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Evaluation of the conversion of farming systems and scaling up of agroecological approaches in Nepal

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Abstract. Conventional farming systems face challenges such as ensuring smallholder farmers' livelihoods, conserving biodiversity, reducing emissions, and minimizing climate change impact. Transitioning to agroecological farming is the only sustainable alternative. This article examines Nepal's efforts to adopt sustainable agriculture and agroecological practices, focusing on climate change, declining soil fertility, and socioeconomic pressures. Agroecological approaches integrate ecological principles with agricultural practices to enhance productivity, resilience, and environmental health. Strategies include promoting a range of farming methods, making the soil healthier with organic additions, combining old and new technologies, getting institutional and policy support, ensuring market access for agroecological products, and involving the community in the process. Capacity-building, farmer cooperatives, and localized extension services are essential for widespread adoption. It is shown that agroecology has the power to change Nepal's farming problems, but for these practices to be used by more people, they need to be backed by long-term investments in research, education, and policy reform.

Keywords: *Biodiversity, sustainable agriculture, productivity, resilience and soil health*

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1. Introduction

Conventional farming is an agricultural method that relies significantly on synthetic chemical inputs like herbicides, pesticides, fertilizers, modern technologies, and monocropping practices to enhance production (Altieri, 1996; Nicholls & Altieri, 2016). Conventional farming is a general practice in which farmers use chemical or synthetic fertilizers, pesticides, herbicides, hybrid seeds, and genetically modified organism (GMO) to produce crops. Although the production level obtained through industrial agriculture is high, agroecological farming is gaining popularity nowadays due to conventional farming practices' detrimental impacts and instability. These practices have harmed ecosystems, increased greenhouse gas emissions, and resulted in problems like soil erosion, water pollution, and pesticide resistance (Gliessman, 2014). Monoculture-dominated modern agriculture has resulted in ecological imbalances, biodiversity loss, and resource inefficiencies (Nicholls & Altieri, 2016). Modern agriculture disrupts global ecological processes, negatively impacts human health, degrades genetic diversity, and destroys natural habitats, thereby jeopardizing future productivity (Gliessman, 2014). Additionally, corporations neglect farmers and farmworkers who play crucial roles as stewards of agricultural land.

Agroecology is an interdisciplinary domain that integrates agricultural practices with ecological concepts (Chaudhary et al., 2023). It is an applied science using known ecological principles to build and manage agroecosystems. It focuses on using natural processes like allopathy, biological pest control, and improved soil fertility instead of outside inputs (Nicholls & Altieri, 2016). Because agroecology gives us flexible guiding principles instead of rigid technological answers, many approaches will focus on finding out how well these principles are put into practice and how they impact the ecological, economic, and social aspects of the farm.Even with the current challenges that the global food system is experiencing, including climate change, resource scarcity, and new agroecology, agriculture offers diseases a viable solution. Agroecological farming is a type of farming that follows a specific set of principles that aim to integrate ecological practices and embrace farming diversity and systems. Local knowledge and the use of biological control, fertilizers, and pesticides enhance soil fertility and crop yields while also fostering the development of sustainable and eco-friendly farming practices (Gliessman, 2014).

The transition from conventionally managed farms to agroecologically managed farms is increasingly recognized as essential for addressing pressing global challenges such as food security, biodiversity loss, and climate change. According to Vikas and Ranjan (2024) and Saikanth et al. (2023), agroecology encourages long-term methods that protect biodiversity, make soil healthier, and lower the need for chemical inputs. This makes farming systems more resilient. This shift aims to optimize food production and rectify social and economic inequities inherent in current food systems (Jacobi & Itty, 2024). Changing to different types of crops, integrated pest management, and agroforestry over time will help the ecosystem provide services that will keep crops productive (Niggli et al., 2023; Rai et al., 2024) for a long time. As Raj et al. (2023) also say, eco- farming practices that use few agrochemicals are crucial for protecting both human health and the environment. This shows how important it is for policymakers to support and teach farmers about these practices. Overall, embracing agroecological principles is vital for creating a sustainable and equitable food system that aligns with ecological and social well-being.

Figure 1 emphasizes the system's interconnectedness: activities improve natural processes, providing favorable outcomes and making the farm more resilient and sustainable.

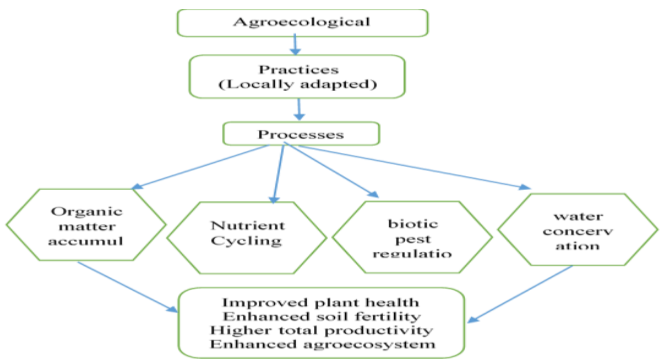

Figure 1. Agro-ecological principles for the conversion farming systems (Wezel, 2017)

2. Criteria and indicators for evaluating agro-ecological farm conversion

Assessing a farm's transition from conventional to agroecological management requires a multifaceted approach considering ecological, social, and economic dimensions. A comprehensive evaluation should incorporate a range of criteria and indicators tailored to the specific context of the farm and its surrounding environment. Several methodologies exist to guide this process. One such approach centers on four essential elements: transformability, agroecosystem quality, management capability, and human capital (Vázquez & Martínez, 2015).

Altieri (1996) has examined an alternative strategy that emphasizes the function of "farmer lighthouses" in promoting the uptake of agroecological practices. This concept acknowledges that individual farms can act as models and catalysts for broader adoption, emphasizing the social and organizational components of agroecological scaling. Ten amplification indicators are suggested as a way to figure out how farmer lighthouses might affect territorial upscaling (McGreevy et al., 2021; Altieri, 2023). According to McGreevy et al. (2021), these indicators include social organization, network engagement, community leadership, and the extent of reliance on markets or policies. Additionally, they cover the extent to which on-farm agroecological methods are being adopted (Altieri, 2023; McGreevy et al., 2021; Silva & Moore, 2017) and the lighthouse farm's total environmental impact. This approach demonstrated how historical circumstances, social dynamics, and the amplifying influence of agroecological farmer lighthouses interact in a Japanese context.

Agroecological conversion involves a comprehensive study considering environmental, economic, and social factors (DeLonge & Basche, 2017). These factors are interconnected and should be evaluated in light of the farm's individual setting, objectives, a Nepal's broader socioeconomic and environmental realities. For example, focusing solely on economic evaluation might overlook crucial environmental benefits like improved soil health and biodiversity. Similarly, a solely environmental assessment might neglect the economic viability and social implications for farming communities. Therefore, a balanced approach that considers the interaction of environmental, economic, and social factors is essential for a thorough evaluation (Table 1).

Several methodologies exist for assessing agroecological performance. Researchers frequently cite the Tool for Agroecological Performance Evaluation (TAPE) and the Agroecology Criteria Tool (ACT) (Costa-Pereira et al., 2024). These tools often incorporate indicators across multiple dimensions.

2.1. Environmental criteria and indicators: ecosystem health and resilience

The environmental criteria analyze the health and resilience of the agroecosystem. This includes measuring indicators for biodiversity, soil health, water management, pest and disease control, and greenhouse gas emissions. The main objective is to find out change has created a more stable and long-lasting ecosystem that offers many advantages, such as better ecological integrity, biodiversity, and resistance to environmental stresses.

2.1.1. Biodiversity

Biodiversity assesses the variety of microbes, beneficial insects, crops, and animals. Species richness (the number of different species present), evenness (the relative abundance of different species), functional diversity (the range of ecological roles that species play), and the presence of beneficial organisms are some of the things that Harkányi and Ujj (2024) and Jeanneret et al. (2021) said make up this diversity. Indicators include the species richness of plants, pollinators (such as bees and butterflies), beneficial insects (such as ladybugs and lacewings), and soil organisms (such as earthworms and microbes) (Liere et al., 2017). A key sign of successful agroecological conversion is the change from monoculture to diverse cropping systems that include a variety of plant species with different ecological roles and growth habits. The evaluation should look at both above- and below-ground biodiversity, and it should be noted how important soil microbial communities are for the health of the ecosystem as a whole and for cycling nutrients.High biodiversity levels are observed in agroecological farms through practices like companion planting and crop rotation (Harkányi & Ujj, 2024).

2.1.2. Soil health

Soil health includes all of its biological (microbial biomass, activity, diversity), chemical (nutrient levels, pH, organic matter content), and structural (soil structure, water infiltration, and aeration) parts (Hou, 2023; Le et al., 2023; Singh et al., 2024) aspects. Some indicators are aggregate stability (how well soil particles stick together), penetration resistance (how hard it is to push a probe into the soil), and microbial biomass carbon (a measure of the total carbon stored in soil microorganisms, which shows how biologically active the soil is) (de Araújo et al., 2013). Better soil structure, higher organic matter levels, and higher microbial activity demonstrate the effectiveness of agroecological practices (Arajo et al., 2013). The assessment should also consider the impact of different soil management practices on soil erosion and nutrient loss.Studies have shown that organic amendments and regenerative practices can significantly improve soil health (Singh et al., 2024).

2.1.3. Water management

Water management is essential for sustainable agriculture, particularly in water-scarce locations like Nepal (Ferguson & Lovell, 2014). Water use efficiency (crop yield with water consumed), irrigation frequency (number of irrigation applications throughout a growing season), and water quality (pollution or excessive salinity) are all critical factors (Kremen & Miles, 2012). Moreover, water management includes efficient irrigation techniques, water conservation, and reduced runoff (Mandal et al., 2023). Implementing water collection techniques (such as rainwater harvesting and terracing), planting drought-resistant crops, and using irrigation systems efficiently are all positive indicators of sustainable water management.

2.1.4. Pest and disease management

A successful transition in pest and disease management involves using ecological strategies, including biocontrol, crop rotation, and companion planting rather than chemical pesticides (Brzozowski & Mazourek, 2018; Surchat et al., 2021). Key indicators include pesticide use (amount and types of pesticides applied), pest incidence (occurrence and severity of pest infestations), and disease prevalence (incidence and severity of plant diseases) (Bhuiyan & Maharjan, 2022). The assessment should also account for beneficial insects and other natural enemies contributing to pest control. High plant diversity and crop rotation are effective pest management strategies (Surchat et al., 2021).

2.1.5. Greenhouse gas emissions

Fewer tilling, cover crops, and carbon sequestration in soil (increasing the amount of carbon stored in the soil) are some of the ways that people are trying to reduce their carbon footprint and slow down climate change (Bux et al., 2022). Some of the things that can be used as indicators are carbon sequestration in soil (changes in soil organic carbon over time), methane emissions (from livestock or rice paddies), and nitrous oxide emissions (from fertilizer use).

2.2. Economic criteria and indicators: farm viability and profitability

Economic criteria evaluate the farm's financial viability and profitability following the transition to agro-ecological practices. This involves examining indicators related to input costs, yields and production, market access and pricing, and economic resilience. The goal is to determine whether the transition has improved or maintained the farm's economic viability while promoting sustainable practices.

2.2.1. Input costs and profitability

Farm sustainability depends on the capacity to endure economic shocks and price volatility. Indicators encompass income stability (examining fluctuations in income over time), diversification of revenue streams (minimizing reliance on one product or market), and debt levels (evaluating the farm's financial liabilities). Agroecological methods can increase economic stability by lowering input expenses and boosting resilience to environmental disturbances. Profitability assesses the farm's financial performance, considering income and expenses (Gambart et al., 2020; Le et al., 2023). While some studies show that agroecological farms may have lower yields than conventional farms (Le et al., 2023), others suggest that the higher prices for organic products can offset this difference.

2.2.2. Yields and production

Although they are not the sole measure of success, yields and production figures should be evaluated for the sustainability of the overall system (Abraham et al., 2014). Some indicators are crop outputs (calculated in tons per hectare or other units), livestock outputs (calculated in kilograms of meat, liters of milk, or other units), and overall farm outputs (the total amount of goods made) (Bhuiyan & Maharjan, 2022). Analyzing yield data in the context of other sustainability indicators is essential. For instance, a slight drop in yield might be acceptable if significant reductions in environmental impacts or improvements in soil health accompany it.

2.2.3. Market access and value chain

Accessing fair markets and potentially elevated prices for agroecological goods is crucial for the economic viability of the transition (Guerra et al., 2017). Some indicators are market entry (looking at how easy it is to sell products), prices obtained for commodities (comparing the costs of organic and conventional goods), and income diversification (looking at the different ways to make money, like direct sales, value-added products, and agritourism). Establishing local markets and direct-to-consumer sales channels can enhance the economic benefits of agroecological farming. This examines the farm's ability to access markets and the efficiency of its value chains. (Hongsprabhas, 2023; Villavicencio-Valdez et al., 2023). Direct marketing fosters connections between producers and consumers, thereby increasing awareness of conservation practices (Harkányi & Ujj, 2024).

2.2.4. Resource efficiency

This involves assessing the farm's use of resources, including land, labor, water, and energy. Agroecological practices promote efficient resource use (Mandal et al., 2023).

2.2.5. Economic resilience

Farm sustainability depends on the ability to withstand economic shocks and price fluctuations. Indicators include income consistency (analyzing changes in income throughout time), diversification of income sources (reducing dependence on a single product and debt status (assessing the farm's financial obligations). Agroecological practices can enhance economic stability by reducing input costs and improving resilience to environmental disruptions.

2.3. Social criteria and indicators: community engagement and equity

The ability to withstand economic disruptions and price fluctuations is crucial to agricultural sustainability. Indicators include income consistency (analyzing variations in income over time), revenue stream diversification (reducing dependence on a single product or market), and debt status (assessing the farm's financial obligations). Agroecological practices can enhance economic stability by reducing input costs and increasing resilience to environmental disruptions.

2.3.1. Farmer knowledge and practices

This involves assessing the farmer's understanding of agroecological principles and their ability to implement them (Escobar et al., 2019; Mapfumo et al., 2022). The transition requires farmers to improve their skills to develop human talent and social capital.The implementation of agroecological principles and practices by farmers serves as a crucial measure of the conversion process's effectiveness (Segnon et al., 2015). Farmers' knowledge of agroecological principles (how well they understand ecological ideas and practices), their use of certain techniques (how fully they have adopted agroecological methods), and their participation in training programs (how much they have learned in workshops, field schools, and other learning opportunities) are all indicators. To ensure the tailoring of agroecological techniques to local circumstances and farmer requirements, a collaborative method for knowledge creation and sharing is essential. The strength of farmer networks and joint initiatives significantly influences the implementation and expansion of agroecological practices. Participation in farmer groups (looking at how many and how active the groups are), cooperatives (looking at how cooperatives provide inputs, market goods, and share information), and knowledge-sharing networks (looking at how farmers share data and work together) are some of the indicators (Isaac et al., 2021). Robust social networks can improve the spread of information, enable cooperative efforts, and encourage innovation.

2.3.2. Community engagement and food sovereignty

This considers the farm's contribution to local food security and its role in empowering communities (Villavicencio-Valdez et al., 2023). Agroecology promotes food sovereignty and regenerates ecosystem functions (Saenz-Lituma, 2025). Local communities' participation in decision-making concerning agroecological transition is crucial for fostering local ownership and long-term sustainability. Signs include how involved communities are in planning (seeing how they help set goals and strategies), putting agroecological practices into action (seeing how involved communities are in using these practices), and keeping an eye on agroecological projects (seeing how involved communities are in judging the success of the transition) (Johansson et al., 2023). Participatory governance frameworks can boost local ownership, foster social learning, and guarantee that the transition is fair and sustainable.

2.3.3. Equity and social justice

Equitable distribution of benefits and resources among farmers and communities is an essential social standard. Indicators include income distribution (looking at how much money different farmers and social groups make), resource access (looking at how easy it is to get land, credit, markets, and technology), and the empowerment of disadvantaged groups (looking at how much the transition has helped women, indigenous communities, and other underrepresented groups) (Johansson et al., 2023).This evaluates the farming system's fairness and inclusivity, guaranteeing an equitable distribution of benefits (Gliessman & Ferguson, 2020). Agroecology emphasizes equity, participation, democracy, and social justice (Gliessman & Ferguson, 2020). The transition to agroecology should focus on enhancing the well-being of all farmers and fostering social equity within the community.

2.3.4. Social networks and collaboration

This examines farmers' participation in networks and their ability to collaborate with other farmers and stakeholders (McGreevy et al., 2021; Surchat et al., 2021). Amplification of agroecological practices relies on social organization and network participation (McGreevy et al., 2021). Before using agroecological farming systems, it's important to make sure that the ways to improve soil health, biodiversity, pest control, and overall resilience are both effective and long-lasting. The table 1 lists necessary standards, metrics, and illustrations for evaluating the effectiveness of agroecological conversion. Farmers and academics may monitor the advancement of sustainable agriculture methods by looking at elements including biodiversity, soil fertility, water management, and economic viability. These metrics shed light on the environmental and financial benefits of agroecology and point the way for future efforts to promote environmental responsibility and resilience in farming systems.

Table 1. Criteria, indicators, and examples for evaluating agroecological conversion

Criteria	Indicators	Examples
Environmental Aspects		
Biodiversity	-Number of crop species and varieties -Abundance of pollinators, beneficial insects, and birds -Presence of natural pests & predators	-Intercropping maize and legumes with flowering plants along the field borders can naturally attract pollinators and reduce pests (Wezel et al., 2014) -Increased population of lady bugs and lacewings in the farm ecosystem
Soil health and fertility	-Soil organic carbon content -Presence of soil fauna (e.g. earth worms) -Water holding capacity -Soil pH	-Using compost and cover crops leads to darker, richer soil with higher organic matter -Studies have shown that composting improves microbial diversity and soil fertility (Altieri,1996)
Pest and disease management	-Pest and disease incidences -Natural predator population -Improved crop health	-A farm using neem oil or introducing Trichogramma wasps to control fall army worm shows progress in reducing reliance on harmful pesticides (Kumar et al., 2022)
Water management	-Efficiency of irrigation methods -Rain water harvesting capacity	-Adoption of drip irrigation in vegetable farming to save water -Farmers switching from flood irrigation to drip systems can save up to 60% of water, demonstrating improved water management (Pretty et al., 2006)
Greenhouse gas emissions	-Carbon sequestration in soil, methane emissions, nitrous oxide emissions	-Implementing cover cropping and reduced tillage practices to enhance carbon sequestration and reduce emissions (Bux et al., 2022)
Economic aspects		
Reduction of input costs	-Costs of fertilizers, pesticides, seeds, and veterinary drugs, expressed as a percentage of total farm expenses or per unit of production.	-Reducing expenditure on chemical fertilizers by adopting the organic composting method -Transition to neem oil and bio-pesticides for pest control instead of synthetic insecticides -Test results show lower nitrate levels in nearby streams after reducing synthetic fertilizers
Market assess & pricing	-Availability of organic certification -Accesses to fair markets for agroecological products	-Group certification in Ilam facilitates organic tea exports, supporting local farmers (Pokhrel &Thapa, 2007) -Value addition, such as producing organic ginger powder, enhances farmer incomes (Altieri & Nicholls, 2020)
Economic resilience	-Cost-benefit ratio of farming activities. -Increase in diversifications of income sources, debt levels	-Farmer reports lower input costs after replacing synthetic fertilizers with compost. -Transitioning from chemical fertilizers to compost reduces input costs, and selling produce in organic markets fetches premium prices (Altieri & Nicholls, 2020). -Diversifying income through value-added products and agritourism to with stand economic shocks.
Yield and production	-Crop yields (tons per hectare), livestock production (kg of meat, liters of milk), overall farm output (total value of all products produced)	-Achieving slightly lower yields with significant improvements in soil health and reduced environmental impact
Social Aspects		

Farmer knowledge and practices	-Frequency of training sessions attended by farmers -Farmer satisfaction with new practices	-Farmer attends workshops on intercropping and agro forestry techniques -Farmer reports higher satisfaction with reduced pest infestations after adopting crop rotation
Social networks and collaboration	-Participation in farmer groups, cooperatives, and knowledge-sharing networks	-Farmers forming cooperatives to share resources, market products, and exchange knowledge about sustainable practices
Community participation & governance	-Community involvement in planning, implementing, and monitoring agro ecological practices	-Community-led initiatives with collaborative planning and implementation of agro ecological practices
Equity and social justice	-Income distribution, access to resources (land, credit, markets, technology), empowerment of marginalized groups	-Initiatives empowering women and Indigenous communities by providing access to land, credit, and training
Environmental and system aspects		
Energy use and emissions	-Energy use per unit of agricultural output -Carbon sequestration in soil	-Reduce diesel consumption by using solar-powered water pumps -Use green manures like legumes to fix nitrogen and increases oil organic carbon
System resilience	-Stability of yields across seasons -Recovery time after extreme weather events	-Consistent yields were observed even during droughts due to adopting drought-tolerant crops -Quick recovery of farm operations after heavy rainfall due to mulching and contour farming -Seed banks in Jumla region have supported farmers -In growing resilient barley and wheat varieties (Regmi & Bhandari, 2020)
Ecosystem services	-Pollinator activity and diversity -Natural pest control	-Increase in native bee activity due to planting flowering cover crops -Predatory birds nesting near the farm and -Controlling rodent populations

3. Scaling up agro-ecological approaches in Nepal

Nepal is highly vulnerable to climate change (Sinisalo et al., 2024; Thorn, 2019) and faces significant challenges in its agricultural sector. Expanding agroecological methods is a viable strategy to improve rural lives, food security, and climate resilience. Expanding agroecological methods requires a diversified approach that takes into account several variables, including political, social, and economic ones. Numerous studies demonstrate agroecology's potential in Nepal. According to Tiwari et al. (2023), the advantages of organic farming for biodiversity, soil health, and resource conservation underscore its significance as a sustainable agricultural approach. It also looks at some of the things that are added to organic farming to make it better (Tiwari et al., 2023): Jholmol, charcoal, Panchagavya, Jeevamrut, Bijamrita, Vermin-compost, and Vermin-wash. However, some obstacles stand in the way of the broad adoption of organic farming, such as low yields compared to conventional farming. Expanding agroecology in Nepal requires a comprehensive strategy that takes into account ecological, economic, and social factors. The key to success is to combine good environmental principles with realistic economic viability and social fairness concerns that are specific to Nepal's wide range of sociocultural environments and agro-ecological zones. Scaling up agroecological practices in Nepal involves expanding adoption while addressing local challenges.

3.1. Agroecology practices/initiatives in Nepal

Nepal is actively promoting agroecology through government initiatives and civil society organization (CSO) efforts. These initiatives aim to enhance sustainable farming, environmental conservation, food security, and community resilience. Nepal is pursuing a multifaceted approach to agroecology, combining top-down policy support with bottom-up community-based initiatives. This integrated strategy aims to create more sustainable, resilient, and equitable agricultural systems.

3.1.1. Government initiatives

Policy and legal framework. The Right to Food and Food Sovereignty Act (2018) provides a policy foundation for agroecology by emphasizing sustainable food systems, traditional farming practices, and indigenous seeds. It prioritizes vulnerable groups (smallholder farmers, marginalized communities, women, Indigenous groups, and Dalits), ensures access to resources (land, water, seeds, and Indigenous knowledge), mandates government implementation at all levels, and promotes sustainable food production through environmentally friendly practices.

Prime minister agriculture modernization project (PMAMP). This project helps agroecology by encouraging organic farming, lowering the use of chemicals, creating pockets of high-value crops, promoting integrated pest management (IPM), soil health management, crop diversification, and giving money to farmers who use organic inputs.

National agro biodiversity policy (2007, updated 2021). This policy emphasizes the conservation and sustainable use of plant genetic resources and links agroecological farming with national food security programs.

Organic agriculture promotion program. This program aims to transition conventional farmers to organic practices through certification systems and financial assistance. It supports sustainable soil fertility management (composting and green manure). Local initiatives like "One Ward, One Organic Farm" establish composting, mixed cropping, and agroforestry demonstration farms. The Karnali Province Organic Agriculture Act aims to make the province fully organic.

Agroforestry promotion. Led by the Department of Forests and Soil Conservation, this initiative integrates forestry with agriculture to enhance biodiversity and soil fertility.

3.1.2. Institutions initiatives

Madan Bhandari University of Science and Technology (MBUST). Madan Bhandari University of Science and Technology (MBUST) is a relatively new university focused on science and technology. It does have postgraduate and Ph.D. programs in organic agriculture that align with agroecology, organic agriculture, and CSA.

Agriculture and Forestry University in Bharatpur (AFUB). Agriculture and Forestry University in Bharatpur (AFUB) is a leading university in Nepal for agricultural education and research. Its strong focus is on agroecology and sustainable agriculture practices, and it offers postgraduate studies in agroecology.

Institute of Agriculture and Animal Science (IAAS). The Institute of Agriculture and Animal Science (IAAS) in Kirtipur offers undergraduate and postgraduate programs in agroecology and conducts research on agro ecological systems and practices.

3.1.3. Civil society organization (CSO) initiatives

International Center for Integrated Mountain Development (ICIMOD). ICIMOD supports agroecology in the Hindu Kush Himalaya (HKH) area, including Nepal. They do this by researching, recording their discoveries, and sharing information through reports and events. ICIMOD also engages in project implementation and field activity. ICIMOD implements projects such as GRAPE, prioritizes youth and gender engagement, and employs community-based approaches. We are actively involved in policy advocacy and capacity building initiatives. They provide support to governments in the development of policies and carry out training programs. Their key focus areas include climate change adaptation, agrobiodiversity conservation, sustainable soil management, and integrated pest management. They achieve this through workshops, research, supporting community seed banks, and providing technical assistance. ICIMOD works at multiple levels, from research to on-the-ground implementation and policy influence, to advance agroecology in the region.

Local Initiatives for Biodiversity, Research and Development (LI-BIRD) & Government collaboration. This partnership focuses on scaling climate-resilient agriculture through farmer field schools (FFS), emphasizing agroecological practices and climate change adaptation strategies. They also work on strengthening seed systems through community seed banks and promoting traditional crop varieties, including Neglected and Underutilized Crops (NUC).

CARE Nepal's LDS-Fill the Nutrition Gap Project. Implemented in Siraha and Saptari districts, this project aims to reduce malnutrition among smallholder and landless women farmers by improving access to nutritious foods and promoting better diets.

It empowers women with access to community land, agricultural training, and support, focusing on home gardens, market access, and transforming harmful social norms around nutrition. Similarly, the CSA project strives to establish gender-responsive, climate-smart villages by implementing climate-smart agriculture practices and advocating for climate-just policies. It will empower marginalized farmers, enhance their adaptive capacities, and integrate their priorities into local policies and plans. The project will contribute to sustainable development and food security in Madhesh Province by fostering climate resilience and reducing greenhouse gas emissions.

Forest and Farm Facility (FFF). Implemented with partners like FAO, IUCN, IIED, and NFGF, this initiative integrates agro-biodiversity and sustainable agriculture into forest-based livelihoods. It provides technical assistance for agroforestry, biofertilizers, participatory guarantee systems (PGS), and crop diversification.

***HASERA Permaculture and Organic Farm*.** This center provides training on permaculture design, organic farming, and agroecological practices. It emphasizes soil health, biodiversity, water management, and sustainable resource use, promoting indigenous knowledge, organic fertilizers, composting, and IPM.

In Nepal, promoting agro-ecological approaches is increasingly acknowledged as an essential strategy for addressing food insecurity, enhancing resilience to climate change, and advancing sustainable agricultural practices. Below are several strategies that can be employed to scale up the adoption of agroecological approaches in Nepal.

1. Knowledge and innovation for sustainable food and agricultural systems. This can manage agroecosystems by supporting food producer organizations, institutions, extension agents, and researchers. This approach aids countries in achieving food security (Paracchini et al., 2020).

2. Promotion of Crop Diversity. Agroecological practices focus on increasing biodiversity through the utilization of a variety of crops. This not only enhances food security but also improves ecosystem resilience. Projects like the Scaling up Climate Resilient Agriculture initiative emphasize low-external-input farming methods that promote crop diversity and sustainable use of agricultural biodiversity (Gautam et al., 2020).

3. Training and capacity building. The need for training and capacity building among farmers, groups, extension staff, service providers, and other stakeholders has been considered an important cross-cutting issue for scaling up the pathway of all CSAs (Gurung et al., 2016). The same applies to promoting agroecological approaches in Nepal since agroecological practices are also looked at in CSAs. Programs like farmer field schools are being introduced to offer practical training in agroecological methods. These initiatives focus on crop rotation, intercropping, and organic pest control offer farmers the abilities required for sustainable agriculture. Additionally, fostering farmer-to-farmer knowledge exchange through networks and cooperatives can amplify the reach and impact of agroecological practices, creating a collaborative learning environment among farming communities (Paudel et al., 2023). Farmers are the key stakeholders in agroecological systems. Building their knowledge and skills ensures agroecological practices. Successful adoption and sustainability. Initiatives such as farmer field schools are being implemented to provide hands-on instruction in agroecological practices. These programs equip farmers with the necessary skills for sustainable farming practices. Agriculture by emphasizing techniques like crop rotation, intercropping, and organic pest control. The adoption of IPM through initiatives like Farmers Field schools has empowered over 99,000 farmers, reducing their dependence on chemical pesticides (GC, 2018).

***4. Building connections for transformative change*.** The initiative is committed to engaging all stakeholders, governments, producers' organizations, consumers, civil society, researchers, and the private sector. We can drive meaningful change by fostering networks and platforms for knowledge exchange and dialogue at national, regional, and international levels. This collaborative approach will enhance cooperation and coordination among UN agencies, ensuring our efforts are impactful and far-reaching (Paracchini et al., 2020).

***5. Policy framework and support*.** The government of Nepal is progressively acknowledging the significance of agroecology and is crafting policies to encourage sustainable farming methods. This involves integrating agro ecological principles into national agricultural policies, thus foster a supportive atmosphere for farmers. Developing and implementing national agro ecology policies, allocating funding for research, education, and extension services, and enhancing the capacity of local governments are crucial steps for advancing agro ecological initiatives. These measures provide the institutional framework and resources needed to support sustainable agricultural practices at a larger scale (Henderson et al., 2016).Developing and implementing policies that prioritize agro ecological practices at the national and local levels. The Nepal government is developing policies to promote sustainable farming practices and is gradually realizing the importance of agroecology. To aid in converting conventional farms, certification mechanisms for fair-trade and organic products should be enhanced to increase market access. The Nepali government could integrate agroecology into its goals for agricultural growth, including the Agriculture Growth Strategy (ADS). By encouraging organic farming, lowering chemical inputs, creating high-value crop pockets and zones, supporting integrated pest management (IPM), managing soil health, encouraging crop diversification, and offering subsidies for organic inputs, vermicompost production, and bio pesticide production, the Prime Minister Agriculture Modernization Project (PMAMP) project promotes agroecology. Through certification programs and financial aid, the organic agricultural support and promotion program seeks to shift conventional farmers in Karnali Province to organic practices. In 2075 BS, the Karnali Province was established as an organic province, and the Organic Agriculture Act seeks to complete the province's organic status. Provide financial support for organic fertilizers, precision irrigation methods, and bio-pesticides.

6. Access to markets for organic products. Initiatives are underway to improve market access for organic goods, including creating certification systems and linking farmers to consumers. Advocating for participatory guarantee systems (PGS) and community supported agriculture (CSA) offer financial benefits by enabling farmers to sell organic products at higher prices.

7. Merging traditional knowledge. Enhancing agro ecological practices in Nepal requires integrating traditional farming knowledge with contemporary methods. This strategy honors local traditions while enhancing agricultural output and sustainability, guaranteeing that the shift is culturally suitable and efficient.

8. Strengthening local seed systems. Local seed systems are vital for preserving biodiversity and ensuring the availability of seeds suited to specific agro-ecological conditions. Community Seed Banks help in protecting indigenous seeds and landraces. Here, farmers can store, exchange, and access traditional seed varieties. Many community seed banks have been established in Nepal to promote biodiversity and save genetic resources. Participatory plant breeding encourages farmers and researchers to collaborate to develop seeds with desirable traits. In the Terai region, community seed banks have maintained rice cultivars that tolerate drought, making them resilient to unpredictable rainfall. Participatory breeding has produced maize cultivars adapted to the local climate in the mid-hills.

9. Promoting diversified farming systems. By replicating natural ecosystems, diversified farming methods promote ecosystem health, lower risks, and enhance resilience. Paddy-wheat systems currently occupy 91.6% of farmed lands, which limits biodiversity (Mandal et al., 2023). Combining trees with crops and livestock enhances soil fertility, provides shade, and diversifies income. Planting different crops together or in succession improves soil health and reduces pest outbreaks. Combining crops, livestock, and aquaculture optimizes resource use and reduces waste. These practices promote a diversified farming system. In the mid-hills, farmers practice agroforestry by integrating fodder trees with crops like millet, improving soil fertility, and providing fodder for livestock. In Terai, integrated rice-fish farming systems enhance productivity by reducing pests and increasing income from fish sales.

10. Participatory research and innovation. Participatory research ensures that agroecological practices are context-specific, practical, and acceptable to farmers. Researchers and farmers collaborate in participatory research, co-designing experiments to test new techniques or crop varieties. Testing agroecological practices directly to evaluate their effectiveness under actual conditions helps innovation. Knowledge-sharing platforms, like forums where farmers, researchers, and policymakers can exchange ideas and results, help in participatory research and innovation. Researchers and farmers can collaborate to test low-cost bio-fertilizers, resulting in improved soil health, and study the effects of traditional pest control methods like neem extracts.

11. Agroforestry systems. Agroforestry in Nepal harmonizes agricultural, environmental, and socioeconomic goals, enhancing soil quality and carbon sequestration (Ghimire et al., 2024).Various systems like agri-silviculture and silvopasture contribute significantly to household income and climate adaptation (Bhattarai et al., 2023). Bhattarai et al. (2023) recommend promoting Non-Timber Forest Products (NTFPs) and periodic tree planting to improve local adaptation strategies.

12. Agrobiodiversity and neglected species. Agrobiodiversity, including neglected and underutilized species (NUS), is vital for food and nutrition security. Strategies like ex-situ and in-situ conservation are employed to preserve these species, which can help achieve several UN Sustainable Development Goals. Investment in research and development is needed to overcome policy constraints and promote NUS.

13. Sustainable agricultural practices. Sustainable soil management and ecological pest control are key adaptive mechanisms against climate change (Panday, 2012). Integrating agriculture with forestry can mobilize local capacities for climate regulation.Emphasizing food sovereignty over food security is crucial for Nepal's agricultural resilience (Panday, 2012).

14. Build market linkages and value chains. Set up weekly farmer markets where customers may purchase agroecological goods directly. Work with eateries, merchants, and export businesses to promote agroecological goods.To boost revenue, teach farmers how to manufacture goods like pickles, jams, or herbal teas. Small cooperatives in the middle hills export organic ginger powder. For example, value addition raises farmer earnings, such as when producing organic ginger powder (Altieri & Nicholls, 2020).

4. Challenges and opportunities in agro-ecological conversion

4.1. Challenges in agro-ecological conversion

4.1.1. Economic viability. The initial conversion costs can be high, and yields may be lower in the early stages (Le et al., 2023). Economic sustainability constraints may limit the extent to which all agroecological elements can be effectively applied (Harkányi & Ujj, 2024).

4.1.2. Market Access. Finding markets for agro ecological products can be challenging, particularly in regions with limited demand for organic or sustainably produced food (Hongsprabhas, 2023; Villavicencio-Valdez et al., 2023).

4.1.3. Knowledge and skills gaps. Farmers may lack the knowledge and skills to implement agroecological practices effectively (Escobar et al., 2019; Mapfumo et al., 2022).

4.1.4. Institutional and policy barriers. Existing agricultural policies and support systems may not favoragroecological practices (Mapfumo et al., 2022; Prasad et al., 2024).

4.1.5. Insufficient investment. Insufficient investments in community-based extension mechanisms and lack of collaboration between state and civil society hinder policy implementation (Prasad et al., 2024).

4.2. Opportunities in agro-ecological conversion

4.2.1. Improved soil health and fertility. Agroecological practices can significantly improve soil health and fertility, leading to long-term productivity gains (Le et al., 2023; Singh et al., 2024).

4.2.2. Enhanced biodiversity and ecosystem services. Agroecological systems support greater biodiversity and provide a range of ecosystem services, such as pest control and pollination (Harkányi & Ujj, 2024).

4.2.3. Increased resilience to climate change. Agroecological systems are often more resilient to climate change impacts, such as drought and extreme weather events.

4.2.4. Improved farmer livelihoods: Agroecological practices can improve farmer livelihoods through increased income, improved food security, and reduced reliance on external inputs (Le et al., 2023).

4.2.5. Strengthened community ties and social capital: Agroecological transitions can strengthen community ties and social capital through collaboration and knowledge sharing (Surchat et al., 2021; Mandal et al., 2023).

5. Concluding remarks: A pathway to sustainable agriculture in Nepal

Transforming traditionally managed farms into agroecological systems in Nepal necessitates an extensive, tailored approach that incorporates ecological, economic, and social factors. Nepal can make big steps toward a more sustainable and resilient agricultural sector (DeLonge et al., 2016) by carefully picking the right criteria and indicators that are tailored to the country's unique agroecological zones and sociocultural settings, using effective scaling strategies, and tackling the problems already talked about. This change requires moving from a production-centered approach to a comprehensive one that considers the interrelationships of environmental, economic, and social elements. More research is needed to improve assessment methods, make agroecological methods fit Nepal's different regions, and look into how long-lasting agroecological changes affect agricultural output, livelihoods, and ecosystem services. Incorporating participatory methods, solid policy backing, and effective market mechanisms will be crucial for securing the sustained success of this change. Ultimately, this achievement relies on equipping Nepalese farmers with the necessary knowledge, resources, and assistance to embrace and modify agroecological practices, thereby creating a more sustainable and just future for the nation.

The conversion of conventional farms to agroecologically-managed farms is a complex process requiring a holistic approach that integrates ecological, social, and economic considerations. While challenges exist, the potential benefits – improved soil heal enhanced biodiversity, increased resilience, and improved farmer livelihoods – make this transition worthwhile. Agroecological ideas and methods need to be used with the right help systems, like training, market access, and rules that encourage change (Surchat et al., 20121; Prasad et al., 2024) for them to work. Anim-Jnr et al. (2023) also say that participatory approaches that use farmers' knowledge and experience are crucial for making sure that the transition works and lasts. Developing robust assessment tools, such as TAPE and ACT, provide valuable frameworks for monitoring and evaluating progress (Costa-Pereira et al., 2024). A continuous learning process involving farmers, researchers, and policymakers is essential to navigate the challenges and unlock the full potential of agroecology (Prasad et al., 2024).

6. Conclusions

Nepal's economy is predominantly reliant on agriculture, distinguished by its diverse climatic conditions and varied topographical features that facilitate many agricultural practices. To effectively address the challenges associated with feeding an expanding population in the future, it is better to shift from industrial agriculture, which often depends excessively on chemicals and causes detrimental effects on the land. An agroecologically based farming system offers a viable strategy for promoting sustainability within the agricultural sector. By following the ideas and methods of agroecology and switching to farming systems that are managed in an agroecological way, we can make farming systems more resistant to climate change while also increasing production and protecting the environment. For agroecosystems to be sustainable and for large-scale production to be possible, it is important to focus on agroecologically managed farming methods. This will help make Nepal's farming sector more resilient.

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