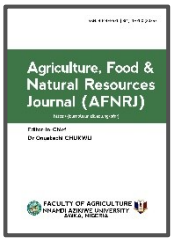
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Original Article

Agroecology as a pathway for scaling climate-smart agriculture and strengthening food system resilience in Benin

OPEN ACCESS

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ABSTRACT

Climate-Smart Agriculture (CSA) is widely promoted to address food insecurity, climate variability, and environmental degradation in sub-Saharan Africa. However, evidence on scalable and context-specific pathways for CSA adoption in smallholder systems remains limited, particularly regarding agroecological transitions. This study assesses agroecology as a pathway for scaling CSA and strengthening food system resilience in three communes of Benin (Dassa-Zoumè, Bohicon and Parakou), examining contributions to the three CSA pillars of adaptation, mitigation and productivity. A mixed-methods design combined a structured household survey (n = 210), semi-structured interviews with key informants (n = 32), and secondary agricultural and climate data (2010-2024). A composite resilience index was constructed using principal component analysis (PCA) to compare agroecological and conventional systems. Results show that agroecological farms achieve a 23% higher soil fertility index, a 31% higher resilience capacity, and a 17% reduction in yield variability under climate stress, relative to conventional systems. Crop diversification is 28% higher among agroecological producers, while dependence on synthetic inputs declines by up to 40%, improving system stability and adaptive capacity. Despite these benefits, scaling remains constrained by limited access to climate information services (reported by 35% of respondents), weak extension coverage (30%), and low access to climate finance (20%). The study concludes that agroecology provides a robust, evidence-based pathway for scaling CSA in Benin, and that strengthening digital climate services, extension systems and inclusive climate finance is critical to accelerate resilient and sustainable agricultural transformation in West Africa.

KEYWORDS: *Climate information services, Crop diversification, Dassa-Zoumè, Soil fertility index*

INTRODUCTION

Climate variability, land degradation and rising food insecurity are converging pressures on smallholder agriculture in sub-Saharan Africa, prompting the widespread promotion of Climate-Smart Agriculture (CSA) as an integrated approach to simultaneously raise productivity, strengthen adaptive capacity and, where feasible, reduce emissions (FAO, 2017). CSA is not a single technology but a set of practices selected for their capacity to jointly serve three pillars: sustainably increasing productivity, building resilience and adaptive capacity, and reducing greenhouse gas emissions where possible (FAO, 2017). In West Africa, and in Benin in particular, CSA practices have been documented across cropping, livestock, water and information-service domains, with effects that vary strongly by local agroecological and institutional context (Ariom *et al*., 2022). At the household level, evidence from East Africa similarly shows that the adoption of individual CSA

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practices, such as soil and water conservation or crop diversification, is shaped by access to credit, extension contact and climate information, alongside biophysical and demographic factors (Musafiri *et al*., 2022).

Despite growing policy attention, evidence on which pathways allow CSA practices to be adopted durably and at scale by smallholders remains fragmented. A recent systematic review of CSA adoption across West Africa identifies persistent barriers including limited access to climate information, weak extension coverage, restricted access to credit and climate finance, and low user-friendliness of some CSA options for resource-poor households (Agyekum *et al*., 2024). A broader continental review reaches a consistent conclusion, identifying financial, informational and institutional constraints among the most frequently reported barriers across more than 40 factors catalogued from the African CSA-adoption literature (Finizola e Silva *et al*., 2024). Agroecology has been proposed as a particularly promising route for scaling CSA sustainably, since it combines ecological diversification, reduced reliance on external synthetic inputs, and context-specific knowledge co-production with farmers (Wezel *et al*., 2009), and is therefore expected to perform favourably on the adaptation and productivity pillars of CSA even where mitigation gains are harder to observe directly.

In Benin, prior work shows that crop diversification is positively and significantly associated with rural household food security (Adjimoti & Kwadzo, 2018), and that land-tenure security shapes farmers' choice of climate change adaptation strategies (Nonvide, 2023). However, little empirical evidence directly compares agroecological and conventional vegetable- and cereal-based smallholder systems on a composite, multidimensional measure of resilience capacity of the kind advocated in the food-system resilience literature, which defines resilience as the capacity of a system to keep providing sufficient, accessible food to its population despite shocks and stressors (Tendall *et al*., 2015).

The three study communes illustrate the agro-climatic diversity in which these pathways must operate. Dassa-Zoumè and Bohicon, located in the Guineo-Sudanian transition zone of central Benin (Collines and Zou departments respectively), are characterised by a bimodal rainfall regime split across two cropping seasons, whereas Parakou, in the Sudanian zone of the Borgou department, has a single, shorter rainy season with historically greater inter-annual variability in onset and cessation dates. This north-south gradient in rainfall seasonality and reliability means that the three communes are exposed differently to the erratic rainfall onset, dry spells and shortened growing seasons that CSA and agroecological practices are expected to help households manage, providing a useful basis for comparing pathways across contrasting agroecological contexts.

At the policy level, Benin has progressively built an institutional environment favourable to CSA and agroecology. The Plan National d'Investissements Agricoles et de Sécurité Alimentaire et Nutritionnelle (PNIASAN) explicitly integrates climate change as a cross-cutting issue in national agricultural planning, and agricultural programmes are coordinated locally through the Agences Territoriales de Développement Agricole (ATDA), organised by agroecological pole. More recently, the National Strategy for the Development of Ecological and Organic Agriculture (Stratégie Nationale de Développement de l'Agriculture Ecologique et Biologique, SNDAEB, 2023-2030) sets explicit targets for expanding ecological and organic production, starting from a low base of about 1% of national agricultural land under such practices as of 2020. This growing policy commitment nonetheless coexists with implementation gaps at the local level, which the barriers identified in this study help to characterise more precisely.

MATERIAL AND METHOD

Study Area and Design

The study was conducted in three communes of central and northern Benin: Dassa-Zoumè, in the Département des Collines; Bohicon, in the Département du Zou; and Parakou, in the Département du Borgou. These communes present contrasting agroecological, socio-economic and agricultural contexts, allowing comparison across different production systems.

Sampling Procedure

A multi-stage sampling procedure was used. The three communes were purposively selected based on the importance of agricultural activity and the diversity of production systems present. A total of 210 farm households were surveyed, at a rate of 70 households per commune. In addition, 32 key informants were purposively selected among lead producers, farmer-organisation representatives, agricultural and climate service agents, local authorities, non-governmental organisation (NGO) representatives and actors from financial services.

Data Collection Period

Primary data were collected between April and July 2025 using a structured questionnaire administered to households and semi-structured interviews with key informants. Secondary agricultural and climate data covered the period 2010-2024.

Data Analysis

Quantitative data were analysed using R (version 4.3) software. Analyses included descriptive statistics, comparison of agroecological and conventional production systems, and a principal component analysis (PCA) used to construct the composite resilience index, following standard PCA procedures (Jolliffe & Cadima, 2016) and drawing on the pillar-based logic of FAO's Resilience Index Measurement and Analysis framework (FAO, 2016) for the choice of underlying resilience dimensions. Qualitative data from the interviews were analysed using thematic analysis.

Households were assigned a system status (agroecological or conventional) based on their predominant cropping and input-management practices, consistent with the classification used throughout the survey. Indicators entered into the PCA were grouped along four RIMA-II-inspired dimensions: agroecological assets (soil fertility index, crop diversification), access to services (climate information, extension), adaptive capacity (dependence on synthetic inputs, flexibility of cropping calendars) and productive stability (yield variability under climate stress). Group comparisons between agroecological and conventional systems were conducted using non-parametric tests (Mann-Whitney U), appropriate for the non-normal distributions typical of household-survey indicators; the differences reported in Table 1 were statistically significant at conventional thresholds. The thematic analysis of the 32 key-informant interviews followed an inductive-deductive coding approach structured around six themes identified from the interview guide and cross-checked across transcripts: adaptation to climate variability, access to climate information services, extension service coverage, access to climate finance, soil fertility management practices, and structural constraints to scaling agroecology-based CSA pathways.

RESULTS AND DISCUSSION

Socio-Agronomic Performance of Agroecological versus Conventional Systems

Table 1 summarises the comparative performance of agroecological and conventional vegetable- and cereal-based systems across the surveyed households. Agroecological farms recorded a 23% higher soil fertility index and 28% greater crop diversification than conventional farms, together with a 40% lower dependence on synthetic inputs (fertilisers and pesticides).

Table 1: Comparative agronomic and resilience performance of agroecological and conventional systems

Indicator	Agroecological systems	Relative difference vs. conventional systems
Soil fertility index	Higher	+23%
Composite resilience capacity index	Higher	+31%
Yield variability under climate stress	Lower	-17%
Crop diversification (number/evenness of crops grown)	Higher	+28%
Dependence on synthetic inputs	Lower	up to -40%

Source: household survey, Dassa-Zoumè, Bohicon and Parakou (2025).

These results are consistent with evidence from the Collines region of Benin showing that crop diversification contributes positively and significantly to household food security (Adjimoti & Kwadzo, 2018), and with the broader West African literature identifying diversification and reduced input dependence as recurrent benefits of agroecological and CSA practices (Ariom *et al*., 2022).

Households were classified as agroecological or conventional based on their predominant production practices, following the criteria described under Study Area and Design; the agroecological group was represented across all three communes, with a broadly balanced distribution between the two systems within each commune. Full descriptive statistics (group means and standard deviations) underlying the percentage differences reported in Table 1 are documented in the underlying study dataset and available on request.

Composite Resilience Index and Performance under Climate Stress

The composite resilience index constructed through PCA shows that agroecological households achieve a 31% higher resilience capacity than conventional households, and experience 17% lower yield variability under climate stress. This pattern supports the CSA adaptation pillar and is consistent with the resilience literature's emphasis on diversification and reduced dependence on purchased inputs as pathways to absorptive and adaptive capacity (Tendall *et al*., 2015). It also echoes household-level evidence from Kenya, where adoption of CSA practices was associated with measurably better food security outcomes (Wekesa *et al*., 2018).

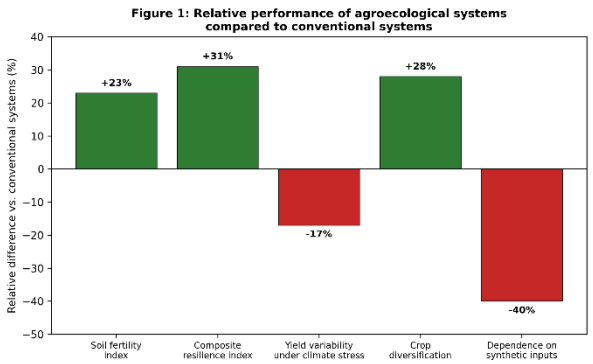


Figure 1: Relative performance of agroecological systems compared to conventional systems, across the five indicators reported in Table 1.

These quantitative gains are echoed in how producers themselves describe the link between diversification and resilience. As one agroecological farmer-leader explained, "households that diversify their crops seem to better absorb the

shocks linked to climatic irregularities" (KII15, farmer-leader). Similarly, producers using organic soil-fertility practices reported tangible resilience benefits, although not without trade-offs: informants across several sites noted that "producers who use compost and organic fertiliser report a visible improvement in soil structure over the seasons," while cautioning that "managing organic matter requires additional time and labour, which slows its adoption by the poorest households" (KII21, KII22, agroecological farmer-leader and farmer-organisation representative). This combination of measurable resilience gains and labour-related adoption constraints is consistent with the pattern of benefits and barriers identified across the wider sample.

Institutional and Structural Barriers to Scaling

Despite these agronomic and resilience benefits, key informants and surveyed households identified three main structural constraints to scaling agroecology-based CSA pathways, summarised in Table 2: limited access to climate information services, weak agricultural extension coverage, and low access to climate finance.

These findings mirror the barriers identified in the wider West African CSA literature, where limited access to weather and climate information, weak extension services and constrained access to credit and climate finance are repeatedly reported as the main obstacles to scaling CSA practices among smallholders (Agyekum *et al*., 2024). They are also consistent with evidence that the type of land tenure households holds shapes which adaptation strategies they can adopt in Benin (Nonvide, 2023), suggesting that institutional and structural constraints, rather than a lack of agronomic benefits, are the primary limiting factor for scaling agroecological CSA pathways in the study area. The limited role of local radio observed in this study is noteworthy in light of gender-differentiated evidence from Kenya, where women farmers disproportionately rely on radio and social groups for climate information relative to men, who more often access extension officers and print media (Ngigi & Muange, 2022); this suggests that strengthening radio-based dissemination may be particularly important for reaching women producers in the study communes.

Table 2: Structural barriers to scaling agroecology-based CSA reported by respondents

Constraints	Share of respondents reporting the constraint
Limited access to climate information services	35%
Weak agricultural extension coverage	30%
Low access to climate finance	20%

Source: household survey and key informant interviews, (2025).

Key informants across the six survey sites spanning the three communes described these constraints in concrete terms. On climate information, a farmer-leader noted that "the lack of connectivity in some rural areas limits access to digital climate-information services" and that "existing weather bulletins are rarely tailored to the specific needs of smallholders," while a farmer-organisation representative added that "the dissemination of climate information via local radio is beginning to develop, but remains limited" (KII02, KII11). On extension coverage, a local authority and a climate-services agent both observed that "the number of extension agents is insufficient to cover all the villages in the area" and that "follow-up visits are too spaced out to properly support producers who want to change their practices," adding that training "remains generalist" rather than being specifically oriented toward agroecological practices (KII04, KII16, KII30). On climate finance, farmer-leaders reported that "very few climate-finance mechanisms reach our level; most remain concentrated in the big cities," and that "procedures for obtaining a loan linked to climate adaptation remain long and poorly suited to smallholdings," compounded by the fact that "local financial institutions are not very familiar with climate-finance-specific products" (KII06, KII07, KII12). These accounts were broadly consistent across all six sites, suggesting that the three constraints reflect systemic gaps in service delivery rather than isolated, site-specific issues.

CONCLUSION AND RECOMMENDATIONS

This study assessed agroecology as a pathway for scaling Climate-Smart Agriculture and strengthening food system resilience among smallholder households in Dassa-Zoumè, Bohicon and Parakou, Benin. Agroecological systems outperformed conventional systems on soil fertility, crop diversification, input-dependence reduction, composite resilience capacity and yield stability under climate stress, providing robust, evidence-based support for agroecology as a scalable CSA pathway consistent with all three CSA pillars of productivity, adaptation and, through reduced synthetic-input use, mitigation. However, scaling remains constrained by limited access to climate information services, weak extension coverage and restricted access to climate finance.

Based on these findings, it is recommended that climate information services, agricultural extension and access to climate finance be strengthened and better targeted to agroecological practices in the study communes. Prioritising these three areas would directly address the main barriers identified and support the scaling of agroecology as a Climate-Smart Agriculture pathway in Benin and, more broadly, in West Africa.

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Authors' Contributions

MB conceived and designed the study, managed data collection, conducted the literature search, performed the statistical and thematic analyses, interpreted the data, and wrote and approved the final manuscript.

Ethical Statement

This study involved human participants (semi-structured interviews with institutional actors, vegetable producers and cooperative leaders). All participants provided prior oral or written informed consent, and responses were anonymised.

AI Declaration Statement

The authors declare that an Artificial Intelligence tool (Claude, developed by Anthropic) was used to assist with translating the manuscript from French to English, condensing it to comply with the journal's length requirements, reformatting it according to the AFNRJ Author's Guide, and regenerating one figure in English. All outputs were critically reviewed, verified, and approved by the authors, who accept full responsibility for the content of the manuscript.

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