

Ethnoecology-Based Traditional Agricultural Systems as a Strategy for Sustainable Agricultural Development

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Input : January 17, 2026 *Revised* : February 22, 2026
Accepted : February 18, 2026 *Published* : February 26, 2026

Abstract

Sustainable agricultural development has become increasingly urgent due to environmental degradation, climate change, and rural socio-economic inequality caused by high-input modern agricultural systems. In this context, ethnoecology-based traditional agricultural systems offer an alternative framework grounded in local ecological knowledge, cultural values, and community-based resource governance. This study aims to analyze how traditional agricultural systems can be formulated as a strategic approach to sustainable agricultural development within modern policy frameworks. The research employed a qualitative design using in-depth interviews, participatory observation, and document analysis in rural communities practicing traditional agriculture. Data were analyzed through thematic coding and an interactive model of data reduction, display, and interpretation. The findings reveal three main dimensions: ecological sustainability through diversification and agroforestry practices; socio-institutional resilience through customary governance; and potential hybridization with modern technologies such as precision irrigation and climate-smart tools. The study concludes that integrating traditional ecological knowledge with contemporary agricultural innovation and legal recognition of customary institutions can strengthen inclusive and resilient sustainable agricultural development.

Keywords : Ethnoecology; Sustainable agricultural development; Traditional agricultural systems; Agroecology; Policy integration.

Citation :

Kamakaula Y & Tjoli I. 2026 Ethnoecology-Based Traditional Agricultural Systems as a Strategy for Sustainable Agricultural Development. *MSJ: Majority Science Journal*, 1(1), 202-211

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1. Introduction

Sustainable agricultural development has become an increasingly urgent global agenda in response to escalating environmental degradation, climate change, and persistent rural socio-economic inequalities. The dominant model of high-input modern agriculture, characterized by intensive monoculture, excessive chemical fertilizers and pesticides, and large-scale mechanization, has undoubtedly contributed to short-term productivity gains. However, such a model has simultaneously accelerated soil degradation, water pollution, biodiversity loss, and greenhouse gas emissions, thereby undermining the ecological foundations upon which agricultural productivity depends (Gamage et al., 2023; Shahmohamadloo et al., 2021). These environmental consequences have heightened the vulnerability of food systems to climate variability and ecological shocks, threatening long-term food security. In this context, sustainable agricultural development is no longer a normative aspiration but a structural necessity to ensure ecological resilience and intergenerational equity.

The urgency of sustainable agricultural development is also closely linked to the achievement of the Sustainable Development Goals, particularly those related to zero hunger, climate action, clean water, and life on land. Agricultural transformation toward environmentally sound, resource-efficient, and climate-resilient systems is widely recognized as a prerequisite for meeting these global commitments (Viana et al., 2021; Dönmez et al., 2024). Contemporary



approaches such as agroecology, regenerative agriculture, and organic farming emphasize soil restoration, biodiversity conservation, and ecosystem-based management as central strategies for sustainability (Boix-Fayos & De Vente, 2023; Gamage et al., 2023). At the same time, technological innovations, including precision and smart agriculture supported by Internet of Things devices, sensors, machine learning, and intelligent irrigation systems, are promoted as solutions to enhance resource-use efficiency and reduce environmental externalities (Goel et al., 2021; Araújo et al., 2023; Xing & Wang, 2024).

Despite these advancements, technology-driven solutions alone have proven insufficient to address the multidimensional challenges faced by agricultural communities, particularly smallholder farmers. Structural poverty, unequal access to land and capital, and limited institutional support continue to constrain rural livelihoods. Sustainable agricultural development therefore requires not only technical innovation but also socio-institutional transformation that recognizes farmers as stewards of ecosystem services and custodians of rural landscapes (Viana et al., 2021; Dönmez et al., 2024). Without such recognition, modernization efforts risk reinforcing dependency on external inputs while marginalizing locally embedded knowledge systems that have historically sustained ecological balance.

Within this broader debate, traditional agricultural systems grounded in ethnoecology offer a compelling alternative framework. These systems have evolved through long-term interactions between local communities and their surrounding environments, generating ecological knowledge deeply embedded in cultural norms, customary institutions, and spiritual values. From an ethnoecological perspective, agriculture is not merely an economic activity but an integrated socio-ecological system shaped by locally specific understandings of soils, water cycles, biodiversity, and seasonal patterns. Empirical evidence indicates that practices such as crop diversification, agroforestry, rotational farming, organic fertilization, community-based water management, and traditional seed-saving mechanisms significantly contribute to soil conservation and biodiversity maintenance (Jaizul et al., 2025; Kamakaula, 2024; Fenetiruma & Kamakaula, 2023).

Furthermore, traditional systems demonstrate strong adaptive capacity in the face of climate change due to their reliance on ecological diversity and context-specific management strategies. Diversified cropping systems and tree integration within agroforestry landscapes reduce the risk of total crop failure and buffer climatic fluctuations, thereby enhancing food system resilience (Adefila et al., 2024; Kamakaula et al., 2023). Beyond ecological benefits, these practices strengthen community identity and social cohesion through collective resource governance and intergenerational knowledge transmission (Jaizul et al., 2025; Fenetiruma & Kamakaula, 2023). Consequently, traditional agricultural systems embody ecological, social, and cultural dimensions that align closely with the principles of sustainable development.

However, the continuity of traditional agricultural systems is increasingly threatened by rapid modernization, market expansion, urbanization, and intensified climate change impacts. Agricultural policies in many contexts remain oriented toward productivity maximization and global market integration, often prioritizing standardized technological packages over locally adapted practices. As a result, traditional knowledge is frequently marginalized, perceived as inefficient or economically inferior, and gradually abandoned by younger generations (Sekhar et al., 2024; Kamakaula, 2024). Moreover, insufficient legal recognition of customary institutions and indigenous ecological knowledge contributes to the erosion of time-tested resource management systems (Fenetiruma & Kamakaula, 2023; Kamakaula et al., 2023).

This situation reveals a significant research and policy gap. While the literature on sustainable agriculture increasingly advocates agroecological and regenerative frameworks, much of the discussion remains either technologically oriented or macro-structural in nature (Boix-Fayos & De Vente, 2023; Shahmohammadloo et al., 2021). Studies focusing on traditional agricultural systems often emphasize anthropological or cultural preservation aspects without systematically linking these systems to contemporary agricultural policy design. As a result, the strategic role of ethnoecology-based traditional systems in shaping sustainable agricultural development remains under-theorized and insufficiently operationalized within policy frameworks.

Although certain scholars highlight the importance of integrating indigenous ways of knowing into regenerative system design, practical institutional mechanisms for such integration are rarely elaborated (Boix-Fayos & De Vente, 2023; Dönmez et al., 2024). Legal recognition of customary land governance and local ecological institutions has been proposed as a pathway toward strengthening sustainable resource management (Jaizul et al., 2025; Huo & Chen, 2024; Kamakalula et al., 2025). In parallel, hybrid approaches combining traditional practices such as crop rotation and organic fertilization with precision irrigation, integrated pest management, and climate-smart technologies are increasingly discussed as viable pathways for sustainability (Tarun et al., 2025; Sekhar et al., 2024; Xing & Wang, 2024). Nevertheless, comprehensive conceptual frameworks that position ethnoecology-based traditional agricultural systems as strategic pillars of sustainable agricultural development remain limited.

The novelty of this study lies in repositioning traditional agricultural systems grounded in ethnoecology not merely as cultural heritage or localized subsistence strategies, but as a strategic and policy-relevant framework for sustainable agricultural development. This study integrates three critical dimensions: the ecological urgency of sustainability transitions, the adaptive and resilience capacities embedded in traditional systems, and the need for policy reform that accommodates plural knowledge systems within modern agricultural governance. By bridging these dimensions, the research advances a holistic conceptualization that recognizes traditional systems as epistemological foundations and practical models for resilient, inclusive, and context-sensitive agricultural development.

Accordingly, the objective of this study is to analyze how ethnoecology-based traditional agricultural systems can be formulated and operationalized as a strategic approach to sustainable agricultural development within contemporary policy frameworks. Through this analysis, the study aims to contribute theoretically to the advancement of integrative sustainability discourse and practically to the formulation of agricultural policies that harmonize local ecological knowledge with scientific and technological innovation in a balanced and sustainable manner.

2. Method

This study employed a qualitative research design with a socio-ecological and policy analysis approach to examine how ethnoecology-based traditional agricultural systems can be formulated as a strategic framework for sustainable agricultural development. The research was conducted in selected rural communities where traditional agricultural practices are still actively maintained. Data were collected through in-depth semi-structured interviews with key informants, including traditional farmers, community leaders, customary institution representatives, and local agricultural officers. In addition, participatory observation was undertaken to document farming practices, land management patterns, cropping systems, and local ecological knowledge embedded in daily agricultural activities. Document analysis was also conducted on relevant policy documents, regional agricultural development plans, and legal frameworks concerning land governance and sustainable agriculture. These multiple data collection techniques were employed to ensure triangulation and to enhance the credibility and validity of the findings.

Data analysis was carried out using an interactive model consisting of data reduction, data display, and conclusion drawing. Interview transcripts, field notes, and policy documents were coded thematically to identify key patterns related to ecological practices, institutional arrangements, adaptive strategies, and policy integration mechanisms. The analysis combined inductive and deductive approaches: inductive coding allowed themes to emerge from empirical findings in the field, while deductive analysis was guided by theoretical frameworks of ethnoecology, agroecology, and sustainable agricultural development. The findings were then interpreted within a socio-ecological systems perspective to assess how traditional knowledge systems interact with modern agricultural policies and technological innovations. This analytical process enabled the formulation of a strategic model that integrates traditional ethnoecological principles with contemporary sustainable agricultural governance..

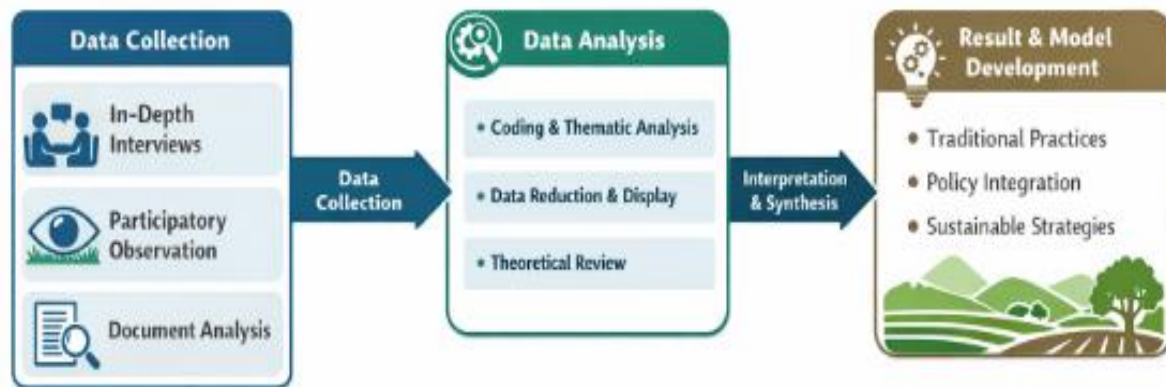


Figure 1. Diagram Conceptual Research

3. Results and Discussion

Based on field observations, in-depth interviews, and document analysis, the findings reveal three major dimensions that explain how ethnoecology-based traditional agricultural systems contribute to sustainable agricultural development: ecological sustainability, socio-institutional resilience, and policy integration potential. The synthesized results are presented in Table 1.

Table 1. Summary of Research Findings on Ethnoecology-Based Traditional Agricultural Systems

Dimension	Empirical Findings	Sustainability Contribution	Policy Implication
Ecological Sustainability	Crop diversification, agroforestry practices, organic fertilization, traditional water management, and local seed-saving systems are consistently practiced by farmers.	Improved soil fertility, biodiversity conservation, reduced chemical dependency, and enhanced climate resilience.	Integration into agroecological and climate-smart agriculture programs; support for organic and regenerative farming schemes.
Socio-Institutional Resilience	Strong customary institutions regulate land use, planting calendars, and collective labor systems; knowledge transmitted intergenerationally.	Strengthened social cohesion, collective resource governance, and long-term ecological stewardship.	Legal recognition of customary law and community-based resource management within formal agricultural governance.
Technological and Policy Integration	Selective adoption of modern tools (irrigation pumps, weather information systems) combined with traditional practices; limited access to precision technologies.	Hybrid model increases productivity without abandoning ecological principles.	Development of hybrid policy frameworks combining traditional knowledge with precision agriculture, integrated pest management, and climate-adaptive incentives for smallholders.

The findings indicate that ethnoecology-based traditional agricultural systems possess strong ecological and socio-cultural foundations that align with the principles of sustainable agricultural development. Ecologically, diversified and organic-based practices enhance soil health and biodiversity while reducing environmental risks. Socially, customary institutions function as effective governance mechanisms that regulate land and resource use in a sustainable manner. However, the analysis also shows that the absence of formal policy recognition and limited technological access constrain the scalability of these systems. Therefore, a strategic hybrid approach that formally integrates traditional ecological knowledge with modern agricultural innovation and supportive policy instruments is essential to achieve inclusive and resilient sustainable agricultural development.

Discussion

The findings of this study demonstrate that ethnoecology-based traditional agricultural systems possess substantial ecological, social, and institutional capacities that directly respond to the urgency of sustainable agricultural development. As previously outlined, modern high-input agricultural systems have contributed significantly to soil degradation, biodiversity loss, water pollution, and increased vulnerability to climate change (Gamage et al., 2023; Shahmohamadloo et al., 2021). The empirical evidence presented in Table 1 shows that traditional practices such as crop diversification, agroforestry, organic fertilization, and community-based water management actively maintain soil fertility and ecological balance. These findings align with the broader argument that sustainable agricultural development requires a systemic shift from extractive production models toward regenerative and ecosystem-based approaches (Boix-Fayos & De Vente, 2023; Viana et al., 2021). In this regard, traditional systems are not relics of the past but living models of ecological sustainability.

From an environmental perspective, the diversification strategies observed in traditional systems significantly reduce ecological risks associated with monoculture farming. Crop rotation and polyculture enhance soil organic matter and reduce pest outbreaks naturally, thereby minimizing dependence on chemical inputs. This ecological function directly addresses the environmental dimension of sustainability, particularly the restoration of degraded soils and conservation of biodiversity, which are central to achieving SDGs related to climate action and life on land (Dönmez et al., 2024; Shahmohamadloo et al., 2021). Agroforestry systems documented in the field further illustrate how integrating trees with crops improves carbon sequestration, microclimate regulation, and water retention, reinforcing findings in recent sustainability literature (Gamage et al., 2023). Thus, the ecological dimension of traditional agriculture substantively answers the first research concern regarding why sustainable agricultural development is urgent and how it can be operationalized through locally grounded practices.

In addition to environmental sustainability, the study highlights the socio-institutional resilience embedded in customary agricultural governance. Traditional institutions regulate planting calendars, land use, water allocation, and collective labor systems, ensuring that ecological practices are maintained across generations. This institutional dimension is often overlooked in technology-centered sustainability discourse. However, sustainable agriculture is inseparable from governance structures that coordinate collective action and manage common-pool resources. The recognition of farmers as ecosystem stewards rather than mere producers is emphasized in sustainability scholarship (Viana et al., 2021; Dönmez et al., 2024). The empirical findings demonstrate that customary law functions as an informal yet effective regulatory mechanism that ensures ecological compliance and social accountability, thereby strengthening rural resilience.

These findings resonate with arguments that sustainable agricultural development must integrate social justice and institutional recognition, particularly for smallholder farmers who are disproportionately affected by climate change and market volatility (Reddy, 2025). By preserving community-based resource management systems, traditional agriculture enhances social cohesion and reduces rural inequality. In contrast, the modernization paradigm often prioritizes productivity gains without sufficiently addressing structural vulnerabilities. Therefore,

the socio-economic dimension identified in this study confirms that sustainable development is multidimensional and cannot be reduced to technological efficiency alone.

The technological dimension of the findings reveals a nuanced reality. While traditional systems rely primarily on local ecological knowledge, farmers selectively adopt modern tools such as irrigation pumps and weather information systems when these technologies complement rather than replace traditional practices. This selective adoption supports the concept of hybridization between indigenous knowledge and scientific innovation. The literature on precision and smart agriculture emphasizes the role of sensors, machine learning, and intelligent irrigation systems in enhancing resource-use efficiency (Goel et al., 2021; Araújo et al., 2023; Xing & Wang, 2024). However, without contextual adaptation, such technologies may exacerbate dependency and marginalize local practices. The study shows that when technological tools are integrated within an ethnoecological framework, they enhance productivity while preserving ecological principles. This finding substantiates calls for climate-smart agriculture that is socially inclusive and culturally adaptive (Boix-Fayos & De Vente, 2023).

The discussion of ethnoecology as an analytical lens further clarifies the strategic value of traditional agricultural systems. Ethnoecology emphasizes the integration of ecological knowledge, cultural norms, and spiritual values in resource management. Empirical findings confirm that practices such as seed saving, organic fertilization, and agroforestry are not merely technical activities but expressions of culturally embedded environmental ethics. This supports previous research demonstrating that indigenous and local knowledge systems contribute significantly to biodiversity conservation and climate adaptation (Jaizul et al., 2025; Kamakaula, 2024; Fenetiruma & Kamakaula, 2023). By maintaining genetic diversity through traditional seed systems, communities enhance adaptive capacity in the face of unpredictable climatic conditions.

Nevertheless, the study also confirms that traditional systems face substantial pressures from modernization and policy neglect. Urbanization, market integration, and generational shifts threaten the continuity of local knowledge transmission (Sekhar et al., 2024; Kamakaula, 2024). The lack of formal legal recognition for customary institutions further weakens their capacity to govern land sustainably (Huo & Chen, 2024; Kamakaula et al., 2025). This policy gap reflects a structural disconnect between sustainability discourse and agricultural governance practice. While global narratives increasingly endorse agroecology and regenerative systems, implementation often remains biased toward standardized technological packages and productivity metrics (Shahmohamadloo et al., 2021).

Addressing this gap requires reconfiguring agricultural policy frameworks to accommodate plural knowledge systems. The literature suggests that agroecological frameworks explicitly respect indigenous ways of knowing in regenerative system design (Boix-Fayos & De Vente, 2023; Dönmez et al., 2024). The findings of this study provide empirical grounding for this argument by demonstrating that traditional governance mechanisms already embody principles of ecological balance and adaptive management. Legal recognition of customary land rights and community-based institutions would therefore not only protect cultural heritage but also strengthen ecological sustainability outcomes (Jaizul et al., 2025; Huo & Chen, 2024).

Furthermore, policy instruments should encourage hybrid models that combine traditional ecological practices with modern technological innovation. For instance, integrating traditional crop rotation systems with precision irrigation and integrated pest management can optimize productivity while reducing environmental risks (Tarun et al., 2025; Xing & Wang, 2024). Such hybridization aligns with the concept of regenerative agricultural systems that harmonize ecological processes with scientific advancement (Boix-Fayos & De Vente, 2023). Importantly, adoption incentives and capacity-building programs must prioritize smallholder farmers to prevent technological exclusion and ensure equitable sustainability transitions (Sekhar et al., 2024).

By synthesizing ecological, socio-institutional, and technological dimensions, this study directly addresses the research objective of formulating ethnoecology-based traditional agricultural systems as a strategic framework for sustainable agricultural development. The

findings indicate that sustainability cannot be achieved solely through technological modernization or market-driven reforms. Instead, it requires an integrative governance model that recognizes traditional ecological knowledge as a foundational asset. Such a model repositions local communities as central actors in sustainability transitions rather than passive recipients of policy directives.

In theoretical terms, the study contributes to sustainability discourse by bridging agroecological theory with ethnoecological perspectives. While agroecology emphasizes ecological processes and systemic resilience, ethnoecology highlights the cultural and epistemological dimensions of environmental management. Integrating these perspectives produces a more holistic framework for sustainable agricultural development. Practically, the findings offer policy recommendations centered on legal recognition of customary governance, institutional support for community-based management, and strategic hybridization of traditional and modern practices.

Ultimately, the urgency of sustainable agricultural development, as articulated in global sustainability literature, can be meaningfully addressed by revitalizing and institutionalizing traditional agricultural systems within modern policy frameworks (Viana et al., 2021; Dönmez et al., 2024). Ethnoecology-based systems demonstrate that ecological sustainability, social resilience, and technological innovation are not mutually exclusive but mutually reinforcing when integrated thoughtfully. Therefore, sustainable agricultural development should be conceptualized not as a linear modernization trajectory but as a pluralistic and adaptive process grounded in both local wisdom and scientific advancement.

4. Conclusions and Suggestions

This study concludes that ethnoecology-based traditional agricultural systems can be strategically formulated as a comprehensive framework for sustainable agricultural development by integrating ecological resilience, socio-institutional strength, and adaptive technological innovation within modern policy structures. The findings demonstrate that traditional practices such as crop diversification, agroforestry, organic fertilization, and community-based resource governance not only contribute to soil conservation, biodiversity protection, and climate adaptation, but also reinforce social cohesion and long-term stewardship of natural resources. At the same time, selective and context-sensitive integration of modern technologies, including precision irrigation and climate-smart tools, enhances productivity without undermining ecological principles. Therefore, achieving sustainable agricultural development requires policy reform that formally recognizes customary institutions, protects local ecological knowledge, and promotes hybrid models combining traditional wisdom with scientific and technological advancements. In this way, ethnoecology-based systems are repositioned not as peripheral cultural remnants, but as foundational pillars for inclusive, resilient, and sustainable agricultural governance.

Future agricultural policies should prioritize the formal recognition and protection of ethnoecology-based traditional agricultural systems by integrating customary institutions and local ecological knowledge into national and regional sustainable development frameworks. Governments are encouraged to design hybrid policy instruments that combine traditional practices such as crop diversification, agroforestry, and organic fertilization with climate-smart and precision agriculture technologies that are accessible to smallholder farmers. Capacity-building programs, participatory extension services, and inclusive financing schemes should be strengthened to ensure that technological innovation complements rather than replaces local knowledge systems. In addition, further empirical research across diverse agroecological regions is recommended to refine context-specific models of integration between traditional systems and modern agricultural governance, thereby enhancing the scalability and long-term sustainability of agricultural transformation strategies.

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