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Contribution Of Eco-Technologies to Sustainable Agriculture and Rural Development in North East India

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Abstract
Eco-technologies include low-input external systems, integrated farming, conservation agriculture, and renewable energy solutions. They are becoming important for sustainable farming and rural development in Northeast India. This area has rich biodiversity, tough terrain, and many smallholder and subsistence farmers. Such technology faces unique challenges, including soil erosion, changing farming practices, and limited access to modern resources. Research indicates that eco-technologies tailored to local conditions, such as integrated farming systems, bio-village models, traditional agroforestry, and organic farming, can substantially enhance crop yields. This technology offers different ways to earn a living. It improves soil fertility and helps with water conservation. It also combines scientific innovations, local knowledge, and supportive policies to construct a more sustainable and stable rural life. It even helps marginalized groups, including youth and women. However, there are several challenges to using these technologies. These challenges include providing proper access and addressing institutional and socio-economic barriers. This technology is essential for sustainable farming and rural development in the northeastern states of India. These tools increase crop yields, save natural resources, help rural communities, and improve farmers' livelihoods. They also lower environmental impact. This paper examines how eco-technologies support sustainable farming and rural development, foster strong livelihoods, protect the environment, and promote inclusive growth for rural communities in Northeast India.

Keywords: *Eco-technologies, rural livelihoods, Sustainable livelihood, North East, technologies, JEL Classification : A14,J24,O18,P25,Q15*

1. Introduction

Eco-technology, or green technology, focuses on new ideas and solutions that reduce harmful environmental effects and improve resource use. Eco-technology includes many improvements meant to make human activities more sustainable. These innovations aim to lessen environmental damage and make better use of resources. It plays an important role in tackling global issues like waste management and climate change. At the same time, it supports sustainable economic growth. Its goal is to reduce pollution, conserve resources, and minimize waste during the entire life cycle of products and services. It encourages the practical usage of energy, water, and raw materials by locking material loops and promoting the recycling and reuse of materials. Eco technology aims to support sustainable development by integrating

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environmental considerations into products, processes, and systems. It can be technological, such as new devices, materials, or methods. It can also be about organization, such as new management systems. Lastly, it can involve systems, meaning changes in how products and services are delivered. Sustainable rural and agricultural development in North East India (NEI) is influenced by the area's unique geography, rich biodiversity, and varied indigenous cultures. The area is known for its traditional farming methods, like shifting cultivation, which is also called jhum. This practice is important for local livelihoods and culture. However, it faces growing criticism because of worries about soil degradation, deforestation, and reduced productivity (Montagnini, 1992; Bhardwaj, 2024; Ray et al., 2021). Current studies show the benefits of combining indigenous knowledge with modern eco-technologies and policy efforts to promote sustainable practices, improve rural living conditions, and protect natural resources (Jeengaph, 2023; Samal et al., 2016; Sanjay-Swami, 2021; Das et al., 2021). The transition from shifting cultivation to more sustainable methods, such as agroforestry, integrated farming systems, and organic agriculture, has guaranteed to improve productivity, boost income, and improve ecological resilience (Ray et al., 2019; Paul et al., 2020; Das et al., 2019; Chatterjee et al., 2021). However, challenges exist which include small landholdings, poor infrastructure, limited market access, and the impacts of climate change (Jain et al., 2022; Bhalerao et al., 2021; Ghosal & Gangabhusha, 2024; Patra & Babu, 2020). Gender dynamics, youth empowerment, and community participation are recognized as important factors for successful rural development (Tamang & Yadav, 2024; Varkey et al., 2024; Baishya et al., 2021). Overall, the literature highlights the need for participatory,context-specific, and inclusive strategies to achieve sustainable agriculture and rural development in north-east India (Bani et al., 2022; Bharadwaj et al., 2024; Ghosh et al., 2010; Upadhaya et al., 2020; Athawale, 2023).Eco-technologies improve environmental sustainability and help with food security, reduce poverty, and empower marginalized groups, including women and youth (Samal et al., 2016; Sen & Sinha, 2008; Borgohain, 2020; Bani et al., 2022). However, adoption is often blocked by social, economic, and policy issues. This shows that we need strategies designed for specific situations and support from institutions (Borgohain, 2020; Mathur & Bhattacharya, 2023; Das et al., 2021). The literature generally indicates that eco-technologies are important for reaching sustainable rural development and agricultural resilience in Northeast India. This review synthesizes the current state of research on eco-technologies in Northeast India, highlighting both the successes and ongoing challenges in achieving sustainable agriculture and rural development.

2. Can eco-technologies contribute to sustainable agriculture and rural development?

Eco-technologies, which include digital, green, and resource-efficient innovations, are essential for creating sustainable agriculture and improving rural areas. The goal is to reduce environmental impacts, make better usage of resources, and promote economic growth in rural regions. This technology can also enhance the sustainability and resilience of agriculture.

➢ Fundamental Contributions of Eco-Technologies

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Contribution Area	Example Technologies/Practices	Impact on Sustainability & Rural Development	Citations
Resource Efficiency & Pollution Control	Precision agriculture, circular economy, eco-industrial chains	Reduces fertilizer/pesticide use, controls pollution, optimizes resource cycles	(Sierov, 2024; Liu et al., 2023; Pathak, 2024; Saikanth et al., 2024; Wang et al., 2022)
Renewable Energy & Energy Conservation	Solar-powered irrigation, biogas, wind energy	Lowers energy costs, reduces greenhouse gas emissions, supports rural energy access	(Pathak, 2024; Tejaskumar & Manish, 2012; Ghadiyali & Kayasth, 2012)
Digital & Smart Farming	IoT, AI, blockchain, digital platforms	Enhances decision-making, market access, and financial inclusion for rural communities	(Saikanth et al., 2024; Che et al., 2024; Balayev & Mirzayev, 2022; Koutridi & Christopoulou, 2023)
Eco-Friendly Farming Practices	Organic farming, integrated pest management, microbiota use	Maintains soil health, biodiversity, and long-term productivity	(Sharma & Kanta, 2021; Tejaskumar & Manish, 2012; Manimozhi & Gayathri, 2012)
Socio-Economic Benefits	Community engagement, rural innovation, women's empowerment	Promotes self-reliance, poverty reduction, and inclusive growth	(Nasution et al., 2025; Bhatt et al., 2022; Kitchen & Marsden, 2009)

➢ Challenges and Considerations

Barriers: High initial costs, lack of awareness, insufficient policy support, and digital divides can limit adoption, especially among smallholders and in less developed regions (Sierov, 2024; Koutridi & Christopoulou, 2023; Che et al., 2024; Balayev & Mirzayev, 2022).

Policy Needs: Effective strategies include state support, investment in R&D, training, and fostering collaboration among stakeholders (Sierov, 2024; Chaparro-Banegas et al., 2024; Koutridi & Christopoulou, 2023).

Eco-technologies play a crucial role in making agriculture more sustainable and supporting rural development. Utilizing these technologies enables environmental protection, promotes economic growth, and stimulates stronger rural communities. However, Success depends on tackling challenges with supportive policies, investment, and education.

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3. Literature Review

A comprehensive literature review was conducted using Consensus, which aggregates over 170 million research papers from databases such as Semantic Scholar and PubMed. The search strategy involved 21 targeted queries across seven thematic groups, focusing on eco-technologies, sustainable agriculture, rural development, indigenous knowledge, and related policy and implementation challenges in North East India. In total, 1,045 papers were identified, 582 were screened, 431 were deemed eligible, and the 50 most relevant and high-quality papers were included in this review.

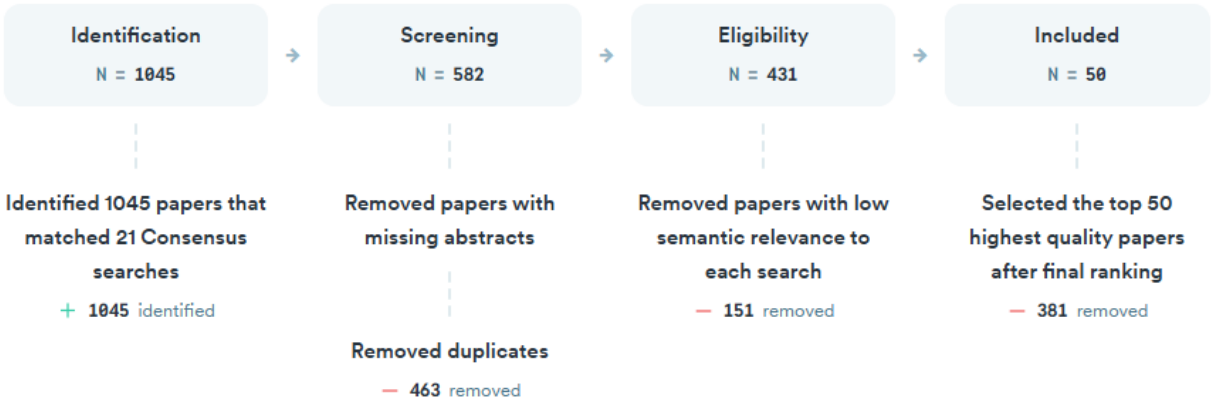

Figure 1: Flow diagram of the literature search and selection procedure

Twenty-one unique searches were conducted, systematically covering eco-technologies, sustainability, and rural development in Northeast India.

➢ Results

★ Types and Attributes of Eco-Technologies

The literature identifies a range of eco-technologies suited to North East India, including integrated farming systems, conservation agriculture, agroforestry, renewable energy (solar, biogas), vermicomposting, and the usage of indigenous technical knowledge (ITK) (Samal et al., 2016; Ray et al., 2019; Yadav et al., 2021; Bani et al., 2022; Ghosh et al., 2010; Balusamy et al., 2025; Layek et al., 2015; Saha et al., 2024; Saha et al., 2010; Arunachalam et al., 2013). These technologies are usually low-cost and use resources efficiently. They are also suited to the region's different agro-ecological zones.

★ Impacts on Livelihoods and Agricultural Productivity

Adoption of eco-technologies has guided to measurable improvements in crop yields, income diversification, soil health, and employment opportunities. For example, integrated farming systems and rainwater harvesting increased cereal yields by 29%, oilseeds by 40.7%, and vegetables by 298%, while also boosting net income and employment (Ray et al., 2019). Conservation agriculture and agroforestry can restore soil organic carbon, reduce erosion, and support biodiversity (Yadav et al., 2021; Bani et al., 2022; Ghosh et al., 2010; Saha et al., 2010).Renewable energy solutions like micro solar systems and solar dryers improve rural

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electrification and post-harvest value, while also supporting livelihoods (Aggarwal et al., 2022; Dhiman et al., 2017; Thakur et al., 2022; Kumar et al., 2023; Chel & Kaushik, 2011).

★ Environmental and Social Benefits

Eco-technologies help the environment by reducing chemical use, saving water, and supporting biodiversity. Traditional and indigenous methods, like jhum agroforestry and ITK-based soil conservation, effectively maintain ecosystem services and preserve cultural heritage (Sanjay-Swami, 2021; Bani et al., 2022; Balusamy et al., 2025; Das et al., 2021; Saha et al., 2024; Mylliemngap, 2021; Pandey et al., 2024). Socially, these technologies enable women and youth, encourage community participation, and help reduce poverty (Samal et al., 2016; Sen & Sinha, 2008; Borgohain, 2020; Das et al., 2021; Rana et al., 2024).

★ Barriers, Challenges, and Policy Context

Despite the clear benefits, barriers to the widespread use of eco-technologies include limited awareness, a deficiency of institutional support, gaps in infrastructure, and the need for changes specific to different contexts (Borgohain, 2020; Suji, 2019; Rakholia et al., 2024; Priyadarshini & Abhilash, 2020; Paul et al., 2023). Policymakers point out the necessity to improve extension services and to support value chains and market access also emphasize the significance of incorporating eco-technologies into wider rural development strategies (Borgohain, 2020; Rakholia et al., 2024; Priyadarshini & Abhilash, 2020; Chaudhuri et al., 2020; Tanti et al., 2022).

Key Papers

Paper	Methodology	Focus Area	Key Results	Year
(Ray et al., 2019)	Action research, field trials	Integrated farming, rainwater harvesting	Yield increases (cereals +29%, vegetables +298%), higher income, improved soil health	2019
(Samal et al., 2016)	Review, case studies	Low-cost eco-technologies, shifting cultivation	Improved crop yields, entrepreneurship for youth, pro-poor and pro-nature approaches	2016
(Yadav et al., 2021)	Review, synthesis	Conservation agriculture	Soil health restoration, erosion control, and increased cropping intensity	2021

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(Bani et al., 2022)	Field survey	Traditional agroforestry	70–80% decline in jhum, improved socio-economic and ecological outcomes	2022
(Ghosh et al., 2010)	Long-term field study	Conservation tillage, residue management	49% higher yield, improved soil carbon, and cost-effective double cropping	2010

Figure 2: Comparison of key studies on eco-technologies for sustainable agriculture and rural development in North East India.

The literature shows that eco-technologies benefit sustainable agriculture and rural development in North East India. They improve productivity, livelihoods, and environmental sustainability. However, successful scaling and long-term impact need adaption to institutional support, local conditions, and integration with broader development policies. The evidence clearly supports the positive effects of eco-technologies on sustainable agriculture and rural development in North East India. High-quality field studies and reviews demonstrate that integrated, low-input, and locally adapted technologies can significantly enhance productivity, income, and environmental outcomes (Samal et al., 2016; Ray et al., 2019; Yadav et al., 2021; Bani et al., 2022; Ghosh et al., 2010; Layek et al., 2015; Saha et al., 2024; Saha et al., 2010). The integration of indigenous knowledge and community participation is a recurring theme, highlighting the importance of context-specific solutions (Sanjay-Swami, 2021; Balusamy et al., 2025; Das et al., 2021; Saha et al., 2024; Mylliemngap, 2021; Pandey et al., 2024). However, the literature also highlights ongoing challenges, including infrastructure limitations, knowledge gaps, and the need for supportive policies and institutional frameworks (Borgohain, 2020; Suji, 2019; Rakholia et al., 2024; Priyadarshini & Abhilash, 2020; Paul et al., 2023). While the benefits are clear, expanding these technologies needs focused actions, skill development, and policies that match local conditions.

4. Claims and Evidence Table

Claim	Evidence Strength	Reasoning	Papers
Eco-technologies improve agricultural productivity and rural livelihoods in NE India	Evidence strength: Strong (9/10)	Multiple field studies show significant yield and income gains with integrated, low-cost, and locally adapted technologies.	(Samal et al., 2016; Ray et al., 2019; Yadav et al., 2021; Bani et al., 2022; Ghosh et al., 2010; Layek et al., 2015; Saha et al., 2024; Saha et al., 2010)

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Conservation agriculture and agroforestry enhance soil health and biodiversity	Evidence strength: Strong (8/10)	Long-term studies and reviews document improved soil carbon, reduced erosion, and increased biodiversity.	(Yadav et al., 2021; Bani et al., 2022; Ghosh et al., 2010; Saha et al., 2010; Mylliemngap, 2021)
Indigenous knowledge and traditional practices are practical for sustainable resource management	Evidence strength: Moderate (7/10)	Surveys and case studies highlight the role of ITK in soil and water conservation, as well as ecosystem services.	(Sanjay-Swami, 2021; Balusamy et al., 2025; Das et al., 2021; Saha et al., 2024; Mylliemngap, 2021; Pandey et al., 2024)
Renewable energy solutions support rural development and post-harvest value addition	Evidence strength: Moderate (7/10)	Studies on solar dryers, micro solar systems, and biogas show improved energy access and income.	(Aggarwal et al., 2022; Dhiman et al., 2017; Thakur et al., 2022; Kumar et al., 2023; Chel & Kaushik, 2011)
Barriers to adoption include knowledge gaps, lack of institutional support, and infrastructural deficits	Evidence strength: Moderate (6/10)	Reviews and policy analyses identify persistent challenges to scaling up eco-technologies.	(Borgohain, 2020; Suji, 2019; Rakholia et al., 2024; Priyadarshini & Abhilash, 2020; Paul et al., 2023)
Eco-technologies alone cannot address all rural development challenges without supportive policy and market interventions	Evidence strength: Moderate (5/10)	Some studies note that technology adoption must be integrated with broader development strategies.	(Borgohain, 2020; Rakholia et al., 2024; Priyadarshini & Abhilash, 2020; Chaudhuri et al., 2020; Tanti et al., 2022)

Figure 3: Key claims and support evidence identified in these papers

5. Future Research Scope

Future research should focus on scaling up eco-technologies, evaluating their long-term impacts, and integrating modern and traditional approaches to promote inclusive rural development.

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Question	Why
How can eco-technologies be scaled up sustainably among smallholder farmers in the diverse hill ecosystems of Northeast India?	Scaling up is essential for regional impact, but requires an understanding of local barriers, incentives, and support systems.
What are the long-term socio-economic and environmental impacts of integrating indigenous knowledge with modern eco-technologies?	Long-term studies are necessary to evaluate the sustainability, resilience, and cultural preservation outcomes.
How can policy and market interventions be optimized to support inclusive adoption of eco-technologies, especially for women and youth?	Inclusive development depends on targeted policies and market access, which remain under-researched for marginalized groups.

Figure 4: Research questions for future introspections on eco-technologies in North East India

In summary, eco-technologies offer clear benefits for sustainable farming and rural development in Northeast India. However, more research and policy support are necessary to improve their impact and inclusivity.

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