Turkish Journal of Agriculture - Food Science and Technology, 13(2): 504-513, 2025
DOI: https://doi.org/10.24925/turjaf.v13i2.504-513.7115

Turkish Journal of Agriculture - Food Science and Technology

Available online, ISSN: 2148-127X | www.agrifoodscience.com | Turkish Science and Technology Publishing (TURSTEP)

Exploring Farmers' Resilience: Climate Change and Sustainable Adaptation Strategies in the Agricultural Sector of Nepal

Shikha Sharma[1,a,*], **Srijana Neupane**[1,b]

[1]*Faculty of Agriculture, Agriculture and Forestry University, Rampur, Chitwan, Nepal*
[*]*Corresponding author*

A R T I C L E   I N F O

Review Article

Received : 05.09.2024
Accepted : 28.10.2024

Keywords:
Sustainability
Food Security
Climate change
Ecosystem
Agriculture productivity

A B S T R A C T

Agriculture is a cornerstone of the economy, providing livelihoods for a significant portion of population. However, climate change significantly affects people, their lifestyles, and the ecosystems posing a critical challenge to the global community, particularly the underprivileged in developing nations. Recognizing the indispensable role of agriculture and the challenges posed by a changing climate, this paper emphasizes the paramount need for proactive adaptation strategies. Central to these strategies is the pivotal concept of Climate-Smart Agriculture (CSA), a multifaceted approach that encompasses a range of practices, including agroforestry, conservation agriculture, and the adoption of climate-resilient crop varieties. Delving deeper, the paper navigates through the farmer's perceptions, unraveling their understanding of climate change, and the complex barriers like social barriers, institutional limitations, financial barriers, and limited awareness that impede effective adaptation, and illuminates the instrumental roles that governmental bodies and institutions, and extension agents play in shaping and fostering climate-resilient practices. Collaboration between local communities, governments, and non-governmental organizations is essential to ensure the successful implementation of sustainable adaptation strategies. Embracing sustainable and forward-thinking approaches, particularly CSA, including agroforestry, conservation agriculture, water management techniques, climate-resilient crop varieties, ICT, and climate-smart pest management, the agricultural sector gains the potential to bolster its resilience against climate-induced disruptions, ensuring consistent agricultural output that contributes significantly to broader food security initiatives.

[a] sajjsharma44@gmail.com   https://orcid.org/0000-0002-0709-7234 | [b] siruneupane666@gmail.com   https://orcid.org/0000-0001-8595-6332

Introduction

Agriculture is a vital part of the economy in Nepal, with about 65.1% of the population relying on it for their livelihoods. It is a major source of employment and sustenance, and its contribution of 24.1% to the GDP highlights its economic importance (MoF, 2023). However, the susceptibility of agriculture to climate change underscores the urgency of implementing effective adaptation strategies to ensure its continued stability and productivity. Climate change involves the prolonged transformation of average climatic conditions, driven by both natural processes and human activities. It impact lives, ecosystems, and global development, particularly affecting vulnerable populations in developing nations (Khanal, 2009; Weber, 2010). By 2030, South Asia is expected to witness substantial negative impacts on crop production due to climate change, with staple crops such as rice potentially facing yield reductions of around 10%, while maize and millet might experience even more significant reductions exceeding 10% (Lobell et al., 2008). Undoubtedly, climate change poses substantial challenges to global food security, projected to exacerbate by factors like population growth, urbanization, economic development, and natural hazards. An estimated 9 billion people may have worsening living conditions by 2050, increasing poverty and hunger (FAO, 2017). Climate change poses a significant risk to African countries, especially in drylands where 70% of the population depends on these areas for everyday survival. By 2055, there might be an estimated 10% decrease in maize production in Latin America and Africa, translating into $2 billion in losses annually (Altieri & Koohafkan, 2008). These yield declines are predicted to be worse as temperatures rise and rainfall patterns change (Altieri & Koohafkan, 2008; Jones & Thornton, 2003). To address the looming challenges and guarantee the resilience of food systems in the face of changing climate conditions, it is essential to deploy effective adaptive techniques in agricultural production (Teklewold, 2019).

The concept of climate-Smart Agriculture (CSA) emerges as a critical strategy that aligns with the growing need for sustainable and adaptable agricultural solutions in the face of climate change. It addresses climate change by implementing adaptive techniques that mitigate the adverse effects on crops while simultaneously enhancing agricultural resilience and sustainability (Barasa et al., 2021). The key focus of climate smart agriculture is on food security, productivity, profitability, sustainability, GHG emission reduction, vulnerability reduction, and capacity building (Adesipo et al., 2020). It aims to find trade-offs and synergies among the three core pillars of CSA: food security, adaptation, and mitigation to optimize balance between improving agricultural output and reducing environmental impacts (Nagothu & Kolberg, 2016; Campbell et al., 2014). To achieve this balance, CSA builds on the principles of sustainable intensification that not only enhance the farm production but also maintain good ecological sustainability. As a part of CSA, sustainable intensification combines local knowledge, and land conservation measures that boosts the productivity and enhance the soil health and farm profitability. This strategy is beneficial against the climate risk while simultaneously lowering GHG emission (Engel & Muller, 2016). Furthermore, CSA prioritizes sustainable methods in low-income agricultural systems, encompassing practices such as conservation agriculture, agroecology, ecosystem services utilization, small-scale irrigation, aquaculture, and agroforestry, while also advocating for integrated approaches like combined crop-livestock systems, landscape management, and reduced tillage techniques (Chandra et al., 2018).

This review paper explores the challenges posed by climate change to agriculture and provides an overview of climate change trends in Nepal, elucidates the climate-related challenges faced by farmers, examines their perceptions of climate change, and discusses sustainable adaptation strategies, the role of government and institutions, and the barriers to effective implementation. Lastly, it explores the benefits of climate adaptation practices and offers recommendations for future prospects. By comprehensively addressing these aspects, this paper aims to provide a holistic understanding of climate-smart agricultural approaches for building resilience and ensuring sustainable food systems.

Materials and Methodology

The content of this review is solely based on information from qualitative sources of existing literature like articles, journals, and books. The relevant information was gathered through extensive exploration of platforms like Google Scholar. The review's findings incorporate a range of analyses conducted across various articles. The methods and tools used by different researchers for analysis are mentioned below:

- Multivariate probit model (MVP) and the random-effects ordered probit model (Teklewold et al., 2019)
- Leximancer^{TM} Version 4 (Chandra et al., 2018)
- Multi-regional computable general equilibrium (CGE) models (Chalise et al., 2017)
- Questionnaire, FGD, KII (Bom et al., 2023)
- Climate trend analysis (Manandhar et al., 2011)
- Statistical Software ‘R’ (version 3.4.3) and Spearman correlation test (Amir et al., 2020)
- Snowball sampling, RQDA computer program, R package for analysis (Ghimire et al., 2022)

Findings

Overview of Climate Change Trends in Nepal

Nepal, with its diverse geography in a relatively small area and rugged terrain (Shrestha & Aryal, 2011), faces the impact of varying climatic elements like temperature, solar radiation, and rainfall, all of which can significantly affect its agricultural productivity. Despite ongoing efforts to mitigate climate change repercussions, Nepal's agricultural sector remains beset by these challenges. Over three decades from 1975 to 2006, Nepal has witnessed a gradual temperature rise of 1.8°C, with an annual average increase of 0.06°C, leading to recurring issues including droughts, intense flooding, landslides, and adverse effects on crop yields, highlighting the impact of climate change in agriculture (Malla, 2008). Increasing temperatures and shifting precipitation patterns across various region due to climate change are expected to impact the availability of water resources in the future (Dahal et al., 2020). Globally, Nepal ranks 4th in vulnerability to climate change, 11th for earthquakes, and 13th for food-related risks (DCA, 2021). Highlighting this vulnerability, a recent climate change vulnerability and risk assessment (MoFE, 2021b) indicate that a substantial portion of Nepal's districts (50 out of 77 districts) exhibit high levels of vulnerability to climate change impacts.

Climate change-related Challenges Faced by Farmers

The effects of climate change are not limited to just environmental concerns but have significant social and economic implications, particularly for vulnerable populations. Extreme events like floods and droughts can have profound and far-reaching impacts on crop productivity and food supply in South Asia, and these effects can indeed lead to upward pressure on food prices (Chalise et al., 2017). Rising temperatures and unpredictable rainfall led to poor crop growth, causing many farmers to switch from growing grains to cultivating vegetables (Shrestha & Nepal, 2016). The study conducted by Rayamajhee et al (2021) on the impact of climate change on rice production has revealed that 1°C rise in average summer temperature has led to a substantial reduction of 4183 kg in rice production, highlighting the tangible impact of climate change on agricultural outcomes. It was reported that the severe winter drought during 2008-2009 led to a 14.5% decrease in wheat production and a 17.3% reduction in barley production, significantly impacting local food security and livelihoods in Nepal (Sapkota & Rijal, 2016). In 2005/06, Eastern Terai faced a rain deficit causing a 12.5% reduction in national crop production as 10 % of agricultural land remained fallow due to insufficient rainfall, while heavy rain and floods in the Midwest Terai led to a 30% decrease in production (Regmi, 2007). Climate change not only directly impacts production but also exacerbates issues through increased pest infestations (Gruda et al., 2019).

Research shows that there was 57% more damage in soybean field by different pests when it was grown under the elevated CO2 level as compared to normal atmospheric condition (Hamilton et al., 2005). Similarly, as compared to normal condition, the population of wireworms was high in the upper portion of soil due increased summer rainfall (Gregory et al., 2009). Moreover, it can even influence conditions within protected environments. Teitel et al. (2005), for example, showed that in a naturally ventilated greenhouse used for pepper cultivation, the population of whiteflies was more significant near the roof opening, where wind entered the greenhouse. This suggests that the introduction of insects into greenhouse conditions may be impacted by modifications in wind patterns brought on by climate change.

Farmer's Perception on Climate Change

According to Bom et al. (2023), Farmers' attitudes about climate change significantly impact how they respond to its effects in various economic and social contexts within a given area. The willingness of producers to implement climate change adaptation strategies can be strongly influenced by their perception of changes in local weather patterns (Khanal et al., 2018). Many farmers recognize climate change and use their indigenous knowledge and personal experience to adapt, which is a positive step. Indigenous knowledge act as a useful resource that may inform and improve formal methods for climate adaptation (Manandhar,2011). At the local level, collaborative methods that fuse scientific ideas with traditional knowledge might improve the sustainability and efficacy of climate resilience initiatives. More and more people are realizing that the best ways to deal with the problems caused by climate change are to embrace local knowledge, include agricultural communities in managing their rural landscapes, and use bioresources sustainably (Negi et al., 2017). In response to issues like erratic rainfall and water shortages, farmer have adopted strategies such as growing improved varieties, raising goats to diversify income, and planting fodder trees to ensure stable supply to animal feed. These actions demonstrate initiatives to improve resilience and adjust to the effects of climate change (Baul & McDonald, 2014).

Farming communities are well-informed about weather and climate change, they understand how it affects their crops, livestock, and overall well-being. Amir et al. (2020) report that agricultural output declines have impacted livelihoods and increased vulnerability. However, they see opportunities for adaptation through technical and financial help. According to Abid et al. (2015), the majority (58%) of farm households have altered their agricultural practices in response to climate change because of widespread awareness. The opinion of farmer coincided with short-term weather data, which shows greater temperatures and less precipitation. Their readiness to change was most influenced by perceived behavioural control elements, followed by attitude and subjective standards (Arunrat et al., 2017).

Budhathoki and Zander (2020) found that farmers' perceptions of maximum temperature trends across stations and planting seasons matched actual climate data. Over a 30-year period, 80.7% of respondents in rural farmlands reported rising temperatures, while more than 90% reported decreasing rainfall. According to Devkota et al. (2018), 73% of farming households have employed adaptive methods to offset the detrimental effects of climate change on rice cultivation, with higher adoption rate observed in the terai region compared to hilly areas.

Sustainable Adaptation Strategies for Climate Change Mitigation

In the global context, Nepalese agriculture faces increasing challenges due to the impacts of climate change. Farmers are experiencing shifts in weather patterns, uncertain rainfall, and more frequent extreme events, which affects the traditional farming practices in many ways. In order to cope up with these challenges, it is crucial to develop and implement sustainable adaptation strategies that enhance both climate resilience and contribute to the long-term sustainability of agricultural systems (Rasul & Sharma, 2016).

Agroforestry is the key sustainable adaptation strategy, which is an integrated land-use approach that combines trees, crops, and livestock on the same land. Agroforestry systems provide a wide array of benefits, like biodiversity enhancement, carbon sequestration, microclimate regulation, and diversified income sources (Nair et al., 2021). Alley cropping, as an agroforestry practice helps to foster not only ecological resilience but also the economic resilience by minimizing the risks of crop failure and offering alternative income streams (Quinkenstein et al., 2009). Also, by integrating tree species with traditional crops, farmers can create beneficial microclimates that protect the crops from extreme heat and wind, mitigate soil erosion, as well as improve soil health. Additionally, trees serve as carbon sinks, which contribute to climate change mitigation (Aba et al., 2017). Globally, agroforestry systems are known for their dual benefits like protecting farmers from climate changes and sequestering carbon, resulting in lower net greenhouse gas emissions compared to other agricultural intensification methods (Altieri & Koohafkan, 2008).

Water management and irrigation practices are also a crucial practice that falls under sustainable adaptation practices especially at a changing precipitation pattern. Implementing modern irrigation techniques, such as drip or sprinkler systems, along with rainwater harvesting, can significantly enhance water efficiency (Handy et al., 2003). Proper water management ensures sufficient moisture for crops by minimizing water wastage, especially during periods of scarcity (Zahoor et al., 2019). Moreover, there are some advanced techniques which detects the plant water requirement rather than just soil moisture content (Erdem et al., 2010). This offers more precise irrigation solutions during the period of scarcity. Nepalese farmers can better manage water resources and enhance resilience against the erratic rainfall by integrating traditional knowledge with modern technology, ultimately fostering agricultural resilience.

Soil health management and conservation techniques form another vital pillar of sustainable adaptation. To maintain good crop productivity and climate resilience, different soil management techniques like cover cropping, no-till farming, and organic soil amendments, are highly important. These practices improve soil structure, moisture retention, and nutrient cycling. Additionally, managing carbon and nitrogen cycle by applying the strategy of soil amendments and precision agriculture can help to manage issues like soil erosion, low soil quality, and reduced crop productivity (Cordovil et al., 2020; Handayani & Folz, 2021). Mulching, in particular, serves as a good agricultural technique with multiple benefits, particularly in the context of climate-smart farming. Mulching mitigates water stress by retaining soil moisture and reducing evapotranspiration losses. Also, in case of organic mulch, it enriches the soil with organic matter. In climate-resilient approach, mulching stands out as a good strategy as farmers often use ground-covering plants or straw mulches to lower radiation and heat, prevent moisture loss, and absorb the impact of rain and hail on newly planted surfaces (Altieri & Koohafkan, 2008). Additionally, by embracing practices like zero tillage in integration with mulching and other soil management methods farmers enhance carbon sequestration within the soil. Natural mulch materials offer the advantages of moderating soil temperatures, minimizing disease and pest outbreaks, and safeguarding soil moisture levels. This integrated approach of mulching as a climate resilient strategy helps to promote resource-efficient and sustainable farming practices (Mulumba & Lal, 2008; Nyong et al., 2007).

Conservation agriculture offers the potential to reverse the degradation caused by conventional tillage. By reducing soil disturbance, promoting crop diversity, and maintaining soil cover, conservation agriculture improves soil health and mitigate greenhouse gas emissions and fertilizer usage, and enhance carbon sequestration (Pisante et al., 2015). The foundation of sustainable agricultural practices lies in the principles of reducing soil disturbance, practicing crop rotation, and maintaining soil cover (Malhi et al., 2021). Several factors influence the adoption of conservation agriculture, including perceived individual benefits, effective market exchange for resources, economic incentives, farmer organization development, and collaborative efforts between farmer groups and institutions (Malhi et al., 2021).

Climate-smart pest Management (CSPM) is another strategy of sustainable adaptation that helps to addresses the complex challenges posed by climate change in agriculture. When climate change occurs, the shifts in climate results shifts in temperature, precipitation patterns, and extreme weather events, which influence the dynamics of pests. CSPM enables effective management of new and existing crop pests, reduces crop losses and enhances farmer livelihoods by addressing the challenges posed by climate change-induced pest impacts. It entails various components like prevention, early warning systems, and adaptive strategies, which allow timely intervention and reduce the likelihood of pest outbreaks. By utilizing the climate and pest monitoring, coupled with risk forecasting, CSPM helps prevent the buildup and emergence of pest issues (Bouri et al., 2022), thereby increasing agricultural system resilience and reducing vulnerability to climate-induced disruptions. Furthermore, it promotes tailored pest control methods, such as integrated pest management (IPM) and agroecological practices. CSPM is the best strategy that benefit farmers directly by increasing income and food security. A study by N'dakpaze (2022) has reported that using CSPM technique in tomato production has resulted in improved production with reduction in chemical use, pest density, and environment pollution. As it has broader positive impacts on ecosystems, economy, and society, it requires coordinated efforts from extension, research, and the public and private sectors for successful implementation (Heeb et al., 2019; Ayoub et al., 2022).

Use of climate-resilient crop varieties is also one of the climate-smart farming technique to withstand the challenges posed by changing climatic conditions, such as increased temperatures, altered precipitation patterns, and more frequent extreme weather events. In the face of climate uncertainties, these varieties are bred for traits like drought tolerance, heat resistance, and disease resilience, to ensure stable and productive agricultural systems (Acevedo et al., 2020; Maheshwari et al., 2019). In the area with the high problem of drought, a drought-resistant variety could enhance resilience in the water scarcity period. For instance, wheat can be cultivated in the water scarce area rather than rice, as wheat requires less irrigation. Smallholder farmers have also explored drought-resistant crop varieties as adaptive measures to climate change (Ngigi, 2009). These climate-resilient crops help to ensure stable yields and contribute to resource efficiency by reducing the need for excessive water or inputs. Moreover, they reduce dependence on chemical pesticides by incorporating natural resistance mechanisms against pests and diseases.

Information and Communication Technology (ICT) has emerged as a powerful enabler of climate adaptation strategies within the agricultural sector with wide array of technologies, from traditional ones like landlines and television to rapidly advancing systems such as the internet, mobile communication, social networks, and remote sensing (Eakin et al., 2014). By using different kinds of sensor networks and remote sensing technologies, farmers can gather real-time data on various environmental factors, such as temperature, humidity, soil moisture, and rainfall patterns. When they have access to such data, they can make informed decisions on when to plant, irrigate, and harvest, aligning their practices with prevailing climate conditions. This helps in two ways; to optimize resource utilization and helps mitigate potential losses caused by extreme weather events, such as droughts or heavy rains (Jayaraman et al., 2016; Ajwang & Nambiro, 2022).

ICT also plays an important role in knowledge-sharing and capacity-building among farming communities. There are various channels such as online platforms, mobile apps, and virtual networks for farmers to access information about climate-resilient practices, innovative cultivation techniques, and pest management strategies (Gbangou et al., 2020; Eakin et al., 2014). Moreover, ICT supports supply chain management and market access (Zhang et al., 2016). Also, digital platforms help to facilitate the direct connection between producers and consumers, as a result there will be less intermediaries which ultimately improve the efficiency of agricultural markets (Kos & Kloppenburg, 2019). Farmers can secure their better prices for their output, and it would help to reduce the post-harvest loses, which will contribute to overall sustainability. Moreover, ICT has its role in mitigation of carbon emissions by automating and optimizing various sectors, reducing energy use, promoting electric vehicles, and minimizing travel through virtual alternatives, contributing to significant climate change mitigation (Ajwang & Nambiro, 2022).

Factors Affecting the Adoption of Different Strategies

According to Fosu-Mensah et al. (2012), factors such as access to extension services, availability of credit, soil fertility, and land tenure play a critical role in shaping the perceptions and decisions of farmers regarding adaptation. Similarly, according to Abid et al. (2015) education, farm experience, household size, land area, tenancy status, tube well ownership, market information access, weather forecasting, and agricultural extension services are the influential factors in farmers' adaptation decisions. Similarly, age, years of education, climate change training, and participation in cooperatives were identified as significant factors affecting individuals' awareness of climate change (Adhikari et al., 2022). When the household head is educated there was a positive and significant influence on adaptation. Likewise, it was positive with variables like household head's education, household size, male household head, livestock ownership, received advice on production, credit access, and temperature. On the other hands, larger farm size and high annual precipitation were negatively correlated with adaptation (Deressa et al., 2011). Moreover, the situation like government extension services, participation in farmer field school, subsidies, access to energy, and perceptions of climate shocks also influence the farmer's adoption of different strategies (Tanti et al., 2022).

Challenges and Barriers

There are multiple challenges and barriers associated with the climate change adaptation strategies which hinders to mitigate the impacts of changing climatic conditions (Hamin et al., 2014). A diverse range of barriers such as social, institutional, cognitive, and financial barriers are associated. A comprehensive understanding of these barriers is essential for crafting robust and successful adaptation measures (Biesbroek et al., 2013). In social barriers the cognitive behavior and normative practices, often lead to an underestimation of future climatic impacts and a preference for traditional methods over innovative solutions (Jones & Boyd, 2011). Institutional barriers, on the other hand, are associated with unequal political power and caste-related neglect, limiting the access to resources for marginalized communities and hindering their ability to respond effectively to climatic challenges (Jones & Boyd, 2011).

Uncertainty and lack of awareness pose another formidable barrier. The lack of certainty regarding the impacts of climate change and the effectiveness of adaptation strategies can hinder motivation to become more aware of the risks. On the other hand, limited awareness can negatively affect the efforts aimed at reducing uncertainty, underscoring the intricate bidirectional relationship between awareness-building and uncertainty reduction (Eisenack et al., 2014). The situation of no adequate budgets, financial crises, or competing priorities falls under the financial constraints which persistently hinder adaptation efforts. These financial challenges furthermore magnify other barriers related to information gaps, coordination challenges, and personal beliefs, in turn exacerbating the complexities faced in implementing climate adaptation strategies (Eisenack et al., 2014; Antwi-Agyei et al., 2015).

Additionally, the land tenure status and farm size also emerge as a crucial determinant in the adoption rate of climate change adaptation measures. Constraints related to land availability, high farmland costs, and communal land ownership systems all contribute to the intricate web of barriers to a climate change adaptation strategy (Ozor et al., 2010).

Government and Institutional Roles in Climate-Smart Agriculture

The Government of Nepal plays a crucial role in climate adaptation through the implementation of programs like the National Adaptation Programme of Action, Climate Change Policy, Local Adaptation Plans of Action, and the promotion of climate-friendly agricultural practices, demonstrating its commitment to enhancing resilience and sustainability in the face of climate challenges (Paudel et al., 2017). The objective of the Agriculture Development Strategy (ADS) is to improve climate resilience and sustainability by strengthening the capacities of farmers and extension workers in Climate-Smart Agriculture (Khatri-Chhetri et al., 2017). In addition to tackling climatic concerns through capacity-building and enhanced information sources (radios, television), extension agents help implement government plans at the field level by providing advice on farming methods, pest control, and sustainability (Antwi-Agyei & Stringer, 2021).

The availability of meteorological information, farmer training, and the ability to access Extension services are all elements that affect how effective climate adaptation strategies—such as Direct Seeded Rice (DSR), enhanced crop varieties, and sophisticated irrigation techniques—are. These factors work together to influence how well these methods work to solve the climatic issues in agriculture. Access to Extension services, training, and meteorological data all have a favourable impact on the adoption of these techniques and improve their execution (Regmi et al., 2023).

Multiple institutions work together under Nepal's Climate Smart Village (CSV) approach to address how climate change affects agriculture. Interventions are customised to the local environment, and sustainable farming practices are promoted (Ghimire et al., 2022). Global organisations such as the FAO and the World Bank promote the use of contemporary agricultural techniques in order to improve adaptive capacity and climate-smart agriculture (CSA) (Iqbal et al., 2021). Climate-smart solutions for widespread adoption in agriculture in the face of climate change are being researched by the CGIAR initiative CCAFS (Vernooy & Bouroncle, 2019). A key component of the Climate Smart Village (CSV) concept, CCAFS integrates socio-economic and CSA components, highlighting the necessity of improving the capacities of local leaders and government representatives (Pudasaini et al., 2019).

Benefits

The adoption of sustainable climate smart adaptation practices has a crucial role in improving crop yields and increasing the income for farmers (Ghosh, 2019). Furthermore, modest investments in small-scale infrastructure, such as the enhancement of irrigation systems and the establishment of facilities for seed storage, present an economical motivation for policymakers and donors to support farmers in enhancing their productivity and ensuring more effective harvest protection (Azadi et al., 2021). Adoption of zero tillage technique for wheat cultivation is gaining traction in South Asia as it saves 15-16 % cost. Also, there is a higher and more consistent outputs in wheat and maize when farmers use this practice (Powlson et al., 2014). Similarly, when the farmers apply diversified farming system along with cropping drought-resistant varieties, there was greater stability and profitability in yield (Singh & Singh, 2017). Utilizing resistant varieties through crop breeding offers numerous benefits. Some of them are tolerance to thermal stresses, vernalization needs, heat shocks, and drought conditions. Besides tolerance, these varieties also exhibit resistance to pests and diseases, maintain high protein and nutritional levels, and ensure efficient irrigation even in water-scarce environments, thereby contributing directly to the mitigation of climate change impacts (Gruda et al., 2019).

The Resilient Mountain Village pilot project in Kavrepalanchowk district (2014-2016) demonstrated climate-smart practices such as bio-fertilizer ("Jholmal"), green manuring, and mulching. These methods in particularly improved crop yields, with jholmal and green manuring increasing rice yields by 10.1% and 8.1% respectively, and mulching enhancing the bitter-gourd yield by 18.1%, highlighting the effectiveness of these techniques in enhancing agricultural resilience (Subedi et al., 2019). Furthermore, in agroforestry practices there are low external input requirements, and effective integration of trees, crops, and animals reduces the vulnerability of agricultural systems to climate-related risks as well as enhances the agroecosystem diversity (Mbow et al., 2014). Additionally, ecosystem-based approaches leverage nature to protect communities from climate impacts by delivering services such as food security, and livelihood diversification (Munang et al., 2013).

Discussions

Farming communities are aware of the effects of weather and climate change on their crops, animals, and general well-being (Amir et al., 2020). This is in line with the study of Adaawen (2021) where he mentioned that in the rural study area, most farmers possess intuitive perceptions of changing climatic and environmental conditions. These perceptions stem from their direct experiences with shifting weather patterns, altered growing seasons, variable crop yields, and challenges with pests and water availability. Focusing on a drought-resistant variety in areas prone to drought could enhance resilience in water scarcity periods. For instance, wheat, requiring less irrigation than dry-season rice, could be cultivated (Ngigi, 2009). Similar studies conducted by Bikila (2013) and Saguye (2016) have documented comparable findings with Ngigi (2009), they observed that farmers often employ specific climate change adaptation strategies, such as utilizing drought-resistant improved crop varieties and opting for short-maturing crop varieties. Around 80.7% of respondents in rural farmlands noted a temperature rise over a 30-year span, while over 90% believed rainfall had decreased during that period. In response, 73% of farming households have implemented adaptive measures to mitigate climate change's negative effects on rice cultivation, with higher adaptation rates in the Terai region and lower rates in the hilly region (Devkota et al., 2018). Across various incidents, a consistent pattern emerges where a minimum of 80% or more respondents acknowledged experiencing climatic changes with potentially adverse effects on agricultural practices. Notably, a substantial majority (84%) of participating farmers affirmed adopting one or more recognized adaptive measures (Uddin et al., 2014). This is in line with the study of Dhaka et al. (2010), where a substantial portion of farmers were observed employing diverse adaptation strategies in response to the challenges posed by climate change. Besides the negative impact of climate change on agriculture given by (Lobell et al., 2008), Aydinalp & Cresser (2008) argue that there are some positive impacts of climate change on agriculture like Elevated atmospheric CO_2 levels are anticipated to positively impact certain plants by accelerating their growth rates and reducing transpiration, thereby enhancing water efficiency. Additionally, a noteworthy consequence of rising temperatures, especially in regions with limited agricultural production due to cold conditions, is the potential extension of the available growing season for plants. This change may result in shorter maturation times for crops. According to a cross-country study of factors impacting adaptation decisions to perceived climate change, farmers were more likely to adjust when they had access to extension services, credit, and land (Baryan et al., 2009). The findings of Fosu-Mensah et al. (2012)'s logit regression analysis match the findings of Baryan et al. (2009), who found that the four main relevant factors influencing farmers' perspective and adaptation are land tenure, credit availability, soil fertility, and access to extension services.

Conclusion

Climate change poses serious problems to Nepal's agriculture, affecting food security and crop output. Farmers' adaptation methods are significantly shaped by their perceptions. Climate Smart Agriculture (CSA) provides a promising pathway for adaptation, which includes techniques like agroforestry, conservation agriculture, and climate-resilient crops. However, barriers like limited awareness, financial constraints, and institutional limitations hinder implementation. Government and institutions must collaborate to foster an enabling environment. The benefits of sustainable practices are evident through improved yields and resource efficiency. Integrating CSA is crucial for building resilience and securing sustainable food systems in Nepal's changing climate landscape.

Future Prospects and Recommendations

Considering insights from multiple studies, a holistic perspective on future prospects for sustainable adaptation strategies emerges. Strengthening local institutions emerges as a crucial step in enabling communities to adopt and sustain climate-resilient practices (Tiwari et al., 2014). Likewise, Information and Communication Technologies

(ICTs) showcase the potential to enhance prevention efforts, ensuring fairness, informing policies, and bolstering overall social and environmental sustainability of adaptation measures (Eakin et al., 2014). Moreover, policymakers have a pivotal role in supporting producers' climate adaptation efforts. This involves integrated approaches that consider diverse needs, existing programs, and adaptable policies to address growing climate challenges while enhancing adaptive capacity in the agricultural sector through sustainable practices (wall & Smith, 2008). On a global scale, the expansion of organic agriculture presents an opportunity for advancing climate-friendly farming practices. However, unlocking its full potential requires increased investments in research and development (Scialabba & Muller-Lindenlauf, 2010). Considering these findings, fostering collaborations between local communities, governments, and non-governmental organizations is essential to successfully implement sustainable adaptation strategies. Moreover, investing in education and awareness campaigns can empower individuals to actively participate in climate-resilient practices and contribute to the collective effort to mitigate climate change impacts.

Declarations

Acknowledgements

We are grateful to all the researchers and scientists whose work has contributed as a foundation for this review article and greatly contributed to its development.

Conflicts of Interest

The author here declares that no conflicts of interest are involved with this article.

References

Aba, S. C., Ndukwe, O. O., Amu, C. J., & Baiyeri, K. P. (2017). The role of trees and plantation agriculture in mitigating global climate change. *African Journal of Food, Agriculture, Nutrition and Development*, *17*(4), 12691-12707.

Abid, M., Scheffran, J., Schneider, U. A., & Ashfaq, M. J. E. S. D. (2015). Farmers' perceptions of and adaptation strategies to climate change and their determinants: the case of Punjab province, Pakistan. *Earth System Dynamics*, *6*(1), 225-243. https://doi.org/10.5194/esd-6-225-2015

Acevedo, M., Pixley, K., Zinyengere, N. *et al.* (2020). A scoping review of adoption of climate-resilient crops by small-scale producers in low- and middle-income countries. *Nat. Plants* **6**, 1231–1241 (2020). https://doi.org/10.1038/s41477-020-00783-z

Adaawen, S. (2021). Understanding climate change and drought perceptions, impact and responses in the rural Savannah, West Africa. *Atmosphere*, *12*(5), 594. https://doi.org/10.3390/atmos12050594

Adesipo, A., Fadeyi, O., Kuca, K., Krejcar, O., Maresova, P., Selamat, A., & Adenola, M. (2020). Smart and climate-smart agricultural trends as core aspects of smart village functions. *Sensors*, *20*(21), 5977. https://doi.org/10.3390/s20215977

Adhikari, S., Rawal, S., & Thapa, S. (2022). Assessment of Status of Climate Change and Determinants of People's Awareness to Climate-Smart Agriculture: A Case of Sarlahi District, Nepal. *Advances in Agriculture*, *2022*(1), 1556407.

Ajwang, S.O., & Nambiro, A. W. (2022). Climate Change Adaptation and Mitigation using Information and Communication Technology. International Journal of Computing Sciences Research, 6, 1046-1063. doi: 10.25147/ijcsr.2017.001.1.101

Altieri, M. A., & Koohafkan, P. (2008). *Enduring farms: climate change, smallholders and traditional farming communities* (Vol. 6). Penang: Third World Network (TWN).

Amir, S., Saqib, Z., Khan, M. I., Khan, M. A., Bokhari, S. A., Zaman-ul-Haq, M., & Majid, A. (2020). Farmers' Perceptions and Adaptation Practices to Climate Change in Rain-fed Area: A case study from district Chakwal, Pakistan. *Pakistan Journal of Agricultural Sciences*, *57*(2). DOI: 10.21162/PAKJAS/19.9030

Antwi-Agyei, P., & Stringer, L. C. (2021). Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. *Climate Risk Management*, *32*, 100304. https://doi.org/10.1016/j.crm.2021.100304

Antwi-Agyei, P., Dougill, A. J., & Stringer, L. C. (2015). Barriers to climate change adaptation: evidence from northeast Ghana in the context of a systematic literature review. *Climate and Development*, *7*(4), 297-309. https://doi.org/10.1080/17565529.2014.951013

Arunrat, N., Wang, C., Pumijumnong, N., Sereenonchai, S., & Cai, W. (2017). Farmers' intention and decision to adapt to climate change: A case study in the Yom and Nan basins, Phichit province of Thailand. *Journal of Cleaner Production*, *143*, 672-685. https://doi.org/10.1016/j.jclepro.2016.12.058

Aydinalp, C., & Cresser, M. S. (2008). The effects of global climate change on agriculture. *American-Eurasian Journal of Agricultural & Environmental Sciences*, *3*(5), 672-676.

Ayoub, L., Irshad, S. S., Yaqoob, M., Siraj, M., Gull, A., Wani, F. F., ... & Rasool, J. (2022). Insect pests under changing climate and climate-smart pest management. *Pharma Innov. J*, *11*, 648-652.

Azadi, H., Moghaddam, S. M., Burkart, S., Mahmoudi, H., Van Passel, S., Kurban, A., & Lopez-Carr, D. (2021). Rethinking resilient agriculture: From climate-smart agriculture to vulnerable-smart agriculture. *Journal of Cleaner Production*, *319*, 128602. https://doi.org/10.1016/j.jclepro.2021.128602

Barasa, P. M., Botai, C. M., Botai, J. O., & Mabhaudhi, T. (2021). A review of climate-smart agriculture research and applications in Africa. *Agronomy*, *11*(6), 1255. https://doi.org/10.3390/agronomy11061255

Baul, T. K., & McDonald, M. A. (2014). Agro-biodiversity management: using indigenous knowledge to cope with climate change in the Middle-Hills of Nepal. *Agricultural Research*, *3*, 41-52. https://doi.org/10.1007/s40003-014-0096-8

Biesbroek, G.R., Klostermann, J.E.M., Termeer, C.J.A.M. *et al.* (2013). On the nature of barriers to climate change adaptation. *Reg Environ Change* 13, 1119–1129. https://doi.org/10.1007/s10113-013-0421-y

Bikila, A. (2013). Farmers' Perception and Adaptation to Climate Change and Variability: The Case of DodotaWoreda, Arsi zone, Oromia Region, Ethiopia. *Addis Ababa University*.

Bom, U., Tiefenbacher, J., & Belbase, S. (2023). Individual and community perceptions of climate change in Lower Mustang, Nepal. *Environment, Development and Sustainability*, *25*(7), 5997-6031. https://doi.org/10.1007/s10668-022-02291-w

Bouri, M., Arslan, K. S., & Şahin, F. (2023). Climate-smart pest management in sustainable agriculture: Promises and challenges. *Sustainability*, *15*(5), 4592. https://doi.org/10.3390/su15054592

Bryan, E., Deressa, T. T., Gbetibouo, G. A., & Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: options and constraints. *Environmental science & policy*, *12*(4), 413-426. https://doi.org/10.1016/j.envsci.2008.11.002

Budhathoki, N. K., & Zander, K. K. (2020). Nepalese farmers' climate change perceptions, reality and farming strategies. *Climate and Development*, *12*(3), 204-215. https://doi.org/10.1080/17565529.2019.1612317

Campbell, B. M., Thornton, P., Zougmoré, R., Van Asten, P., & Lipper, L. (2014). Sustainable intensification: What is its role in climate smart agriculture?. *Current Opinion in Environmental Sustainability*, *8*, 39-43. https://doi.org/10.1016/j.cosust.2014.07.002

Chalise, S., Naranpanawa, A., Bandara, J. S., & Sarker, T. (2017). A general equilibrium assessment of climate change–induced loss of agricultural productivity in Nepal. *Economic Modelling*, *62*, 43-50. https://doi.org/10.1016/j.econmod.2017.01.014

Chandra, A., McNamara, K. E., & Dargusch, P. (2018). Climate-smart agriculture: perspectives and framings. *Climate Policy*, *18*(4), 526-541. https://doi.org/10.1080/14693062.2017.1316968

Cordovil, C. M., Bittman, S., Brito, L. M., Goss, M. J., Hunt, D., Serra, J., ... & Hutchings, N. (2020). Climate-resilient and smart agricultural management tools to cope with climate change-induced soil quality decline. In *Climate change and soil interactions*. Elsevier. 613-662. https://doi.org/10.1016/B978-0-12-818032-7.00022-9

Dahal, P., Shrestha, M. L., Panthi, J., & Pradhananga, D. (2020). Modeling the future impacts of climate change on water availability in the Karnali River Basin of Nepal Himalaya. *Environmental Research*, *185*, 109430.

Deressa, T. T., Hassan, R. M., & Ringler, C. (2011). Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. *The Journal of Agricultural Science*, *149*(1), 23-31. https://doi.org/10.1017/S0021859610000687

Devkota, N., Phuyal, R. K., & Shrestha, D. L. (2018). Perception, determinants and barriers for the adoption of climate change adaptation options among Nepalese rice farmers. *Agricultural Sciences*, *9*(3), 272-298. https://doi.org/10.4236/as.2018.93021

Dhaka, B. L., Chayal, K., Poonia, M. K., & Kendra, K. V. (2010). Analysis of farmers' perception and adaptation strategies to climate change. *Libyan Agriculture Research Center Journal International*, *1*(6), 388-390.

Eakin, H., Wightman, P. M., Hsu, D., Gil Ramón, V. R., Fuentes-Contreras, E., Cox, M. P., ... & Kammen, D. M. (2015). Information and communication technologies and climate change adaptation in Latin America and the Caribbean: A framework for action. *Climate and Development*, *7*(3), 208-222. https://doi.org/10.1080/17565529.2014.951021

Eisenack, K., Moser, S. C., Hoffmann, E., Klein, R. J., Oberlack, C., Pechan, A., ... & Termeer, C. J. (2014). Explaining and overcoming barriers to climate change adaptation. *Nature climate change*, *4*(10), 867-872. https://doi.org/10.1038/nclimate2350

Engel, S., & Muller, A. (2016). Payments for environmental services to promote "climate-smart agriculture"? Potential and challenges. *Agricultural Economics*, *47*(S1), 173-184. https://doi.org/10.1111/agec.12307

Erdem, Y., Arin, L., Erdem, T., Polat, S., Deveci, M., Okursoy, H., & Gültaş, H. T. (2010). Crop water stress index for assessing irrigation scheduling of drip irrigated broccoli (Brassica oleracea L. var. italica). *Agricultural Water Management*, *98*(1), 148-156. https://doi.org/10.1016/j.agwat.2010.08.013

FAO. (2017). Climate-Smart Agriculture Sourcebook: Summary.

Fosu-Mensah, B. Y., Vlek, P. L., & MacCarthy, D. S. (2012). Farmers' perception and adaptation to climate change: a case study of Sekyedumase district in Ghana. *Environment, Development and Sustainability*, *14*, 495-505. https://doi.org/10.1007/s10668-012-9339-7

Gbangou, T., Sarku, R., Slobbe, E. V., Ludwig, F., Kranjac-Berisavljevic, G., & Paparrizos, S. (2020). Coproducing weather forecast information with and for smallholder farmers in Ghana: Evaluation and design principles. *Atmosphere*, *11*(9), 902. https://doi.org/10.3390/atmos11090902

Ghimire, R., Khatri-Chhetri, A., & Chhetri, N. (2022). Institutional Innovations for Climate Smart Agriculture: Assessment of Climate-Smart Village Approach in Nepal. *Frontiers in Sustainable Food Systems*, *6*, 734319. https://doi.org/10.3389/fsufs.2022.734319

Ghosh, M. (2019). Climate-smart agriculture, productivity and food security in India. *Journal of Development Policy and Practice*, *4*(2), 166-187. https://doi.org/10.1177/2455133319862404

Gregory, P. J., Johnson, S. N., Newton, A. C., & Ingram, J. S. (2009). Integrating pests and pathogens into the climate change/food security debate. *Journal of experimental botany*, *60*(10), 2827-2838. https://doi.org/10.1093/jxb/erp080

Gruda, N., Bisbis, M., & Tanny, J. (2019). Influence of climate change on protected cultivation: Impacts and sustainable adaptation strategies-A review. *Journal of Cleaner Production*, *225*, 481-495. https://doi.org/10.1016/j.jclepro.2019.03.210

Hamdy, A., Ragab, R., & Scarascia-Mugnozza, E. (2003). Coping with water scarcity: water saving and increasing water productivity. *Irrigation and Drainage: The Journal of the International Commission on Irrigation and Drainage*, *52*(1), 3-20. https://doi.org/10.1002/ird.73

Hamilton, J. G., Dermody, O., Aldea, M., Zangerl, A. R., Rogers, A., Berenbaum, M. R., & Delucia, E. H. (2005). Anthropogenic changes in tropospheric composition increase susceptibility of soybean to insect herbivory. *Environmental entomology*, *34*(2), 479-485. https://doi.org/10.1603/0046-225X-34.2.479

Hamin, E. M., Gurran, N., & Emlinger, A. M. (2014). Barriers to municipal climate adaptation: Examples from coastal Massachusetts' smaller cities and towns. *Journal of the American Planning Association*, *80*(2), 110-122. https://doi.org/10.1080/01944363.2014.949590

Handayani, I. P., & Folz, N. (2021). Adaptive Land Management for Climate-Smart Agriculture. In *2021 IEEE International Conference on Health, Instrumentation & Measurement, and Natural Sciences (InHeNce)*, 1-7.

Heeb, L., Jenner, E., & Cock, M. J. (2019). Climate-smart pest management: building resilience of farms and landscapes to changing pest threats. *Journal of Pest Science*, *92*(3), 951-969. https://doi.org/10.1007/s10340-019-01083-y

Iqbal, J., Iqbal, J., Akhtar, N., Amir, S., Naseer, H. M., & Khan, M. I. (2021). Capacity Assessment of Community Based Organizations for Climate Smart Agriculture Extension to Promote Climate Compatible Development: A Governance Index Approach. *Int. J. Mod. Agric*, *10*, 4258-4271.

Jayaraman, P. P., Yavari, A., Georgakopoulos, D., Morshed, A., & Zaslavsky, A. (2016). Internet of things platform for smart farming: Experiences and lessons learnt. *Sensors*, *16*(11), 1884. https://doi.org/10.3390/s16111884

Jones, L., & Boyd, E. (2011). Exploring social barriers to adaptation: insights from Western Nepal. *Global environmental change*, *21*(4), 1262-1274. https://doi.org/10.1016/j.gloenvcha.2011.06.002

Jones, P. G., & Thornton, P. K. (2003). The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global environmental change*, *13*(1), 51-59.

Khadka, B., & Pradhan, O. (2021). When Climate becomes a Threat, Evidence of Climate Change Induced Loss and Damage in Nepal.

Khanal, R. C. (2009). Climate change and organic agriculture. *Journal of Agriculture and Environment*, *10*, 116-127.

Khanal, U., Wilson, C., Lee, B. L., & Hoang, V. N. (2018). Climate change adaptation strategies and food productivity in Nepal: a counterfactual analysis. *Climatic change*, *148*, 575-590. https://doi.org/10.1007/s10584-018-2214-2

Khatri-Chhetri, A., Poudel, B., Shirsath, P. B., & Chaudhary, P. (2017). Assessment of climate-smart agriculture (CSA) options in Nepal. *CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), New Delhi, India*.

Kos, D., & Kloppenburg, S. (2019). Digital technologies, hyper-transparency and smallholder farmer inclusion in global value chains. *Current Opinion in Environmental Sustainability*, *41*, 56-63. https://doi.org/10.1016/j.cosust.2019.10.011

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., & Naylor, R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. *Science*, *319*(5863), 607-610. DOI: 10.1126/science.1152339

Maheswari, M., Sarkar, B., Vanaja, M., Rao, M. S., Prasad, J. V. N. S., Prabhakar, M., ... & Alagusundaram, K. (2019). Climate Resilient Crop Varieties for Sustainable Food Production under Aberrant Weather Conditions. *ICAR-Central Research Institute for Dryland Agriculture, Hyderabad. P*, *64*.

Malhi, G. S., Kaur, M., & Kaushik, P. (2021). Impact of climate change on agriculture and its mitigation strategies: A review. *Sustainability*, *13*(3), 1318. https://doi.org/10.3390/su13031318

Malla, G. (2008). Climate change and its impact on Nepalese agriculture. *Journal of agriculture and environment*, *9*, 62-71.

Manandhar, S., Vogt, D. S., Perret, S. R., & Kazama, F. (2011). Adapting cropping systems to climate change in Nepal: a cross-regional study of farmers' perception and practices. *Regional Environmental Change*, *11*, 335-348. https://doi.org/10.1007/s10113-010-0137-1

Mbow, C., Smith, P., Skole, D., Duguma, L., & Bustamante, M. (2014). Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. *Current opinion in Environmental sustainability*, *6*, 8-14. https://doi.org/10.1016/j.cosust.2013.09.002

Ministry of Finance (MoF), Government of Nepal (2023), *Economic Survey Report 2022/23, 97. https://www.mof.gov.np/site/publication-detail/3248*

Mulumba, L. N., & Lal, R. (2008). Mulching effects on selected soil physical properties. *Soil and Tillage Research*, *98*(1), 106-111. https://doi.org/10.1016/j.still.2007.10.011

Munang, R., Thiaw, I., Alverson, K., Mumba, M., Liu, J., & Rivington, M. (2013). Climate change and Ecosystem-based Adaptation: a new pragmatic approach to buffering climate change impacts. *Current Opinion in Environmental Sustainability*, *5*(1), 67-71. https://doi.org/10.1016/j.cosust.2012.12.001

Nagothu, U. S., & Kolberg, S. (2016). Climate smart agriculture: is this the new paradigm of agricultural development?. In *Climate Change and Agricultural Development* (pp. 17-36). Routledge.

Nair, P. R., Kumar, B. M., Nair, V. D., Nair, P. R., Kumar, B. M., & Nair, V. D. (2021). Definition and concepts of agroforestry. *An introduction to agroforestry: Four decades of scientific developments*, 21-28. https://doi.org/10.1007/978-3-030-75358-0_2

N'dakpaze, G. S. E. (2022). *Assessment of Climate Resilience of Tomato Production Using Climate Smart Pest Management Technologies, Uganda* (Doctoral dissertation, University of Nairobi).

Negi, V.S., Maikhuri, R.K., Pharswan, D. *et al.* (2017). Climate change impact in the Western Himalaya: people's perception and adaptive strategies. *J. Mt. Sci.* **14**, 403–416. https://doi.org/10.1007/s11629-015-3814-1

Ngigi, S. N. (2009). *Climate change adaptation strategies: water resources management options for smallholder farming systems in sub-Saharan Africa*. New York, NY: The Earth Institute at Columbia University.

Nyong, A., Adesina, F., & Osman Elasha, B. (2007). The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. *Mitigation and Adaptation strategies for global Change*, *12*, 787-797. https://doi.org/10.1007/s11027-007-9099-0

Ozor, N., Madukwe, M. C., Enete, A. A., Amaechina, E. C., & Onokala, P. (2010). Barriers to climate change adaptation among farming households of Southern Nigeria. *Journal of Agricultural Extension*, *14*(1).

Paudel, B., Khanal, R. C., KC, A., Bhatta, K., & Chaudhary, P. (2017). Climate-smart agriculture in Nepal. *Research program on Climate Change, Agriculture and food security*.

Pisante, M., Stagnari, F., Acutis, M., Bindi, M., Brilli, L., Di Stefano, V., & Carozzi, M. (2015). Conservation agriculture and climate change. *Conservation agriculture*, 579-620.

Powlson, D. S., Stirling, C. M., Jat, M. L., Gerard, B. G., Palm, C. A., Sanchez, P. A., & Cassman, K. G. (2014). Limited potential of no-till agriculture for climate change mitigation. *Nature climate change*, *4*(8), 678-683.

Pudasaini, R., Adhikari, L.D., Bhusal, A., Paudel, B., & Khatri-Chhetri, A. (2019). Building Capacities for Scaling-Up Climate Smart Village in Nepal: A training manual. Nepal: Local Initiatives for Biodiversity, Research and Development (LI-BIRD) and The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). https://hdl.handle.net/10568/102247

Quinkenstein, A., Woellecke, J., Böhm, C., Grünewald, H., Freese, D., Schneider, B. U., & Hüttl, R. F. (2009). Ecological benefits of the alley cropping agroforestry system in sensitive regions of Europe. *Environmental science & policy*, *12*(8), 1112-1121. https://doi.org/10.1016/j.envsci.2009.08.008

Rasul, G., & Sharma, B. (2016). The nexus approach to water–energy–food security: an option for adaptation to climate change. *Climate policy*, *16*(6), 682-702. https://doi.org/10.1080/14693062.2015.1029865

Rayamajhee, V., Guo, W. & Bohara, A.K. (2021). The Impact of Climate Change on Rice Production in Nepal. *Economic of Disaster and Climate Change,* 5, 111–134. https://doi.org/10.1007/s41885-020-00079-8

Regmi, H. P., Upendram, S., Cho, S. H., & Clark, C. D. (2023). Examining complementary relationships among climate change adaptation practices of rice producers in Chitwan, Nepal. *Climate and Development*, *15*(6), 480-500. https://doi.org/10.1080/17565529.2022.2107980

Regmi, H. R. (2007). Effect of unusual weather on cereal crop production and household food security. *Journal of Agriculture and Environment*, *8*, 20-29.

Rijal, S., & Rijal, B. (2019). Climate smart agriculture concept and adaptation in Nepal: An Overview. *International Journal of Research & Review*, *6*(1), 47-56.

Saguye, T. S. (2016). Determinants of smallholder farmers' adoption of climate change and variability adaptation strategies: Evidence from Geze Gofa District, Gamo Gofa Zone, Southern Ethiopia. *J. Environ. Earth Sci*, *6*(9).

Sapkota, R., & Rijal, K. (2016). Climate change and its impacts in Nepal. *Tribhuva n University*.

Scialabba, N., & Müller-Lindenlauf, M. (2010). Organic agriculture and climate change. *Renewable Agriculture and Food Systems, 25*(2), 158-169. doi:10.1017/S1742170510000116

Shrestha, A. B., & Aryal, R. (2011). Climate change in Nepal and its impact on Himalayan glaciers. *Regional environmental change*, *11*, 65-77. https://doi.org/10.1007/s10113-010-0174-9

Shrestha, R.P., Nepal, N. An assessment by subsistence farmers of the risks to food security attributable to climate change in Makwanpur, Nepal. *Food Sec.* **8**, 415–425 (2016). https://doi.org/10.1007/s12571-016-0554-1

Singh, R., Singh, G.S. (2017). Traditional agriculture: a climate-smart approach for sustainable food production. *Energ. Ecol. Environ.* 2, 296–316. https://doi.org/10.1007/s40974-017-0074-7

Subedi, R., Bhatta, L. D., Udas, E., Agrawal, N. K., Joshi, K. D., & Panday, D. (2019). Climate-smart practices for improvement of crop yields in mid-hills of Nepal. *Cogent Food & Agriculture*, *5*(1), 1631026. https://doi.org/10.1080/23311932.2019.1631026

Tanti, P.C., Jenia, P.R., & Aryal, J.P. (2022). Role of institutional factors in climate smart technology adoption in agriculture: Evidence from an Indian State. *Environmental Challenges*, 7, 100498.

Teitel, M., Tanny, J., Ben-Yakir, D., Barak, M., (2005). Airflow patterns through roof openings of a naturally ventilated greenhouse and their effect on insect penetration. *Biosyst. Eng*. 92 (3), 341e353. https://doi.org/10.1016/j.biosystemseng.2005.07.013.

Teklewold, H., Mekonnen, A., & Kohlin, G. (2019). Climate change adaptation: A study of multiple climate-smart practices in the Nile Basin of Ethiopia. *Climate and Development*, *11*(2), 180-192. https://doi.org/10.1080/17565529.2018.1442801

Tiwari, K. R., Rayamajhi, S., Pokharel, R. K., & Balla, M. K. (2014). Determinants of the climate change adaptation in rural farming in Nepal Himalaya. *International Journal of Multidisciplinary and Current Research*, *2*(1), 2321-3124.

Uddin, M. N., Bokelmann, W., & Entsminger, J. S. (2014). Factors affecting farmers' adaptation strategies to environmental degradation and climate change effects: A farm level study in Bangladesh. *Climate*, *2*(4), 223-241. https://doi.org/10.3390/cli2040223

Vernooy, R., Bouroncle, C. (2019). Climate-smart agriculture: in need of a theory of scaling. CCAFS Working Paper no. 256. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) https://hdl.handle.net/10568/99822

Wall, E., & Smit, B. (2005). Climate change adaptation in light of sustainable agriculture. *Journal of sustainable agriculture*, *27*(1), 113-123. https://doi.org/10.1300/J064v27n01_07

Weber, E. U. (2010). What shapes perceptions of climate change?. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(3), 332-342. https://doi.org/10.1002/wcc.41

Zahoor, S. A., Ahmad, S., Ahmad, A., Wajid, A., Khaliq, T., Mubeen, M., ... & Nasim, W. (2019). Improving water use efficiency in agronomic crop production. *Agronomic Crops: Volume 2: Management Practices*, 13-29.

Zhang, X., Van Donk, D. P., & van der Vaart, T. (2016). The different impact of inter-organizational and intra-organizational ICT on supply chain performance. *International Journal of Operations & Production Management*, *36*(7), 803-824.