms. Knowledge co-creation has been consistently significant across countries, highlighting the need for participatory learning tools like FFS, co-design platforms, and farmer-led experimentation. Tailoring incentives to contexts is essential, as effectiveness depends on addressing specific constraints such as access to inputs, credit, and market infrastructure. Finally, the reformation of extension systems, by transitioning from linear to network-based models, will better accommodate the complexity of agroecological transitions, particularly for marginalized groups like women and youth. These insights should inform adaptive policy frameworks that integrate agroecology into national food system strategies, while respecting local diversity and equity considerations.

While the world faces a triple crisis of food insecurity, biodiversity loss, and climate change, threatening agricultural sustainability and rural livelihoods, there is a positive prognosis for agroecology providing an integrated solution. However, its adoption depends on responsive extension systems that go beyond information delivery. FFS enable social learning and knowledge co-creation, allowing farmers to experiment, adapt, and share agroecological practices in context. Supporting participatory extension models and targeted incentives is therefore critical to institutionalizing, scaling agroecology, and achieving resilient, inclusive, and sustainable food systems.

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Statement of originality and plagiarism-free

The authors declare that this article is an original work that has not been published elsewhere and is free from plagiarism. All references and citations have been properly acknowledged according to the applicable standards.

Declaration of conflicts of interest

The author declares no conflicts of interest related to this research, authorship, or publication.

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