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Promoting Sustainable Farming Practices among Smallholders

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ABSTRACT

Nepal's agricultural sector faces critical challenges due to climate change, soil degradation, and fragmented land holdings, threatening food security and rural livelihoods. This study examines sustainable farming practices among smallholder farmers in Nepal, focusing on climate-smart agriculture, agroforestry systems, and participatory approaches. Through comprehensive literature review and analysis of recent interventions, the research identifies key barriers including limited financial resources, weak institutional frameworks, and inadequate market access. Findings reveal that integrated approaches combining organic farming, water conservation technologies, and agroforestry can increase productivity by 20-36% while improving environmental sustainability. The study emphasizes the importance of participatory implementation strategies, gender-inclusive policies, and strengthened coordination among stakeholders. Recommendations include enhanced technical capacity building, improved extension services, and development of climate-resilient value chains to ensure long-term agricultural sustainability and food security.

INTRODUCTION

Nepal's agricultural sector serves as the backbone of the national economy, contributing approximately one-third of the gross domestic product and employing over 66% of the population (Khatri-Chhetri et al., 2024). The predominance of smallholder farming systems, characterized by fragmented landholdings averaging less than 0.7 hectares, presents unique challenges and opportunities for sustainable agricultural development (Ghimire et al., 2024). These small-scale farmers operate within diverse agro-ecological zones ranging from the Terai plains to high-altitude mountain regions, each presenting distinct environmental conditions and agricultural practices. Climate change has emerged as one of (Muhsyanur, 2023) the most pressing threats to agricultural productivity in Nepal, with projections indicating rapid increases in air temperature, erratic rainfall patterns, and heightened frequency of extreme weather events (Khanal & Thapa, 2023). These climatic shifts are expected to significantly impact crop yields, with rain-fed maize production projected to decline by 3.3-6.4% by 2030 and 5.2-12.2% by 2050 under current cultivation practices (Khatri-Chhetri et al., 2024).

The vulnerability of Nepalese agriculture to climate change is compounded by several interconnected factors. Conventional farming methods have led to widespread soil degradation, reduced biodiversity, and depletion of soil organic matter, undermining long-term agricultural sustainability (Regmi & Neupane, 2023). Furthermore, the increasing trend of rural-to-urban migration, particularly among youth, has resulted in labor shortages and the feminization of agriculture, placing additional (Muhsyanur et al., 2021) burdens on women farmers who often lack adequate resources and decision-making power (Khatri-Chhetri et al., 2020). The abandonment of traditional agricultural knowledge and practices, coupled with overreliance on chemical inputs, has created a cycle of environmental degradation and reduced farm productivity (Subedi et al., 2022).

Sustainable farming practices offer a promising pathway to address these multifaceted challenges while improving food security and rural livelihoods. Recent research demonstrates that sustainable intensification of mixed farming systems can produce 20-30% higher yields compared to traditional methods while simultaneously reducing environmental impacts (Neupane, 2023). Climate-smart agriculture (CSA) has emerged as a comprehensive framework integrating productivity enhancement, climate resilience, and greenhouse gas emission reduction, aligning with Nepal's Nationally Determined Contributions and Agriculture Development Strategy (World Bank, 2021). Agroforestry systems, traditionally practiced in many regions of Nepal, have shown particular promise in enhancing biodiversity conservation, improving soil fertility, and providing diverse income sources for smallholder farmers (Ghimire et al., 2024).

The implementation of sustainable farming practices in Nepal faces numerous barriers that must be systematically addressed. Limited access to financial resources constrains farmers' ability to invest in improved seeds, equipment, and sustainable

technologies (Khatri-Chhetri et al., 2024). Weak institutional frameworks, fragmented coordination among government agencies, and insufficient extension services hinder the scaling of proven sustainable practices from pilot projects to broader adoption (Timsina, 2023). Market-related challenges, including price volatility, lack of market guarantee, and limited access to value-added opportunities, further discourage farmers from transitioning to sustainable production systems (Swiss Contact, 2023). Additionally, socio-cultural factors, including gender inequalities and insufficient recognition of women's roles in agriculture, impede the inclusive implementation of sustainable farming interventions (Khatri-Chhetri et al., 2020).

Despite these challenges, Nepal presents significant opportunities for sustainable agricultural transformation. The country's rich biodiversity and diverse agro-climatic zones provide a foundation for implementing varied sustainable practices tailored to local conditions (Regmi & Neupane, 2023). Growing global demand for organic products offers market incentives for Nepalese farmers to adopt sustainable production methods (Ghimire et al., 2024). Recent policy developments, including the introduction of Good Agricultural Practices (GAP) in 2018 and the formulation of Climate-Smart Agriculture Investment Plan, demonstrate government commitment to sustainable agricultural development (Adhikari et al., 2022). Furthermore, successful pilot projects and community-based initiatives have generated valuable evidence on effective approaches for promoting sustainable farming among smallholders (Khanal & Thapa, 2023).

This study aims to comprehensively examine the promotion of sustainable farming practices among smallholder farmers in Nepal, analyzing current implementation strategies, identifying key barriers and enablers, and proposing pathways for scaling sustainable agriculture. Through synthesis of recent research and practical experiences, this paper contributes to understanding how sustainable farming practices can be effectively promoted to enhance agricultural productivity, environmental sustainability, and rural livelihoods in Nepal's diverse agricultural landscapes. The findings provide actionable insights for policymakers, development practitioners, and farming communities working toward a more resilient and sustainable agricultural future (Khatri-Chhetri et al., 2024; Ghimire et al., 2024; Regmi & Neupane, 2023).

METHOD

This research employed a comprehensive literature review methodology to examine sustainable farming practices among smallholder farmers in Nepal. The study systematically analyzed peer-reviewed journal articles, policy documents, and project reports published between 2020 and 2024, focusing on climate-smart agriculture, agroforestry systems, organic farming, and participatory approaches in Nepalese agricultural contexts. Following established systematic review protocols, the search strategy utilized multiple academic databases including Web of Science, Scopus, and Google Scholar, with specific keywords such as "sustainable agriculture

Nepal," "smallholder farmers," "climate-smart agriculture," and "agroforestry practices" (Khatri-Chhetri et al., 2024). The inclusion criteria prioritized empirical studies conducted in Nepal, recent policy analyses, and international research with direct relevance to Nepalese agricultural systems, ensuring contemporary and contextually appropriate evidence.

The analytical framework adopted an integrative approach, synthesizing findings across multiple dimensions including technical practices, socio-economic impacts, institutional factors, and policy environments. Data extraction focused on key themes such as adoption rates of sustainable practices, productivity impacts, economic benefits, implementation challenges, and success factors for scaling interventions (Ghimire et al., 2024). The study incorporated comparative analysis across different agro-ecological zones, examining how sustainable farming practices perform under varying environmental conditions and socio-economic contexts within Nepal. Quality assessment of included studies considered methodological rigor, sample size, data collection methods, and relevance to smallholder farming systems, ensuring the reliability of synthesized findings (Regmi & Neupane, 2023). This methodological approach enabled comprehensive understanding of current knowledge on sustainable farming promotion in Nepal while identifying critical research gaps requiring further investigation (Khanal & Thapa, 2023).

RESULT AND DISCUSSION

Climate-Smart Agriculture Adoption and Impact

Climate-smart agriculture has emerged as a transformative approach for smallholder farmers in Nepal, demonstrating significant potential for enhancing productivity while building resilience to climate variability. Recent cost-benefit analyses reveal that most CSA practices generate positive economic returns, with benefit-cost ratios exceeding 1.0 for technologies including improved irrigation systems, organic fertilizer application, and climate-resilient crop varieties (Khatri-Chhetri et al., 2024). The adoption of nutrient-supply technologies in rice cultivation has yielded productivity increases of up to 83%, while irrigation-related CSA practices in winter maize production have shown 23% yield improvements alongside enhanced growth parameters (Khatri-Chhetri et al., 2024). These findings underscore the dual benefits of CSA in addressing both climate adaptation and food security objectives.

The implementation of CSA practices across Nepal's diverse agro-ecological zones has revealed varying patterns of adoption and effectiveness. In the Gandaki River Basin, farmers cultivating rice, wheat, and maize under CSA protocols achieved notable improvements in net present value and internal rates of return, though solar water management systems for maize demonstrated lower profitability with only 6% IRR and extended payback periods (Khatri-Chhetri et al., 2024). The Climate-Smart Village approach, piloted in multiple districts, has successfully increased farmer awareness and adoption of technologies including biopesticides, water harvesting systems, and early-maturing crop varieties (Khatri-Chhetri et al.,

2022). However, scaling these innovations beyond pilot sites remains challenging due to institutional fragmentation and limited coordination among implementing agencies (Khatri-Chhetri et al., 2022).

Gender dimensions of CSA adoption reveal important equity considerations. Research demonstrates that CSA practices can significantly reduce women farmers' drudgery in high climatic risk areas, though women often face additional barriers to accessing information, inputs, and decision-making authority (Khatri-Chhetri et al., 2020). The feminization of agriculture, driven by male out-migration, necessitates development of women-friendly and elderly-friendly farming practices within CSA frameworks (Neupane, 2023). Successful interventions have emphasized participatory approaches engaging women in technology selection, training, and implementation, resulting in higher adoption rates and sustained practice use (Swiss Contact, 2023) and (Muhsyanur et.al, 2025).

Market linkages play a crucial role in sustaining CSA adoption among smallholder farmers. Evidence from the Commercial Agriculture for Smallholder and Agribusiness project demonstrates that market guarantee significantly drives technology uptake, with 60% of participating farmers adopting mulching or tunnel farming and 25% implementing drip irrigation when assured of reliable produce buyers (Swiss Contact, 2023). This demand-driven approach has enabled productivity increases averaging 27%, demonstrating how integrated value chain development complements technical interventions (Swiss Contact, 2023). The integration of digital technologies, including mobile platforms, weather forecasting systems, and market information services, offers additional pathways for enhancing CSA effectiveness and farmer decision-making capabilities (CIMMYT, 2024).

Policy and institutional support systems remain critical determinants of CSA scaling success. Nepal's Climate-Smart Agriculture Investment Plan identifies feasible, practical, and profitable investments for lifting the agricultural sector to higher growth levels while reducing vulnerability (World Bank, 2021). However, implementation requires strengthened coordination mechanisms, enhanced capacity at provincial and local government levels, and sustained financial commitments aligned with federal policy frameworks (World Bank, 2021). The transition to federal governance structures presents both opportunities and challenges for CSA mainstreaming, necessitating development of provincial and local agricultural policies that integrate climate-smart principles while addressing location-specific constraints and opportunities (Timsina, 2023).

Agroforestry Systems for Sustainable Production

Agroforestry systems represent a well-established sustainable farming practice in Nepal, offering multiple benefits for smallholder farmers including enhanced biodiversity, improved soil fertility, and diversified income sources. Traditional agroforestry practices such as home gardens and community forests have contributed substantially to local food security, providing 20% greater dietary diversity compared to commercial monoculture systems (Ghimire et al., 2024). These

integrated systems generate diverse products from compact land areas, including timber, fuelwood, fodder, fruits, and vegetables, meeting household subsistence needs while creating market opportunities (Regmi, 2003). Research demonstrates that agroforestry can rejuvenate severely degraded lands by enhancing soil organic matter, water retention capacity, and crop productivity in areas affected by deforestation or intensive monocropping (Kumar et al., 2015).

The climate adaptation benefits of agroforestry are particularly relevant for Nepal's vulnerable agricultural landscapes. Agroforestry systems moderate climate extremes and temperature fluctuations, making them especially suitable for fragile mountain ecosystems and subsistence farming contexts (Mbow et al., 2014). Integration of trees with crops provides shade, reduces evapotranspiration, and creates microclimates favorable for crop growth under changing climate conditions (Ghimire et al., 2024). Moreover, agroforestry contributes to carbon sequestration and greenhouse gas emission reduction, aligning with Nepal's climate mitigation commitments while providing adaptation benefits at farm level (Somarriba et al., 2017). The resilience-building potential of agroforestry positions it as a triple-benefit approach, simultaneously addressing environmental sustainability, economic productivity, and climate adaptation objectives (Hughes et al., 2020).

Socio-economic impacts of agroforestry extend beyond production outcomes to encompass gender equity and household wellbeing. On-farm fuelwood availability reduces women's time burden for firewood collection, allowing greater focus on education, childcare, and income-generating activities, thereby contributing to Sustainable Development Goals 3, 4, and 5 (Kiptot et al., 2014; Sharma et al., 2016). Energy security provided through accessible fuelwood is fundamental for rural communities' nutritional adequacy and food preparation (Sharma et al., 2016). Commercially-oriented agroforestry systems, while potentially generating five times more income than traditional home gardens, often involve trade-offs with dietary diversity and access to medicinal plants (Ghimire et al., 2024). Balancing commercial and subsistence objectives requires careful planning aligned with household priorities and market opportunities.

The Regenerative Agroforestry for Sustainable Farming project exemplifies innovative approaches to scaling agroforestry among scattered smallholder farms. This initiative integrates carbon credit mechanisms, enabling farmers to generate revenue through ecosystem services while adopting regenerative practices (reNature, 2025). Market connections linking farmers to school canteens and organic buyers create stable demand for agroforestry products, addressing price volatility and income uncertainty (reNature, 2025). Educational components build farmer capacity in agroforestry design, species selection, and management practices, fostering long-term sustainability beyond project duration. Such comprehensive approaches combining technical training, market development, and innovative financing demonstrate pathways for agroforestry expansion across Nepal's diverse agricultural landscapes (Muhsyanur, 2024).

Challenges to broader agroforestry adoption include competing land use priorities, limited technical knowledge, and delayed returns on tree investments. Farmers operating very small landholdings may perceive trees as competing with crop production for limited space, despite long-term complementarities (Ghimire et al., 2024). Extension services often lack specialized expertise in agroforestry system design and species-crop combinations appropriate for local conditions (Regmi & Neupane, 2023). The time lag between tree planting and productive benefits can discourage adoption, particularly among resource-constrained farmers requiring immediate returns. Addressing these barriers requires tailored approaches including fast-growing multipurpose tree species, intercropping designs maximizing land use efficiency, and financial mechanisms supporting farmers during establishment phases (reNature, 2025).

Good Agricultural Practices and Organic Farming

Good Agricultural Practices (GAP) represent a comprehensive framework for sustainable farming, addressing food safety, environmental sustainability, and economic viability. Since GAP's introduction in Nepal in 2018, research demonstrates its potential to increase crop yields by up to 36%, reduce agrochemical use by 31%, and enhance soil organic matter from 3.32% to 3.77% (Adhikari et al., 2022). These outcomes align with multiple sustainability objectives, improving productivity while reducing environmental externalities associated with intensive chemical use. Farmer income improvements exceeding 100% in some cases highlight GAP's economic viability when properly implemented with appropriate market linkages (Adhikari et al., 2022). However, broader GAP adoption faces barriers across production, extension, regulatory, and market domains requiring systematic interventions.

Organic farming offers particular promise for Nepal's agricultural sustainability, given projected climate change impacts and the need for environmentally sound production systems. Modeling studies using EcoCrop assessments identify beans, colocasia, garlic, local radish, and finger millet as highly suitable crops for organic production under both current and 2050 climate scenarios (Svobodová et al., 2024). These climate-resilient crops align with traditional farming knowledge while offering adaptation pathways for smallholder farmers facing climatic uncertainties. Organic farming enhances environmental protection through reduced chemical pollution, improved soil health, and biodiversity conservation, contributing positively to climate change mitigation and adaptation objectives (Svobodová et al., 2024). Growing global demand for organic products presents market opportunities for Nepalese farmers, though accessing premium markets requires certification systems, quality assurance, and value chain development (Regmi & Neupane, 2023).

Soil fertility management constitutes a critical component of sustainable organic farming systems. Traditional practices utilizing farmyard manure and compost have demonstrated effectiveness in maintaining soil organic carbon

contents, though quality and application methods significantly influence outcomes (Gurung et al., 2015). Research shows that improved management of farmyard manure quality enhances soil organic matter accumulation in Middle Hills farming systems, contributing to long-term soil productivity (Gurung et al., 2015). Integration of leguminous cover crops, crop rotation, and green manures provides nitrogen inputs while improving soil structure and biological activity (Regmi & Neupane, 2023). However, many smallholder farmers face challenges accessing sufficient organic inputs due to limited livestock holdings and competing uses for crop residues and manure (Santalia et al., 2025).

Integrated nutrient management combining organic and minimal inorganic inputs offers pragmatic pathways for transitioning toward more sustainable production systems. The 4R principle—applying the right nutrient source at the appropriate rate, time, and location—optimizes nutrient use efficiency while minimizing environmental impacts (Timsina, 2023). Balanced fertilization techniques address soil nutrient imbalances common in Nepalese farms, improving both productivity and sustainability outcomes. Soil testing and site-specific nutrient recommendations enable farmers to make informed decisions about fertilizer application, reducing wastage and environmental contamination. Extension services promoting integrated nutrient management require strengthened technical capacity and access to soil analysis facilities to support farmer adoption (Mulyana et al., 2021).

Institutional pathways for GAP institutionalization include: technical capacity building through farmer field schools and demonstrations; awareness creation among farmers, consumers, and value chain actors; soil fertility management strategies emphasizing organic inputs; extension program strengthening with specialized GAP training; and market development linking GAP-compliant farmers to premium buyers (Adhikari et al., 2022). Policy support mechanisms including certification systems, quality standards, and financial incentives can accelerate GAP adoption across diverse farming contexts. Public-private partnerships engaging agribusinesses, cooperatives, and farmer organizations in GAP promotion leverage complementary resources and expertise for scaling sustainable practices.

Participatory Approaches and Institutional Frameworks

Table 1. Comparative Analysis of Sustainable Farming Interventions in Nepal

Intervention Type	Key Practices	Productivity Impact	Income Increase	Implementation Barriers	Success Factors
Climate-Smart Agriculture	Improved irrigation, drought-resistant varieties,	20-83% yield increase	Variable by practice	Limited financial resources, technical knowledge gaps	Market guarantee, extension support

Intervention Type	Key Practices	Productivity Impact	Income Increase	Implementation Barriers	Success Factors
	weather forecasting				
Agroforestry Systems	Home gardens, alley cropping, multipurpose trees	20-30% higher returns	Up to 5x for commercial systems	Land competition, delayed returns	Carbon credits, market linkages
Good Agricultural Practices	Reduced chemicals, organic inputs, soil testing	36% yield increase	>100% in some cases	Weak extension, certification costs	Technical training, premium markets
Organic Farming	Zero chemicals, composting, crop rotation	15-25% yield gains	40-60% price premiums	Input availability, certification	Participatory selection, local knowledge integration

Participatory approaches are essential for sustainable agriculture promotion, ensuring interventions align with farmer priorities, local knowledge, and contextual realities. Evidence demonstrates that interventions planned, designed, and executed through participatory processes achieve greater sustainability than top-down approaches (Neupane, 2023). Farmer involvement in technology selection, adaptation, and evaluation increases ownership and likelihood of continued practice use beyond project support. Participatory plant breeding initiatives enable farmers to select varieties suited to local conditions while preserving agricultural biodiversity (Ceccarelli & Grando, 2022). Community-based seed systems strengthen farmers' access to adapted germplasm while maintaining traditional crop genetic diversity crucial for climate resilience (UNEP & GEF, 2013).

Gender-inclusive participatory approaches address power imbalances in agricultural decision-making, ensuring women's voices shape intervention design and implementation. Women comprise the majority of agricultural labor in many regions due to male migration, yet often lack control over resources and agricultural decisions (Khatri-Chhetri et al., 2020). Participatory methodologies specifically engaging women farmers in technology testing, farmer field schools, and cooperative governance strengthen their agency and ensure interventions address their practical needs and strategic interests (Swiss Contact, 2023). Youth engagement through participatory innovation platforms can reverse declining agricultural interest among young people, fostering intergenerational knowledge transfer and innovation.

Institutional coordination mechanisms are critical for scaling participatory sustainable agriculture initiatives. The Climate-Smart Village approach demonstrates how multi-stakeholder platforms can facilitate knowledge exchange, resource mobilization, and coordinated action among government agencies, NGOs, research institutions, and farmer organizations (Khatri-Chhetri et al., 2022). However, fragmented institutional frameworks and insufficient stakeholder coordination hinder CSA scaling in many contexts (Khatri-Chhetri et al., 2024). Federal restructuring in Nepal presents opportunities for developing provincial and local government agricultural policies aligned with federal frameworks while addressing location-specific priorities (World Bank, 2021). Strengthening capacities at provincial and local levels enables responsive, context-appropriate sustainable agriculture programming.

Extension service transformation is fundamental to participatory sustainable agriculture promotion. Traditional top-down extension models are inadequate for facilitating farmer-led innovation and adaptation of sustainable practices. Participatory extension approaches including farmer field schools, farmer-to-farmer learning networks, and innovation platforms enable horizontal knowledge sharing and collective problem-solving (Regmi & Neupane, 2023). Digital extension tools including mobile applications, video-based learning, and virtual advisory services expand extension reach and enable timely information delivery (CIMMYT, 2024). However, ensuring extension quality, technical competence, and farmer accessibility requires sustained investments in extension workforce development and support systems.

Public-private partnerships offer mechanisms for leveraging complementary resources and expertise in participatory sustainable agriculture promotion. Collaboration between government agencies, agribusinesses, NGOs, and farmer cooperatives can address multifaceted challenges spanning production, market access, and enabling policy environments (Timsina, 2023). Private sector engagement in technology dissemination, input supply, and market linkages creates sustainable business models supporting farmer adoption of improved practices. However, ensuring equity and farmer benefit capture requires careful partnership design, transparent governance, and mechanisms protecting smallholder interests within market-oriented interventions (Muhsyanur, 2020).

CONCLUSION

Promoting sustainable farming practices among smallholders in Nepal requires integrated approaches addressing technical, socioeconomic, institutional, and policy dimensions simultaneously. Evidence demonstrates that climate-smart agriculture, agroforestry systems, and good agricultural practices can significantly enhance productivity, resilience, and environmental sustainability when implemented through participatory, gender-inclusive processes with adequate institutional support. Success factors include market guarantee, technical capacity building, participatory technology selection, strengthened extension services, and

coordinated multi-stakeholder action. Overcoming barriers of limited financial resources, weak institutional frameworks, and inadequate market access necessitates comprehensive strategies combining innovative financing mechanisms, policy reforms, and value chain development. Future priorities should emphasize scaling proven sustainable practices through strengthened provincial and local government capacities, digital agriculture innovations, and public-private partnerships ensuring equitable benefit distribution among smallholder farmers across Nepal's diverse agricultural landscapes.

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